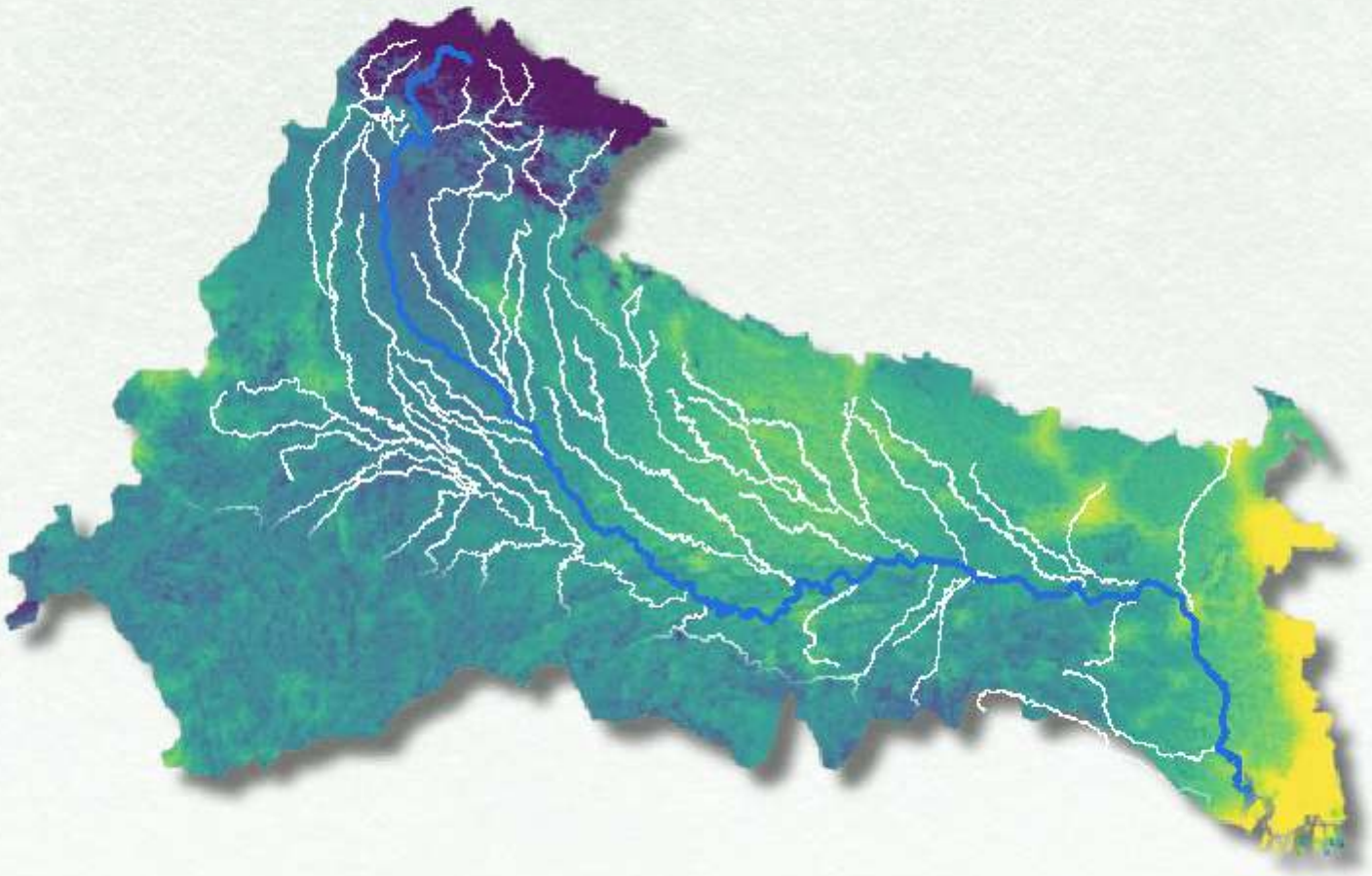
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Wildlife Institute of India



ECOLOGICAL ASSESSMENT *of the* GANGA RIVER *for* CONSERVATION PLANNING

VOLUME - I

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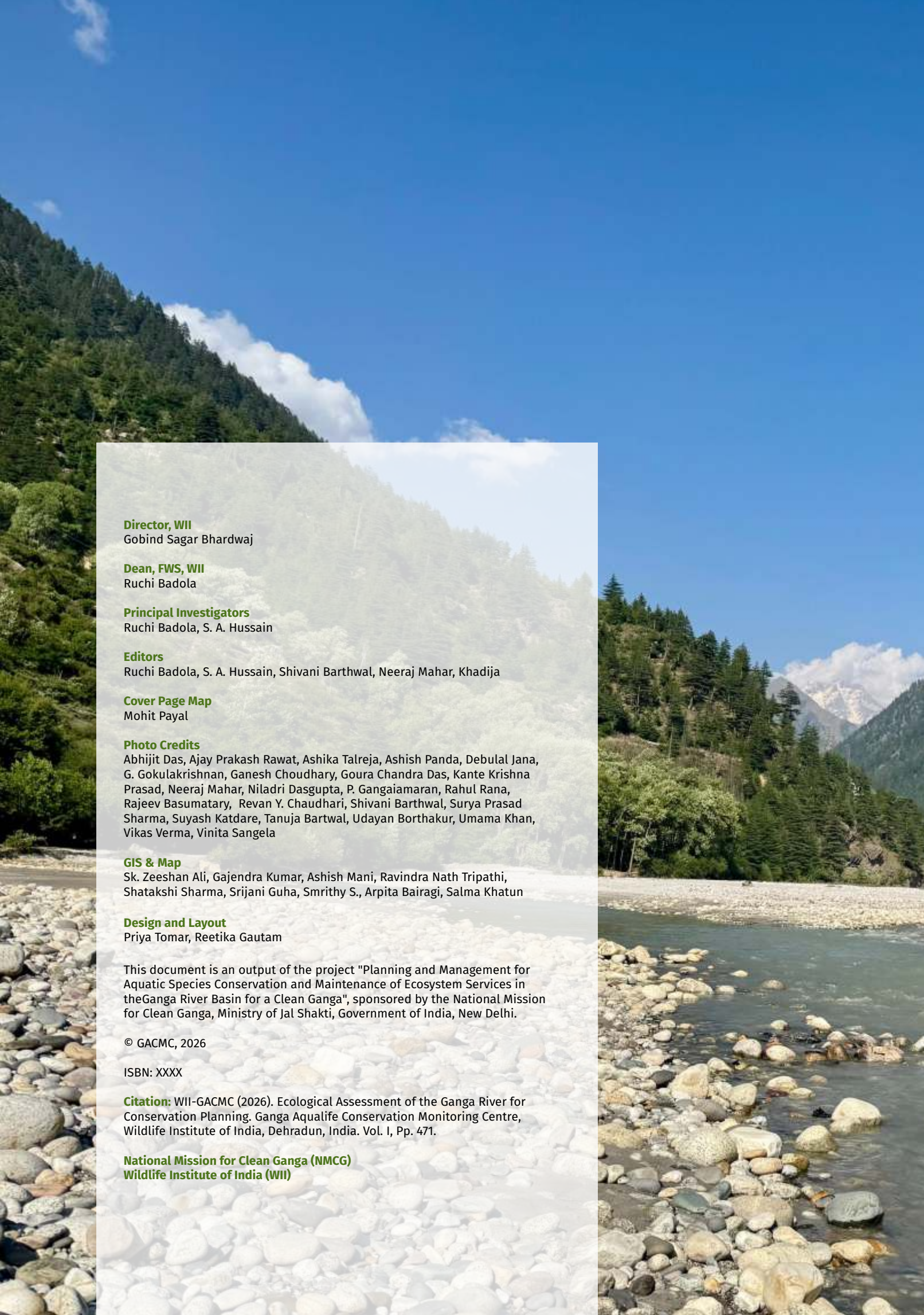
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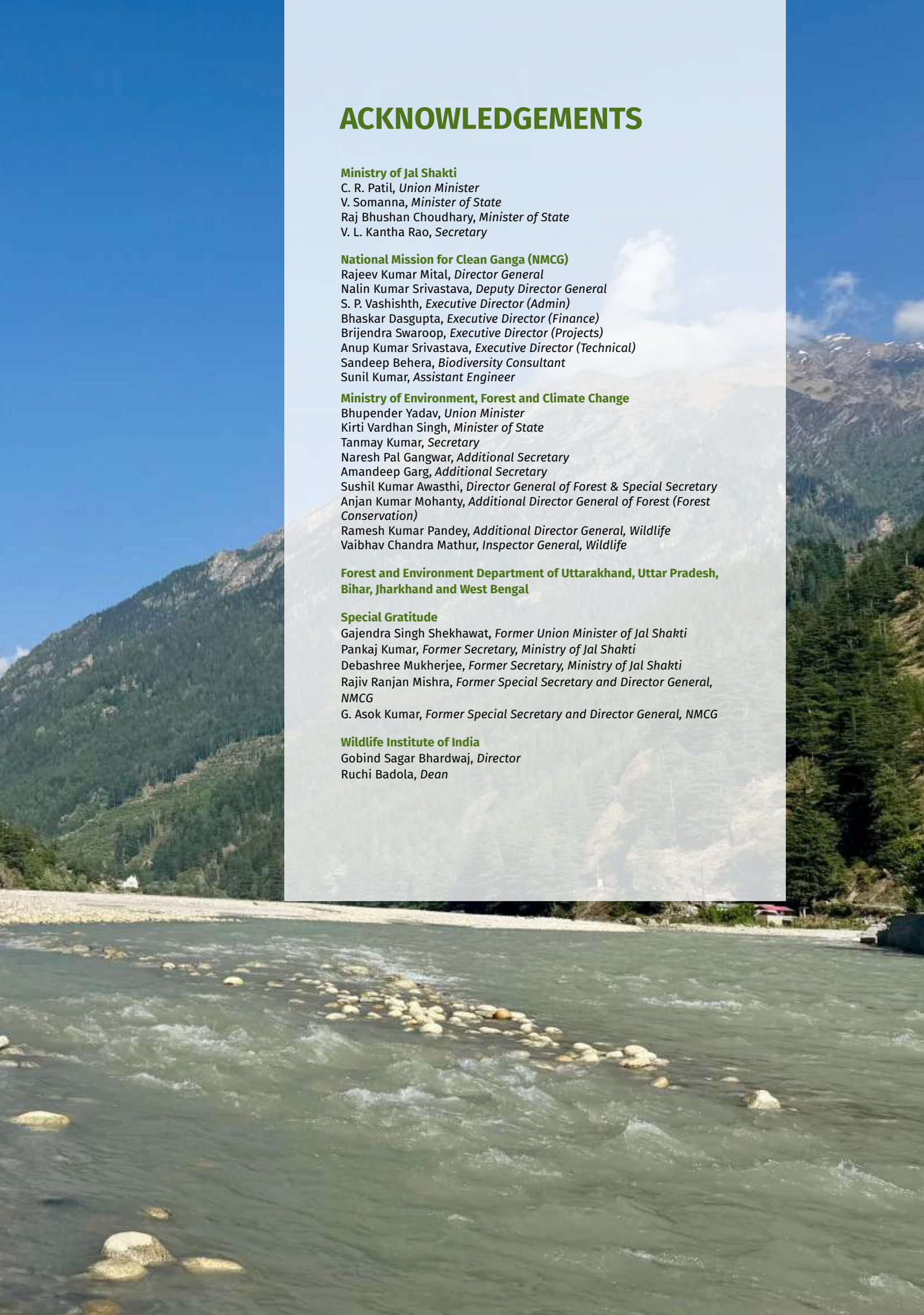
This document is an output of the project "Planning and Management for Aquatic Species Conservation and Maintenance of Ecosystem Services in theGanga River Basin for a Clean Ganga", sponsored by the National Mission for Clean Ganga, Ministry of Jal Shakti, Government of India, New Delhi.

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ISBN: XXXX

Citation: WII-GACMC (2026). Ecological Assessment of the Ganga River for Conservation Planning. Ganga Aqualife Conservation Monitoring Centre, Wildlife Institute of India, Dehradun, India. Vol. I, Pp. 471.

National Mission for Clean Ganga (NMCG)
Wildlife Institute of India (WII)



ACKNOWLEDGEMENTS

Ministry of Jal Shakti
C. R. Patil, *Union Minister*
V. Somanna, *Minister of State*
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Vaibhav Chandra Mathur, *Inspector General, Wildlife*

Forest and Environment Department of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal

Special Gratitude
Gajendra Singh Shekhawat, *Former Union Minister of Jal Shakti*
Pankaj Kumar, *Former Secretary, Ministry of Jal Shakti*
Debashree Mukherjee, *Former Secretary, Ministry of Jal Shakti*
Rajiv Ranjan Mishra, *Former Special Secretary and Director General, NMCG*
G. Asok Kumar, *Former Special Secretary and Director General, NMCG*

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EXECUTIVE

The Ganga River, designated as India's National River in 2008, originates from the Gangotri Glacier at an elevation of approximately 3,892 m above sea level and flows for nearly 2,525 km through five Indian states before discharging into the Bay of Bengal. The Ganga basin extends across approximately 1.086 million km² in four countries-India, Nepal, Tibet (China), and Bangladesh-of which nearly 80% lies within India, covering 280 districts across 11 states and one Union Territory. Supporting an estimated population of 539 million people at a density of 625.89 persons per km², the basin represents one of the most densely populated riverine landscapes in the world. Beyond its immense socioeconomic significance, the river sustains diverse livelihoods, intensive agricultural systems, and longstanding cultural and religious traditions. Ecologically, the basin encompasses five biogeographic zones, nine biotic provinces, six major forest types, and an extensive conservation network that includes 179 Protected Areas, 32 Ramsar sites, 119 Important Bird Areas (IBAs), three UNESCO World Heritage Sites, and four Biosphere Reserves. This report presents the findings of a comprehensive ecological assessment undertaken by the Ganga Aqualife Conservation Monitoring Centre (GACMC), Wildlife Institute of India, under the aegis of the National Mission for Clean Ganga (NMCG), Ministry of Jal Shakti, Government of India. Integrating extensive field surveys conducted between 2017 and 2025 with systematic literature review, spatial modelling, ecotoxicological investigations, and conservation genetic analyses, the study provides one of the most comprehensive ecological assessments of the mainstem Ganga River undertaken to date.

The assessment adopted a spatially structured, multi-taxa approach in which the river was divided into 5 km Biodiversity Evaluation Units (BEUs), supported by 32 intensive monitoring sites across six geomorphological habitat zones. Ecological surveys covered flora, macroinvertebrates, fishes, amphibians, reptiles, birds, and aquatic mammals through vegetation plot, point count survey, extensive boat- and vehicle-based transect. Additional components included ecotoxicological sampling of water, sediment, species distribution modelling using GIS and MaxEnt, and genetic analyses using mitochondrial and nuclear markers to assess population structure and connectivity of selected aquatic fauna.

A total of 998 taxa, including 990 confirmed species across six major taxonomic groups, were documented during the assessment, highlighting the exceptional biodiversity supported by the Ganga River system. Riparian and aquatic vegetation surveys recorded 747 plant taxa representing 119 families, reflecting the ecological diversity of floodplains, wetlands, grasslands, and riverine forests. However, invasive plant species now account for approximately 16% of recorded flora, particularly within the middle and lower stretches of the river, indicating increasing biotic homogenisation and alteration of native habitats.

Macroinvertebrate and odonate diversity along the Ganga River were assessed using combination of literature records (1991-2023) and field surveys conducted during 2017-18 and 2024-25. The results revealed a pronounced upstream-downstream transition in macroinvertebrate communities, characterised by the decline of pollution-sensitive taxa and increasing dominance of pollution-tolerant groups, indicating progressive deterioration in water quality. Odonate diversity declined from 37 species in 2017-18 to 31 species in 2024-25, with the highest diversity recorded in the Hastinapur Wildlife Sanctuary stretch. Altered flow regimes, sedimentation, pollution, pH, discharge, and water temperature emerged as key drivers influencing species richness and community composition. Overall, the findings highlight continuing ecological degradation in the Ganga River and underscore the importance of long-term biomonitoring using odonates as indicators of freshwater ecosystem health.

The Ganga River also supports a diverse ichthyofaunal assemblage comprising 270 documented fish species across 24 orders and 61 families, including globally threatened species such as the Critically Endangered Ganges shark (*Glyphis gangeticus*) and the Endangered golden mahseer (*Tor putitora*). Although some stretches showed partial recovery in fish diversity and catch-per-unit-effort in recent years, threatened species remain largely confined to relatively undisturbed upper reaches. Simultaneously, invasive fishes such as *Cyprinus carpio* and *Oreochromis niloticus* are becoming increasingly widespread across the river system.

SUMMARY

Herpetofauna, comprising amphibians and reptiles, serve as sensitive indicators of freshwater ecosystem health. Surveys along the Ganga River recorded 27 amphibian taxa in 2024, while long-term monitoring revealed increasing trends in turtle and gharial populations in selected stretches. Critically Endangered turtles such as *Batagur dhongoka* and *B. kachuga* were confirmed from the middle Ganga, and gharial populations remained largely restricted to the Hastinapur Wildlife Sanctuary stretch. The findings highlight the importance of protecting sandbars, maintaining natural flow regimes, and strengthening long-term monitoring and habitat conservation across the river system.

Avifaunal assessments identified 236 waterbird species across the Ganga basin, including 52 species classified as threatened or Near Threatened. Although species richness remained broadly stable between survey periods, overall bird abundance declined by approximately 59% between 2017-18 and 2024-25. Specialist riverine birds such as the black-bellied tern (*Sterna acuticauda*), river tern (*Sterna aurantia*), and river lapwing (*Vanellus duvaucelii*) showed consistent declining trends, reflecting increasing disturbance and degradation of nesting islands, floodplain wetlands, and sandbar habitats.

Among aquatic mammals, the Gangetic dolphin (*Platanista gangetica*) remains the flagship species of the river ecosystem. Dolphin encounter rates were highest in the middle stretches between Prayagraj and Kahalgaon, suggesting that these reaches continue to function as important ecological refugia with relatively favourable habitat conditions. Trend analyses indicated a weak but statistically significant increase in dolphin encounter rates between 2018 and 2024. However, habitat fragmentation caused by dams and barrages continues to limit connectivity across much of the river system. Species distribution modelling was also used to assess the potential distribution of otter species along the mainstem Ganga.

Ecotoxicological assessments demonstrated that while the Ganga River is becoming cleaner with respect to conventionally monitored pollutants, ecological risks from emerging contaminants are increasing. Between 2018 and 2025, heavy metals and pesticide residues declined significantly due to improved sewage treatment and industrial regulation under the Namami Gange Mission. However, contaminants such as phthalates, Bisphenol A (BPA), pharmaceuticals, and personal care products were detected throughout the river, with several exceeding ecological safety thresholds. Ecological risk increased downstream, particularly in the Middle and Lower Ganga zones, including the ecologically important Prayagraj-Bhagalpur corridor that supports dense Gangetic dolphin populations. Untreated sewage, agricultural runoff, tributary inflows, and plastic waste emerged as major pathways contributing to residual contamination and bioaccumulation in aquatic fauna.

The assessment further revealed that zones of high biodiversity along the Ganga River frequently coincide with zones experiencing intense anthropogenic pressure. Upper stretches are primarily affected by hydrological modifications from dams and barrages, while middle and lower stretches face cumulative impacts from pollution, navigation, sand mining, fisheries, urbanisation, and expanding infrastructure.

Across the river system, 998 taxa were recorded, including 990 confirmed species representing six major taxonomic groups, reflecting the exceptional ecological significance of the Ganga. However, the findings indicate a gradual shift from native and habitat-specialist communities toward disturbance-tolerant and invasive assemblages, driven by habitat fragmentation, altered flow regimes, and increasing ecological stress. Protected stretches associated with wildlife sanctuaries continue to function as critical ecological refuges, underscoring the need for integrated river basin management, ecological flow restoration, habitat protection, and long-term biodiversity monitoring to sustain the ecological integrity of the river. One of the most important findings of the study is the limited extent of effective habitat protection currently available for riverine biodiversity. Only about 4% of the mainstem Ganga falls within existing Protected Areas. Nevertheless, stretches associated with protected landscapes-particularly the Bijnor-Narora stretch

adjoining Hastinapur Wildlife Sanctuary-consistently supported high biodiversity across multiple taxa, including dolphin, fishes, gharial, odonates, and waterbirds. These findings underscore the importance of protected riparian habitats as biodiversity refuges within an increasingly modified river system.

Based on integrated analysis of biodiversity, habitat quality, connectivity, and threat intensity, the study identified several Conservation Priority Stretches (CPSs) along the mainstem Ganga. These include ecologically important but currently non-protected habitats such as floodplain grasslands, river islands, swamp forests, and wetland complexes. This chapter recommends that these stretches be recognised as Other Effective Area-based Conservation Measures (OECMs) under India's biodiversity commitments. Additional recommendations include restoring longitudinal connectivity through ecologically appropriate fish passages and environmental flow management, regulating infrastructure development in ecologically sensitive reaches, strengthening invasive species management, and implementing nutrient-control measures in agricultural landscapes adjoining high-priority conservation areas.

Recognising that conventional protected-area approaches alone are insufficient for freshwater conservation, the report also proposes a basin-scale rescue and rehabilitation framework for aquatic megafauna, including Gangetic dolphins, gharial, turtles, and otters. The framework emphasises rapid-response rescue systems, veterinary and rehabilitation capacity, post-release monitoring, and long-term community participation within a broader One Health approach linking ecosystem integrity with human wellbeing.

Genetic analyses of selected aquatic fauna revealed important insights into population structure, diversity, and connectivity across the Ganga basin. Fish species such as *Wallago attu* and *Sperata seenghala* exhibited high haplotype diversity and strong inter-river connectivity, whereas *Bagarius bagarius* displayed extremely low genetic diversity, indicating potential population decline associated with habitat fragmentation and anthropogenic pressures. Critically endangered turtles such as *Batagur dhongoka* and *Batagur baska* exhibited evidence of genetic bottlenecks and declining effective populations. Similarly, the Gangetic dolphin

showed very low genetic diversity, consistent with historical founder effects and prolonged isolation. These findings underscore the need for genetically informed conservation planning and maintenance of ecological connectivity across the river system.

Overall, the assessment demonstrates that the Ganga River ecosystem is undergoing gradual but widespread ecological simplification. Native-rich and structurally diverse communities are increasingly being replaced by disturbance-tolerant assemblages, while habitat fragmentation, altered hydrological regimes, and expanding anthropogenic pressures continue to affect ecosystem resilience. Nevertheless, several stretches of the river continue to retain significant ecological value and support important populations of threatened freshwater species.

The findings of this assessment highlight the urgent need for integrated, basin-scale conservation planning that moves beyond fragmented sectoral approaches. Sustaining the ecological health of the Ganga will require coordinated action across water management, urban development, agriculture, fisheries, navigation, and biodiversity governance. By providing a robust scientific baseline and identifying clear conservation priorities, this report is intended to support evidence-based decision-making and strengthen long-term ecological restoration efforts under the National Mission for Clean Ganga.



CHAPTER 1

RIVER PROFILE

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SUMMARY

Ganga River basin represents one of South Asia's largest and most significant river systems, extending over approximately 1.086 million km² across India, Nepal, Tibet (China), and Bangladesh, with nearly 80% of its area located in India. Originating from the Gangotri Glacier and draining into the Bay of Bengal, the Ganga traverses a distance of 2,525 km through five states and 57 districts. The basin spans 280 districts, across 10 States and one Union Territory and supports one of the most densely populated regions in the world, with about 539 million people and a density of 625.89 persons per sq. km. The river system holds immense ecological, economic, and socio-cultural significance, sustaining diverse livelihoods, intensive agriculture, and deeply embedded cultural and religious practices.

The Ganga basin exhibits a highly diverse geological and geomorphological framework shaped by strong altitudinal gradients-from near sea level in the delta to approximately 8,000 m asl in the Himalaya-and by interactions between tectonics, climate, and fluvial processes. It encompasses major physiographic units, including the Himalayan mountain range, the Aravalli, Vindhya, and Satpura ranges, and the Malwa, Bundelkhand, Baghelkhand, and Chhota Nagpur plateaus, reflecting a juxtaposition of young fold mountains and ancient stable shields. Geologically, the basin spans formations from Archean crystalline complexes to Quaternary alluvium, including Precambrian shields, Gondwana sediments, volcanic provinces (Rajmahal Traps and Malwa basalts), Siwalik foreland deposits, and extensive Indo-Gangetic alluvium. Geomorphologically, it can be divided into four units: the Himalayan source region, the Peninsular plateau and Central Highlands, the alluvial plains, and the deltaic region.

The basin exhibits diverse climatic regimes, ranging from alpine and cold-arid conditions in the Himalaya to semi-arid conditions in the west, humid subtropical climates across the plains, and tropical wet and dry conditions in the lower basin. Hydrology is strongly governed by the Indian summer monsoon, which contributes about 70-80% of annual rainfall. The river system is sustained by a network of perennial Himalayan tributaries (e.g., Yamuna, Ghaghra, Gandak, Kosi) and seasonal peninsular rivers (e.g., Son, Chambal, Betwa, Damodar, Kangsabati). Along its longitudinal profile, the river transitions from steep, high-energy Himalayan channels to meandering alluvial plains and braided, distributary systems in the delta. Soils are predominantly alluvial (approx. 58%), extending across the Indo-Gangetic plains, with loamy (56.61%) and clayey (28.09%) textures dominating. Consequently, land use in the basin is largely agricultural (66.31% in 2018-19), followed by forest (16.47%) and wasteland (6.38%).

Ganga basin spans five biogeographic zones and nine biotic provinces, with the Gangetic Plain forming the

dominant biogeographic zone (approx. 39.81% of the total basin area), comprising the Upper Gangetic Plains (7A; 24.52%) and Lower Gangetic Plains (7B; 15.29%). Six major forest types occur across the basin, namely Moist Tropical Forests, Dry Tropical Forests, Montane Subtropical Forests, Montane Temperate Forests, Sub Alpine Forests, and Alpine Scrub. However, non-forest areas predominate (84.07%), with forest cover accounting for only about 15.93% of the basin area. Additionally, the basin harbours a diverse assemblage of aquatic fauna, including five aquatic mammals, three crocodilians, 18 documented chelonians (14 aquatic, one semi-aquatic and two terrestrial species, which includes one with undefined distribution, and one extralimital record), 236 water and water-associated birds, and 259 fish species. It supports an extensive network of Protected Areas (179 PAs, comprising 26 National Parks, 119 Wildlife Sanctuaries, 33 Conservation Reserves, and one Community Reserve), and internationally recognised areas (32 Ramsar sites, 119 IBAs, three UNESCO Natural World Heritage Sites, and four Biosphere Reserves). Collectively, these features underscore the Ganga River basin's status as a complex and globally significant socio-ecological system and highlight its conservation importance.

1.1 INTRODUCTION

Ganga River, anglicized as the "Ganges River," is the longest river in India and was officially declared the National River of India on 4th November 2008. Extending over 2,525 km, this sacred river flows through the states of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal, encompassing 57 districts. It originates at Gaumukh-the snout of the Gangotri Glacier (3,892 m asl) in Uttarkashi district, Uttarakhand-as the Bhagirathi River, which meets the Alaknanda River at Devprayag (Tehri Garhwal district), the fifth of the Panch Prayag (sacred confluences on the Alaknanda), downstream of which it takes the name "Ganga." The river ultimately drains into the Bay of Bengal at Gangasagar in South 24 Parganas district, West Bengal.

Ganga River basin is a transboundary basin spanning four countries, namely India, Nepal, Tibet (an autonomous region in the People's Republic of China), and Bangladesh, and covers an area of approximately 1,086,000 km^2, of which 861,404 km^2 (approx. 80%) lies in India. In India, the Ganga basin lies between 21°06' to 31°21' N latitudes, and 73°02' to 89°05' E longitudes, with a maximum width of approximately 1,024 km and length of approximately 1,543 km (CWC and NRSC, 2014). It is delimited by the Himalaya to the north, the Aravalli Range to the west, the Vindhya and Satpura ranges and the Chhota Nagpur Plateau to the south, and the Brahmaputra Ridge to the east. It spans 11 States and Union Territories (UT), namely the states of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh, and Chhattisgarh, and the UT of National Capital Territory (NCT) of Delhi, and encompasses the jurisdiction of 280 districts.

Ganga basin falls under five biogeographic zones and nine associated provinces, and its geologically, geomorphologically and ecologically diverse landscape harbours rich diversity of flora and fauna. The basin features young fold mountains, geologically ancient mountain ranges and plateaus, vast alluvial plains, and a tide-dominated delta. Six broad forest types occur in the basin, namely Moist Tropical Forests, Dry Tropical Forests, Montane Subtropical Forests, Montane Temperate Forests, Sub Alpine Forests, and Alpine Scrub (Champion and Seth, 1968). Additionally, the Ganga River system supports diverse aquatic fauna, including the National Aquatic Animal of India, the Gangetic dolphin (*Platanista gangetica*). Other flagship and iconic species include Irrawaddy dolphin (*Orcaella brevirostris*), smooth-coated otter (*Lutrogale perspicillata*), Asian small-clawed otter (*Aonyx cinereus*), Eurasian otter (*Lutra lutra*), gharial (*Gavialis gangeticus*), mugger (*Crocodylus palustris*), saltwater crocodile (*Crocodylus porosus*), northern river terrapin (*Batagur baska*), red-crowned roofed turtle (*Batagur kachuga*), three-striped roofed turtle (*Batagur dhongoka*), and elongated tortoise (*Indotestudo elongata*), Indian skimmer (*Rynchops albicollis*), black-bellied tern (*Sterna acuticauda*), golden mahseer (*Tor putitora*), and snowtrout (*Schizothorax richardsonii*).

Ganga River drains one of the most densely populated landscapes in the world, supporting a socially, culturally, and economically diverse population that places often competing demands on its finite resources. The fertile alluvial plains, together with an extensive irrigation network, sustain a highly productive agrarian sector, producing crops such as rice, wheat, and sugarcane, with more than three-fifths of the basin under cultivation. Owing to its high agricultural productivity, the basin is often referred to as the "food bowl of India." Irrigation in the basin relies on both surface water and groundwater resources, facilitated by five major irrigation projects and pump canals like Narayanpur and Gyanpur. The Ganga also supports power generation through seven hydropower projects located along its mainstem, while its waters are also used for cooling in thermal and nuclear power plants, along the river. Apart from groundwater, the surface water is also key to meeting the domestic water requirements of the riverside communities, particularly in the urban centres. Furthermore, river's biotic resources, viz., fish and aquatic vegetation, supports local livelihoods. Beyond its ecological and economic importance, the Ganga River holds profound socio-cultural significance and is anthropomorphised as a goddess, often portrayed as resting on a makar (commonly represented as a gharial or a hybrid mythological creature with parts of both terrestrial and aquatic species), her vahana (vehicle), with its waters central to religious and cultural rituals and practices. An overview of the Ganga River basin is provided in Figure 1.1 and Table 1.1.

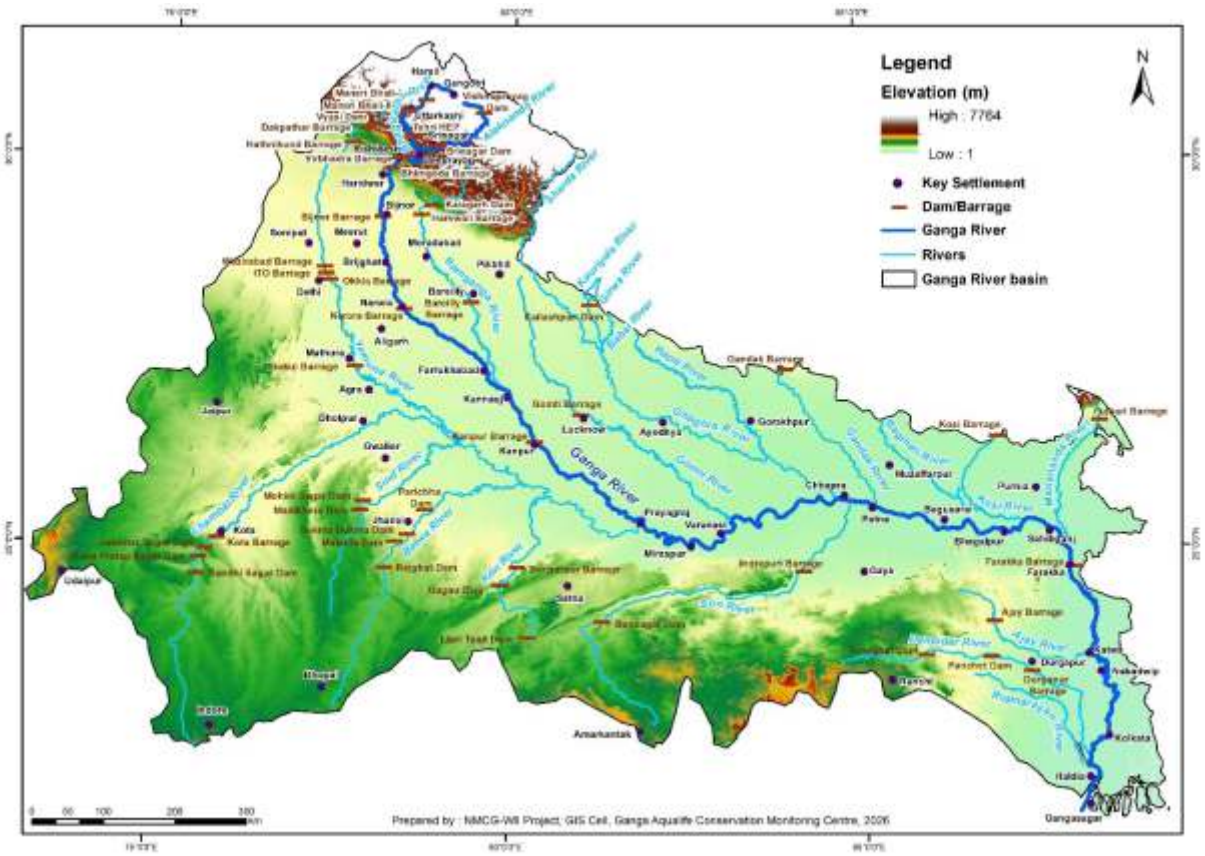


Figure 1.1 An overview of the Ganga River basin.

Table 1.1. An overview of the Ganga River

Type	**Himalayan perennial river of glacial origins**
Origin	Gaumukh-the snout of the Gangotri Glacier (approx. 3,892 m asl; Uttarkashi district, Uttarakhand)-as the Bhagirathi River, which meets the Alaknanda River at Devprayag (Tehri Garhwal district, Uttarakhand), downstream of which it is known as the 'Ganga'
Length	2,525 km
Average annual flow*	Haridwar - 23,900 million m^3; Prayagraj (pre-confluence) - 58,980 million m^3; Prayagraj (post-confluence) - 152,000 million m3; Farakka - 459,040 million m^3
Mainstem States	Five states: Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, West Bengal
No. of districts along mainstem	57
Basin area (India)	861,404 km^2
Altitude of the basin (India)	near sea level to 7,764 m asl
Basin States and Union Territories	Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh, Chhattisgarh, National Capital Territory (NCT) of Delhi
Number of districts in the basin	280#
No. of major sub-basins	18
Major tributaries	Yamuna, Ramganga, Garra, Kali (East), Gomti, Chhoti Sarju, Ghaghra, Gandak, Burhi Gandak, Kosi, Mahananda (Fulhar), Tamsa, Karamnasa, Son, Ajay, Damodar, Rupnarayan, Haldi
Hydropower projects (HEP) on the mainstem	Maneri Bhali-I, Maneri Bhali-II (Uttarkashi district, Uttarakhand), Tehri, Koteshwar (Tehri Garhwal district, Uttarakhand), Vishnuprayag (Chamoli district, Uttarakhand), Srinagar, Chilla (Pauri Garhwal district, Uttarakhand)

Type	Himalayan perennial river of glacial origins
Barrages on the mainstem	Virbhadra (Pashulok) Barrage^ (Rishikesh, Uttarakhand), Bhimgoda Barrage (Haridwar district, Uttarakhand), Chaudhary Charan Singh Madhya Ganga Barrage (Bijnor district, Uttar Pradesh), Narora Barrage (Bulandshahr district, Uttar Pradesh), Lav Kush Barrage (Kanpur, Uttar Pradesh), Farakka Barrage, Jangipur Barrage (Murshidabad district, West Bengal)
Population (districts along mainstem)	183,024,855 persons
Population density (districts along mainstem)	952.55 persons per km^2
Population (basin)	539,140,169 persons
Population density (basin)	625.89 persons per km^2
Biogeographic zones in the basin	Himalaya (West Himalaya - 2B; Central Himalaya - 2C), Semi-Arid (Punjab Plains - 4A; Gujarat Rajputana - 4B), Deccan Peninsula (Central Highlands - 6A; Chotanagpur - 6B), Gangetic Plain (Upper Gangetic Plains - 7A; Lower Gangetic Plains - 7B), Coasts (East Coast - 8B)
Forest cover in the basin (sq. km)	137,205.34 km^2
Aquatic mammals	Gangetic dolphin (*Platanista gangetica*), Irrawaddy dolphin (*Orcaella brevirostris*), smooth-coated otter (*Lutrogale perspicillata*), Asian small-clawed otter (*Aonyx cinereus*), Eurasian otter (*Lutra lutra*)
Crocodilians	Gharial (*Gavialis gangeticus*), mugger (*Crocodylus palustris*), saltwater crocodile (*Crocodylus porosus*)
Chelonians	14 aquatic: Northern river terrapin (*Batagur baska*), red-crowned roofed turtle (*Batagur kachuga*), three-striped roofed turtle (*Batagur dhongoka*), crowned river turtle (*Hardella thurjii*), spotted pond turtle (*Geoclemys hamiltonii*), Indian eyed turtle (*Morenia petersi*), Indian narrow-headed softshell turtle (*Chitra indica*), Indian softshell turtle (*Nilssonia gangetica*), Indian peacock softshell turtle (*Nilssonia hurum*), Indian roofed turtle (*Pangshura tecta*), Indian flapshell turtle (*Lissemys punctata*), brown roofed turtle (*Pangshura smithii*), Indian tent turtle (*Pangshura tentoria*), Indian black turtle (*Melanochelys trijuga*) 2 terrestrial: Elongated tortoise (*Indotestudo elongata*), Tricarinate hill turtle (*Melanochelys tricarinata*) Semi-aquatic (undefined distribution): Assam leaf turtle (*Cyclemys gemeli*), Terrestrial (extralimital record): Indian star tortoise (*Geochelone elegans*)
Water and water-associated birds	236 species belonging to 14 orders and 32 families
Fishes	259 species belonging to 24 orders and 61 families
Number of Protected Areas in the basin	179 (National Parks - 26; Wildlife Sanctuaries - 119; Conservation Reserves - 33; Community Reserves - 1)

* Rao, 1975; # In December 2025, the Delhi Cabinet approved the reorganization of National Capital Territory (NCT) of Delhi, increasing the number of revenue districts from 11 to 13, which increases the number of districts in Ganga River basin to 280; ^ Virbhadra Barrage is part of the Chilla HEP

Note: Species listed and the number of species mentioned in the table include the species documented in the basin; Tehri and Koteshwar dams are part of the Tehri Hydropower Project (HEP); Farakka and Jangipur barrages are part of the Farakka Barrage Project complex

1.2 COURSE OF THE RIVER

Ganga River originates in the state of Uttarakhand and has two primary headwater rivers, namely the Bhagirathi and Alaknanda. Bhagirathi River originates from Gaumukh–the snout of the Gangotri Glacier, at an elevation of 3,892 m asl, and flows for about 205 km through a broad U-shaped valley, in the districts of Uttarkashi and Tehri Garhwal in Uttarakhand. Alaknanda River originates from the snouts of the Satopanth and Bhagirathi Kharak glaciers, descending from the Chaukhamba massif, at an elevation of approximately 3,800 m asl, in the Chamoli district of Uttarakhand, and flows for about 195 km through the districts of Chamoli, Rudraprayag, Pauri Garhwal, and Tehri Garhwal in Uttarakhand. Bhagirathi and Alaknanda meet at Devprayag (Tehri Garhwal), whence the river takes the name 'Ganga'. Bhagirathi is joined by the Kedar Ganga, Jadh Ganga, Kakora Gad, Jalandhari Gad, Siyan Gad, Asi Ganga, and Bhilangna rivers. Alaknanda is joined by the Dhauliganga (Vishnuprayag), Nandakini (Nandaprayag), Pindar (Karnaprayag) and Mandakini (Rudraprayag) rivers, which along with Devprayag are recognised as the five sacred confluences (mentioned in brackets along with the respective rivers) in Hinduism, '*Panch Prayag*'. Key infrastructure projects include Maneri Bhali I HEP, Maneri Bhali II HEP (Uttarkashi district), and Tehri HEP (comprising Tehri and Koteshwar dams in Tehri Garhwal district) on Bhagirathi, Vishnuprayag HEP (Chamoli district) and Srinagar HEP (Pauri Garhwal district) on Alaknanda, and Chilla HEP (comprising Virbhadra Barrage in Rishikesh, which diverts water into the Chilla Canal that meets the Ganga upstream of Haridwar; Pauri Garhwal district) on Ganga. Key settlements include Uttarkashi (Uttarkashi district) along Bhagirathi, Joshimath (Chamoli district) and Srinagar (Pauri Garhwal district) along Alaknanda, and Rishikesh along Ganga.

After traversing the steep gradient of the Garhwal Himalaya in a generally north-east to south-west direction, the Ganga enters the plains at Haridwar (Uttarakhand), where the river is impounded by the Bhimgoda Barrage. Flowing past the Rajaji National Park and Jhilmil Jheel Conservation Reserve, the Ganga enters the state of Uttar Pradesh in Bijnor district. The river is impounded by the Chaudhary Charan Singh Madhya Ganga Barrage, which has led to the formation of the Haiderpur Wetland (Ramsar site). The river flows in north to south direction from Haridwar till Narora (Bulandshahr district, Uttar Pradesh), passing Brijghat (Hapur district) and flowing through the Hastinapur Wildlife Sanctuary on the way. At Narora, Ganga is impounded by the Narora Barrage with the Narora Atomic Power Station sourcing water from the reservoir. Ganga then pivots to a north-west to south-east direction till Mirzapur (Uttar Pradesh), and along the way it flows past the cities of Farrukhabad, Kannauj, Kanpur and Prayagraj; is impounded by the Lav Kush Barrage at Kanpur; through the Kachhua Wildlife Sanctuary (downstream of Prayagraj); and is joined by the Ramganga, Garra and Kali (East) rivers near Kannauj city (close to the tri-junction of the Hardoi, Farrukhabad and Kannauj districts), the Yamuna at Triveni Sangam in Prayagraj city, and the Tamsa in Prayagraj district (downstream of Prayagraj city). From Mirzapur, Ganga flows in a generally south-west to north-east direction, till the Ganga-Gomti confluence (on the border of Varanasi and Ghazipur districts), passing the major cultural and spiritual centre of Varanasi along the way.

From the Ganga-Gomti confluence, Ganga flows in a generally west to east direction till Sahibganj (Jharkhand). It enters the state of Bihar in Buxar district. Along its journey through Bihar, it is joined by the Ghaghra River near Chhapra (Saran district), the Son upstream of Patna city, the Gandak on the opposite bank of Patna city, and the Kosi in Bhagalpur district (downstream of Kahalgaon). Key settlements in Bihar include Buxar, Chhapra, Patna, Hajipur, Raghopur Diara (a prominent inhabited Ganga River Island in Vaishali district, downstream of Patna city), Begusarai, Munger, Bhagalpur and Kahalgaon. Three thermal power plants, namely Barh (Patna district), Barauni (Begusarai district) and Kahalgaon (Bhagalpur district) are situated along the Ganga mainstem in Bihar. The Ganga River stretch from Sultanganj (upstream of Bhagalpur) to Kahalgaon (downstream of Bhagalpur) has been designated the Vikramshila Gangetic Dolphin Sanctuary, which is named after Vikramshila, an 8th-9th century ancient Buddhist Centre of Learning. Ganga River enters the state of Jharkhand in Sahibganj district, which is the only district in Jharkhand along the Ganga mainstem. Fulhar River, a branch of the Mahananda River, joins the Ganga opposite Rajmahal (Sahibganj district) at Paschim Narayanpur village in Malda district. Udhwa Lake Wildlife Sanctuary, a Ramsar site, is situated near the Ganga River, downstream of Rajmahal.

Ganga River enters the state of West Bengal in Malda district, which is opposite the Sahibganj district. It then enters the country of Bangladesh in Murshidabad district, where it takes the name 'Padma'. The Farakka Barrage Project in Murshidabad district, through the 38.38 km long Farakka Feeder Canal, diverts water from the Ganga River to the Bhagirathi-Hoogly river system (around 530 km in length), which follows a north to south directionality till it flows into the Bay of Bengal. Bhagirathi River is a distributary of the Padma River, that branches off near Giria town (Murshidabad district), and flows through the districts of Murshidabad, Nadia and Purba Bardhman. Key settlements along the river include Raghunathganj, Jiaganj Azimganj, Murshidabad, Berhampore (Baharampur), Katwa and Nabadwip. It is joined by the Dwarka and Ajay rivers. At Mayapur (opposite Nabadwip), it is joined by the Jalangi River, a branch of the Padma River, and the river takes the name 'Hooghly'. Hooghly flows through the districts of Nadia, Purba Bardhman, Hooghly, North 24 Parganas, Kolkata, Howrah, South 24 Parganas and Purba Medinipur, and is joined by the Damodar, Rupnarayan, Haldi and Churni (a distributary of Mathabhanga River, which is a branch of the Padma River)

rivers. It passes through the Kolkata Metropolitan Area, major urban agglomeration comprising four Municipal Corporations, 38 Municipalities and 23 Panchayat Samities), and spread over approximately 1,888 km^2 (Kolkata Metropolitan Development Authority).

The Ganga mainstem can be delineated into three stretches, viz. Upper Ganga (Gaumukh to Haridwar; approx. 294 km), Middle Ganga (Haridwar to Varanasi; approx. 1,082 km) and Lower Ganga (Varanasi to Gangasagar; approx. 1,134 km), based on variations in geology, geomorphology, soils, climate, biodiversity, and socio-economic conditions (cGanga and NMCG, 2019; WII-GACMC, 2018; Figure 1.2.). A schematic diagram of the course of the Ganga River is given in Figure 1.3.

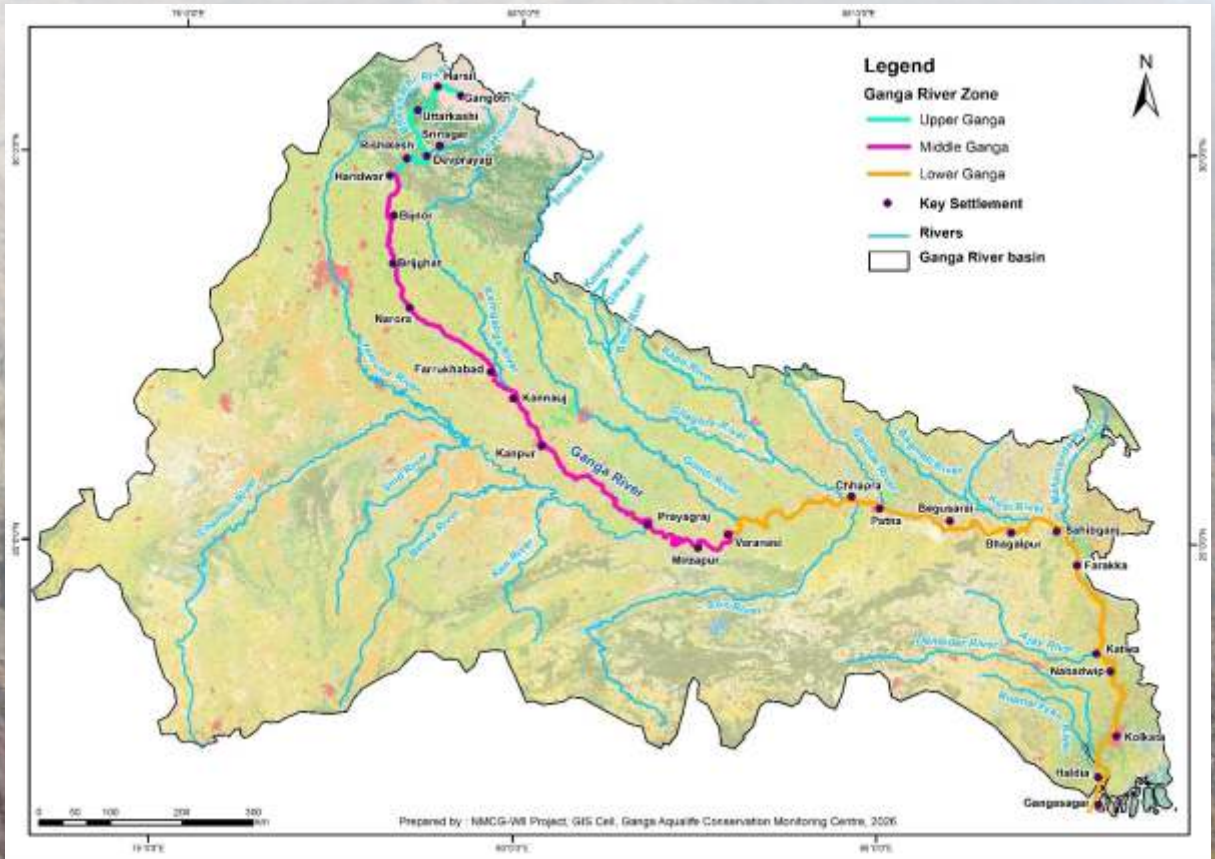


Figure 1.2 Zonation of the Ganga River.

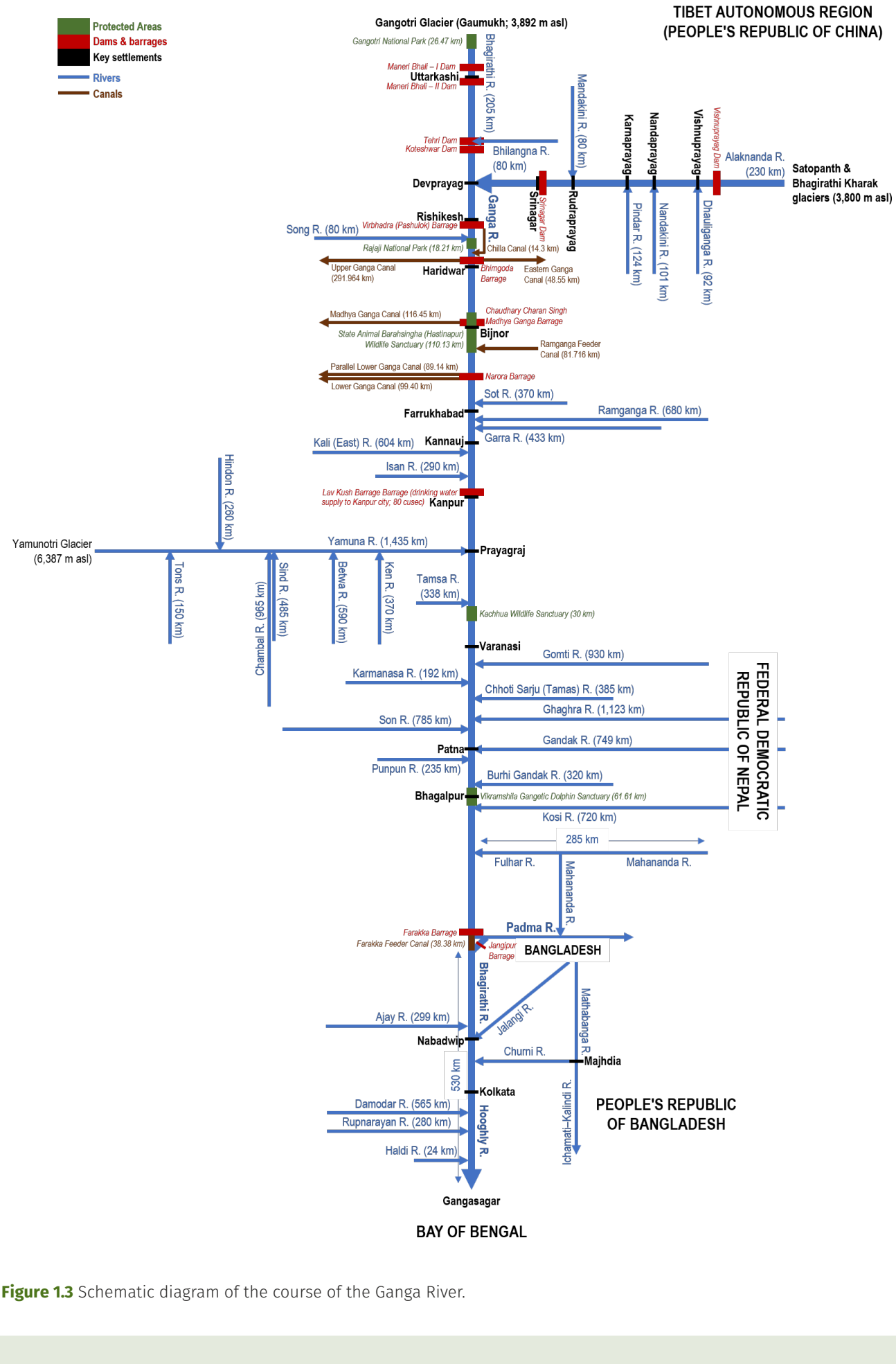


Figure 1.3 Schematic diagram of the course of the Ganga River.

1.3 GEOLOGY AND GEOMORPHOLOGY

Ganga River basin exhibits a highly diverse geological and geomorphological framework, shaped by pronounced altitudinal gradients-from near sea level in the delta to nearly 8,000 m asl in the Himalaya-and by complex interactions between tectonics, climate and fluvial processes. The Mt. Everest is the highest peak in the entire Ganga River basin, while in the Indian part of the basin, the Nanda Devi is the highest peak. The basin extends from the geologically young and tectonically active Himalayan orogen in the north, across the extensive Indo-Gangetic alluvial plains, to the geologically ancient mountain ranges and Peninsular craton and plateau regions in the west and south, and finally to the Sundarbans delta. Major physiographic units include the Himalayan mountain range (characterized by glaciers, steep slopes, rugged terrain, and high seismicity); the Aravalli, Vindhya, and Satpura ranges (with discontinuous ridges, rounded hills, plateaus, and valleys); and the Malwa, Bundelkhand, Baghelkhand, and Chhota Nagpur plateaus, reflecting a juxtaposition of young fold mountains and ancient stable shields (Singh et al., 2007; Valdiya, 2010).

Geologically, the Himalayan domain is subdivided into four major lithotectonic units separated by thrust systems: (i) the Tethyan sedimentary sequence, composed of Paleozoic-Mesozoic carbonates and clastics; (ii) the Higher Himalayan crystalline complex, comprising high-grade metamorphic rocks such as orthogneisses, paragneisses, and migmatites; (iii) the Lesser Himalaya, consisting of metamorphosed and unmetamorphosed Precambrian sequences; and (iv) the Outer Himalaya (Siwalik Group), formed by recently uplifted Miocene-Pleistocene detrital deposits (Gansser, 1964; Valdiya, 1980; Singh et al., 2007). South of the Himalaya lies the vast Ganga foreland basin, composed of thick Quaternary alluvium derived from both the Himalaya and the northern Indian craton during the late Pleistocene-Holocene period (Singh et al., 2007; Singh, 1996). This alluvial tract is further differentiated into four distinct geomorphic belts: (i) the Bhabar Belt, a 10-30 km wide zone of coarse, gravelly deposits along the Himalayan foothills, marked by ephemeral streams (Valdiya, 2010); (ii) the Terai Belt, a 10-15 km wide low-lying area south of the Bhabar, characterized by extensive swamps, ponds, and small sandy rivers (Sinha et al., 2010; Singh, 1987); (iii) the Central Alluvial Plain, which constitutes the major part of the basin and lies between the Piedmont zone and the axial river, exhibiting a predominantly south-eastward drainage pattern; and (iv) the Marginal Alluvial Plain, located south of the axial river, characterized by north-east flowing tributaries and sediments largely derived from the Peninsular craton (Sinha et al., 2010; Tandon et al., 2008; Singh, 1987). The Bhabar and Terai belts together constitute the Piedmont zone (Sinha et al., 2010; Tandon et al., 2008).

The northern Indian craton forms the southern and western margins of the basin and is composed of Archean and Proterozoic formations, including the Aravalli Range (Rajasthan, Delhi, and Haryana), the Bundelkhand plateau (Northern part of Madhya Pradesh and Southern part of Uttar Pradesh), the Vindhyan Range (Central part of Madhya Pradesh, part of Uttar Pradesh including Varanasi and Mirzapur, and Bihar), Malwa plateau (Madhya Pradesh and south eastern Rajasthan), the Chhota Nagpur plateau (Bihar, Jharkhand and West Bengal) (Ramakrishnan and Vaidyanadhan, 2010; Singh et al., 2007; Naqvi and Rogers, 1987).

Gondwana sedimentary sequences (Permian-Late Jurassic/Early Cretaceous) occur in rift-controlled basins such as the Son and Damodar valleys and the Rajmahal Hills, representing an earlier depositional phase that is now buried beneath Quaternary alluvial cover in the deeper parts of the basin (Singh, 1996; Tewari, 1995; Singh et al., 1993; Tewari & Maejima, 2010). The Rajmahal Traps, located in eastern Jharkhand (Sahibganj and Pakur districts), represent Jurassic-Cretaceous volcanic activity and consist of basaltic flows and associated volcanic rocks. These formations act as a rigid structural barrier, influencing regional drainage patterns, including the eastward deflection of the Ganga River, and provide a geological linkage between the Purnea basin of the Ganga valley and the Bengal basin (Kent et al., 2002; Prasad and Pundir, 2017).

Overall, the Ganga River basin encompasses geological formations ranging from Archean crystalline complexes to Quaternary alluvium, including Precambrian shields, Gondwana sediments, volcanic provinces such as the Rajmahal Traps and Malwa Plateau basalts, Siwalik foreland deposits, and extensive Indo-Gangetic alluvial sediments across its spatial extent (Tare et al., 2013; Singh et al., 2007; Table 1.2).



Table 1.2 Geological formations, lithology, and state-wise distribution in the Ganga River basin (Tare et al., 2013; Singh et al., 2007)

Geological Time Scale	Geological Formation	Lithology	States
Archean	Bundelkhand Gneiss Complex	Granitic gneiss, schist, meta sediments	Southern Uttar Pradesh, Madhya Pradesh
Archean-Proterozoic	Chhotanagpur Plateau	Granite, gneisses	Jharkhand, Bihar, West Bengal
Proterozoic	Aravalli and Delhi Supergroup	Quartzite, phyllite, schist, gneiss, marble	Rajasthan, Haryana, Uttar Pradesh
Proterozoic	Vindhyan Supergroup	Sandstone, shale, limestone	Uttar Pradesh, Madhya Pradesh, Bihar
Permian-Late Jurassic/ Early Cretaceous	Gondwana Supergroup	Sandstone, shale	Jharkhand, Chhattisgarh, West Bengal
Jurassic-Cretaceous	Rajmahal Traps	Basaltic lava flows	Jharkhand
Late Cretaceous	Malwa Plateau	Flood basalts	Madhya Pradesh, Rajasthan
Miocene-Pleistocene	Siwalik Group	Sandstone, conglomerate	Uttarakhand, Himachal Pradesh, Haryana
Pleistocene-Holocene	Indo-Gangetic Alluvium	Sand, silt, clay	Uttar Pradesh, Bihar, West Bengal

Geomorphologically, the Ganga River basin can be divided into four broad units: the Himalayan source region, the Peninsular plateau and Central Highlands (forming important tributary source areas), the extensive alluvial plains, and the deltaic region (Sinha, 2004). These units collectively govern erosion, sediment transport, and depositional processes within the basin (Singh et al., 2007). The basin's geomorphology reflects a dynamic interaction of Himalayan tectonics, climate, and sedimentation processes, resulting in a highly active and evolving fluvial system from mountains to delta (Sinha, 2004; Valdiya, 2010).

The Himalayan segment is characterized by steep gradients, high relief, active tectonics, and intense physical weathering, resulting in narrow valleys with high stream power (Gansser, 1964; Valdiya, 2010). Prominent erosional landforms in this region include canyons, gorges, waterfalls, interlocking spurs, and potholes (Sinha, 2004). Upon entering the foreland basin, the Ganga River experiences a sharp reduction in gradient, leading to the development of one of the world's largest alluvial plains. This region is characterized by predominantly meandering and braided channel systems and functions as a major zone of sediment storage and redistribution (Singh, 1987; Sinha et al., 2005; Shukla, 2009). Fluvial processes in the basin are strongly influenced by the Indian summer monsoon, which drives seasonal sediment transport, channel migration, floodplain deposition, and the formation of sandbars and mid-channel islands, with most sediment flux occurring during the monsoon period (Bookhagen and Burbank, 2010; Sinha et al., 2005). In the downstream reaches, the river transitions into a low-gradient deltaic system, where fine-grained sediments (silt and clay) dominate, forming an intricate network of distributaries before discharging into the Bay of Bengal. The Ganga-Brahmaputra delta, the largest in the world, represents a dynamic environment shaped by the interplay of fluvial, tidal, and marine processes (Goodbred and Kuehl, 2000b).

1.4 LAND USE LAND COVER (LULC)

Ganga River basin was predominantly under agriculture (66.31%) in 2018-19, followed by forest (16.47%) and wasteland (6.38%) (NRSC, 2019) (Table 1.3; Figures 1.4 and 1.5). Water bodies accounted for 3.62% of the basin, while built-up land comprised 4.32%, largely concentrated in major urban agglomerations such as Delhi (NCT of Delhi, Haryana and Uttar Pradesh), Kanpur, Prayagraj, Varanasi, Bareilly, Lucknow, Gorakhpur, Jhansi (Uttar Pradesh), Patna, Muzaffarpur (Bihar), Jaipur (Rajasthan), Gwalior, Indore, Bhopal (Madhya Pradesh), Ranchi (Jharkhand), Kolkata Metropolitan Area and Durgapur (West Bengal). Among these, Kanpur, Prayagraj, Varanasi, Patna, and the Kolkata Metropolitan Area are located along the Ganga mainstem. Littoral swamp, primarily confined to the Sundarbans delta, accounted for 0.5% of the basin, while snow cover (0.43%) was restricted to the Trans- and Western Himalaya. Grasslands accounted for only 0.2% of the basin.

Between 2008-09 and 2018-19, the Ganga basin experienced notable land use and land cover changes (NRSC, 2009; NRSC, 2019) (Figure 1.5). Wasteland recorded a substantial decline (-27.25%), indicating a marked reduction relative to its 2008-09 extent. Although snow cover (0.43%) and grassland (0.2%) occupied only a small proportion of the basin, both exhibited pronounced relative declines of -14.22% and -1.71%, respectively. In contrast, built-up area increased significantly (9.78%). Modest increases were observed in agriculture (3.08%), littoral swamp (2.28%), water bodies (1.56%), plantations (0.82%), and forest cover (0.09%).

Table 1.3 Description of land use land cover (LULC) classes and area under each class in the Ganga River basin for the year 2018-19 (NRSC, 2019).

SN	LULC Class	Description	Area (sq. km)
1	Agriculture	Croplands cultivated in at least one cropping season (Rabi, Kharif, or Zaid) and agricultural fallow lands	571,191
2	Forest	Evergreen, deciduous, and mixed forests, along with tree-clad areas outside notified forest boundaries with herbaceous vegetation that is woody in appearance	141,966
3	Wasteland	Barren lands with little to no vegetation cover, including rocky terrains, scrub lands, mining dumps, gullied lands, sand dunes, etc.	54,955.2
4	Built-up Area	Residential areas, industrial zones, transport infrastructure, airports, and other impervious surfaces resulting from anthropogenic activities.	37,177
5	Water Bodies	Rivers, streams, lakes, ponds, reservoirs, and tanks	31,189.5
6	Plantation	Artificially planted trees	15,226.7
7	Littoral Swamp	Areas with seasonal or permanent water inundation, with or without vegetation, excluding features classified under the 'Water Bodies' LULC class, and including ox-bow lakes, tidal flat/mud flat, mangrove, salt marsh/marsh vegetation and other hydrophytic vegetation	4,288.35
8	Snow Cover	Area under snow cover/ice, mostly perennial	3,686.14
9	Grassland	Areas with naturally occurring seasonal or perennial grasses	1,724.1

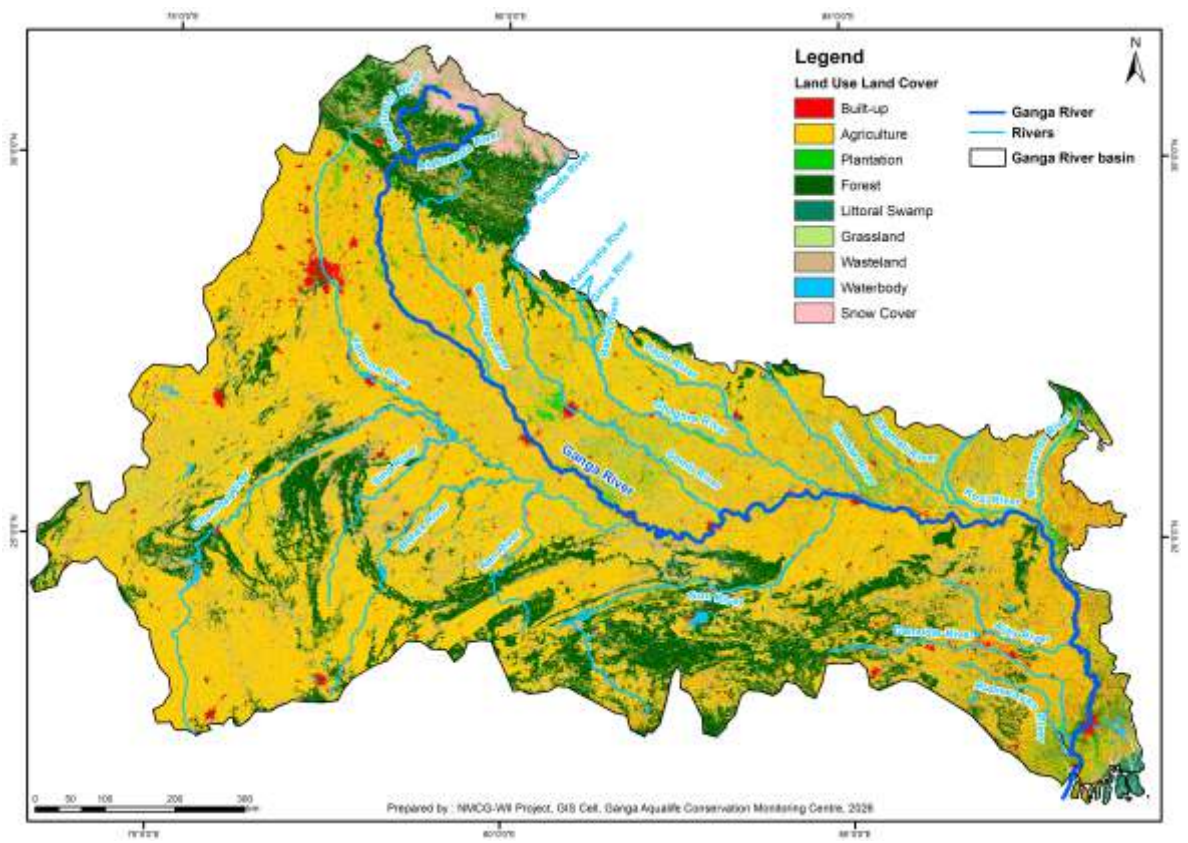


Figure 1.4 Land use land cover (LULC) map of the Ganga River basin for the year 2018-19 (NRSC, 2019).

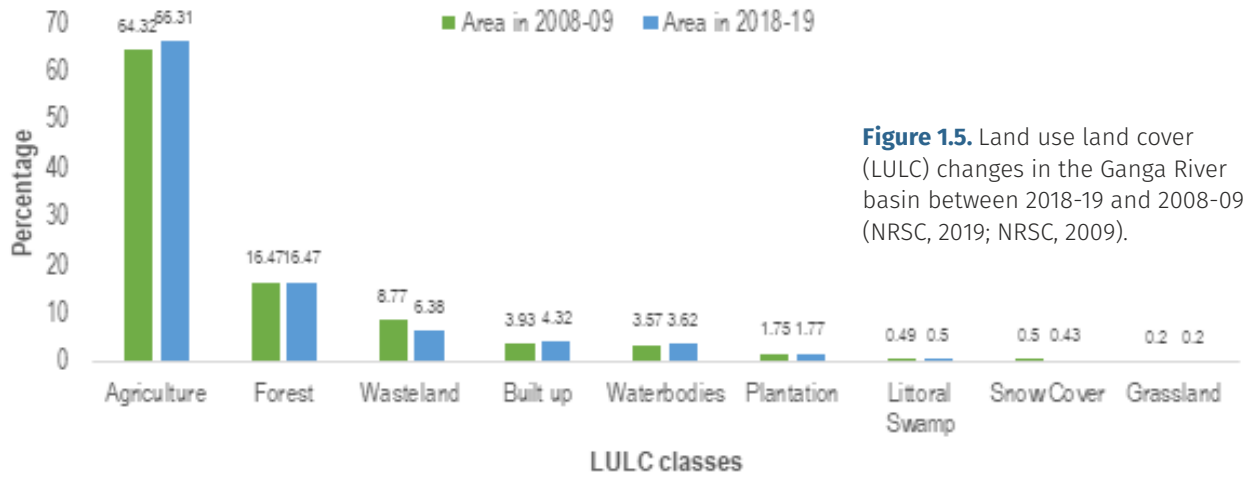


Figure 1.5. Land use land cover (LULC) changes in the Ganga River basin between 2018-19 and 2008-09 (NRSC, 2019; NRSC, 2009).

1.5 SOIL TYPES

Ganga River basin exhibits a diverse range of soil types, shaped by its physiography, fluvial processes, lithology, and climate, making it one of the most agriculturally productive landscapes in the world. The basin is predominantly covered by alluvial soils, which extend across the Indo-Gangetic plains from Uttar Pradesh to West Bengal and account for approximately 58% of the total basin area (Tare et al., 2013). These alluvial deposits are further classified into older alluvium (Bhangar), occurring on slightly elevated terraces, and younger alluvium (Khadar), found in low-lying floodplains and characterized by higher fertility and periodic renewal through fluvial processes.

In addition to alluvial soils, the basin comprises deep to medium black soils (14%), primarily in the peninsular margins of Madhya Pradesh; red soils (12%) and red and yellow soils (8%), which are more prevalent in the southern parts of Bihar and south-western West Bengal; and lateritic soils (6%), typically associated with regions of higher rainfall and leaching (ICAR-NBSS and LUP, 2020; Tare et al., 2013). The Himalayan region is characterized by mountain soils, which are generally shallow, immature, and highly susceptible to erosion due to steep slopes. In contrast, the western parts of the basin exhibit arid and sandy soils, particularly in Rajasthan and Haryana, while the deltaic regions support peaty and marshy soils with high organic content (ICAR, 2018; GSI, 2012).

Texturally, soils in the basin are predominantly loamy (56.61%), followed by clayey soils (28.09%), which play a critical role in influencing agricultural productivity and hydrological processes (ICAR-NBSS and LUP, 2002; Table 1.4; Figure 1.6).

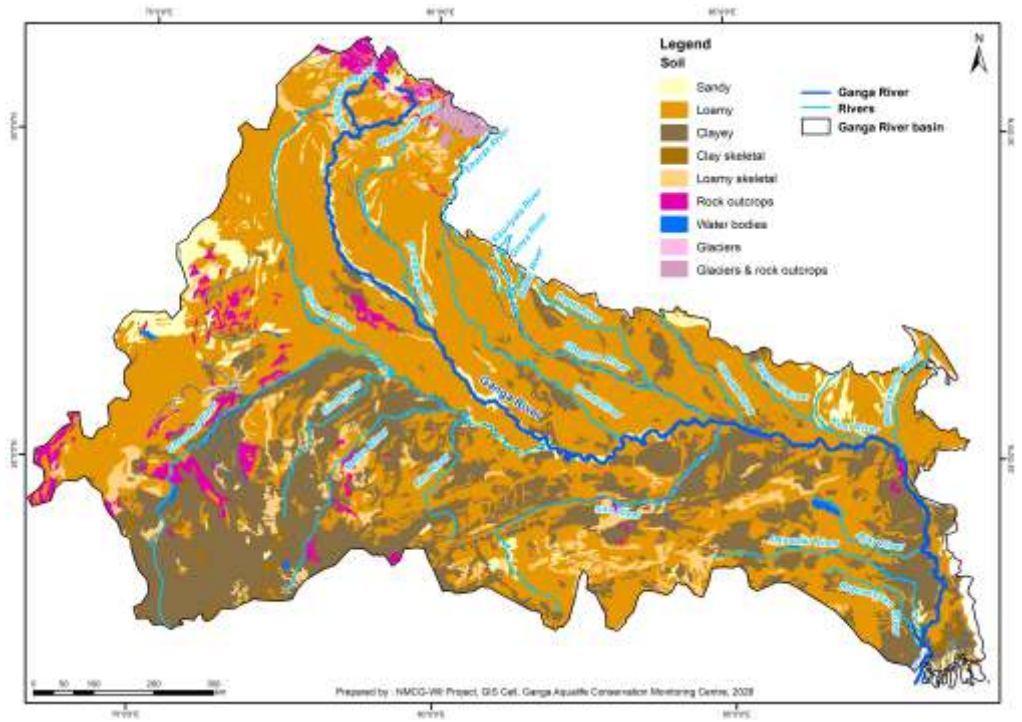


Figure 1.6. Soil texture in the Ganga River basin (ICAR-NBSS and LUP, 2002)

Table 1.4 Soil texture in the Ganga River basin (ICAR-NBSS and LUP, 2002).

Soil Class	Area (sq. km)	Area (% of GRB)
Sandy	37,256.42	4.33
Loamy	487,634.34	56.61
Clayey	241,988.76	28.09
Clayey skeletal	5,389.11	0.63
Loamy skeletal	46,253.25	5.37
Rock outcrops	21,806.08	2.53
Waterbodies	15,718.09	1.82
Glaciers	1,147.64	0.13
Glaciers and rock outcrops	4,210.31	0.49

1.6 CLIMATE

Ganga River basin exhibits marked climatic heterogeneity, driven by strong altitudinal gradients, diverse physiography, and atmospheric circulation systems, particularly the Himalaya and peninsular hill ranges, the South-West Monsoon, and Western Disturbances. According to the Köppen-Geiger classification, climatic conditions range from alpine and cold-arid climates (ET) in the Trans- and Upper Himalaya, to subtropical highland climates (Dwb, Cwb) in the Middle and Lower Himalaya, hot semi-arid steppe conditions (Bsh) in the western transition zone adjoining the Thar Desert, monsoon-influenced humid subtropical climate (Cwa) across much of the Gangetic plains, and tropical wet and dry (savanna) climate (Aw) in the lower basin, particularly in West Bengal (European Food Safety Authority et al., 2026; Beck et al., 2023). The basin is predominantly humid subtropical, with localized semi-arid conditions in the western regions (e.g., Haryana and western Uttar Pradesh) and tropical wet and dry conditions in the downstream deltaic areas, while the upper Himalayan region corresponds to cold humid/tundra climates (Dixit et al., 2024; Arora et al., 2017; Peel et al., 2007).

The basin's climate is characterized by four distinct seasons: winter (January-March), summer (April-May), monsoon (June-September), and post-monsoon (October-December) (Singh et al., 2007; Das Gupta, 1984). Temperature regimes vary considerably, with summer temperatures in the Indo-Gangetic plains ranging from 30-42°C and winter temperatures from 6-15°C, while sub-zero temperatures prevail at higher elevations in the Himalaya (Singh et al., 2023). Recent studies indicate a warming trend, with temperature anomalies exceeding 1.5°C in several parts of the basin (Kaushik et al., 2024). Mean annual precipitation ranges from approximately 350 mm in the western basin to over 2000 mm in the deltaic region, with an average of about 1100 mm (Tare et al., 2013; Kaiser et al., 2023). The South-West Monsoon contributes nearly 70-80% of the annual rainfall, while the Himalayan headwaters receive substantial precipitation (1200-2000 mm), much of which occurs as snowfall (Kaiser et al., 2023; Bookhagen and Burbank, 2010).

1.7 DRAINAGE AND HYDROLOGY

Ganga River basin exhibits a highly diverse drainage pattern and hydrological regime, governed by its complex physiography, lithology, and monsoonal climate. The river system is characterized by distinct geomorphic transitions along its longitudinal profile, from steep, vertically eroding channels in the upper Himalayan reaches, to meandering alluvial channels across the middle Gangetic plains, and braided and distributary networks in the lower and deltaic regions. Correspondingly, drainage patterns vary spatially, with trellis and dendritic systems dominating the Himalaya, dendritic to meandering patterns in the Gangetic plains, and braided and distributary channels in the lower reaches. In the adjoining plateau and peninsular regions, drainage patterns include rectangular and trellis systems in the Malwa and Bundelkhand plateaus, rectangular drainage in the Vindhyan terrain, and radial to trellis patterns in the Chhota Nagpur Plateau, reflecting strong structural and lithological controls. In the foreland alluvial plains, drainage tends to be parallel to sub-parallel, extending towards the Bay of Bengal (Tare et al., 2013; Singh et al., 2007).

The Ganga River system is sustained by a large network of tributaries, broadly classified into Himalayan and Peninsular rivers (Figure 1.7). Major Himalayan tributaries, including the Yamuna, Ramganga, Ghaghra, Gandak, and Kosi, are perennial, originate from high-altitude regions and contribute substantial water and sediment loads (Valdiya, 2010). In contrast, Peninsular tributaries such as the Son, Chambal, Tons, Betwa, Damodar, and Kangsabati arise from the stable cratonic plateau regions and are primarily rain-fed, exhibiting greater seasonal variability in discharge (Singh, 1987). Hydrologically, the basin is strongly influenced by the Indian summer monsoon, which contributes approximately 70-80% of the annual rainfall (Bookhagen and Burbank, 2010). Consequently, river discharge shows pronounced seasonality, with low flows during pre- and post-monsoon periods and peak flows during the monsoon season (Milliman and Meade, 1983).

Groundwater plays a crucial role in sustaining baseflow, particularly in the alluvial plains, where thick sedimentary deposits form extensive aquifer systems (Shukla et al., 2001). The basin's physiography further modulates hydrological processes: the Himalayan region is characterized by high runoff, steep gradients, and high stream power, while the alluvial plains exhibit reduced flow velocities, higher infiltration, and strong surface-groundwater interactions (Sinha et al., 2005). In the deltaic region, hydrology is additionally influenced by tidal dynamics and saline water intrusion, shaping the distributary network and estuarine processes (Goodbred and Kuehl, 2000a).

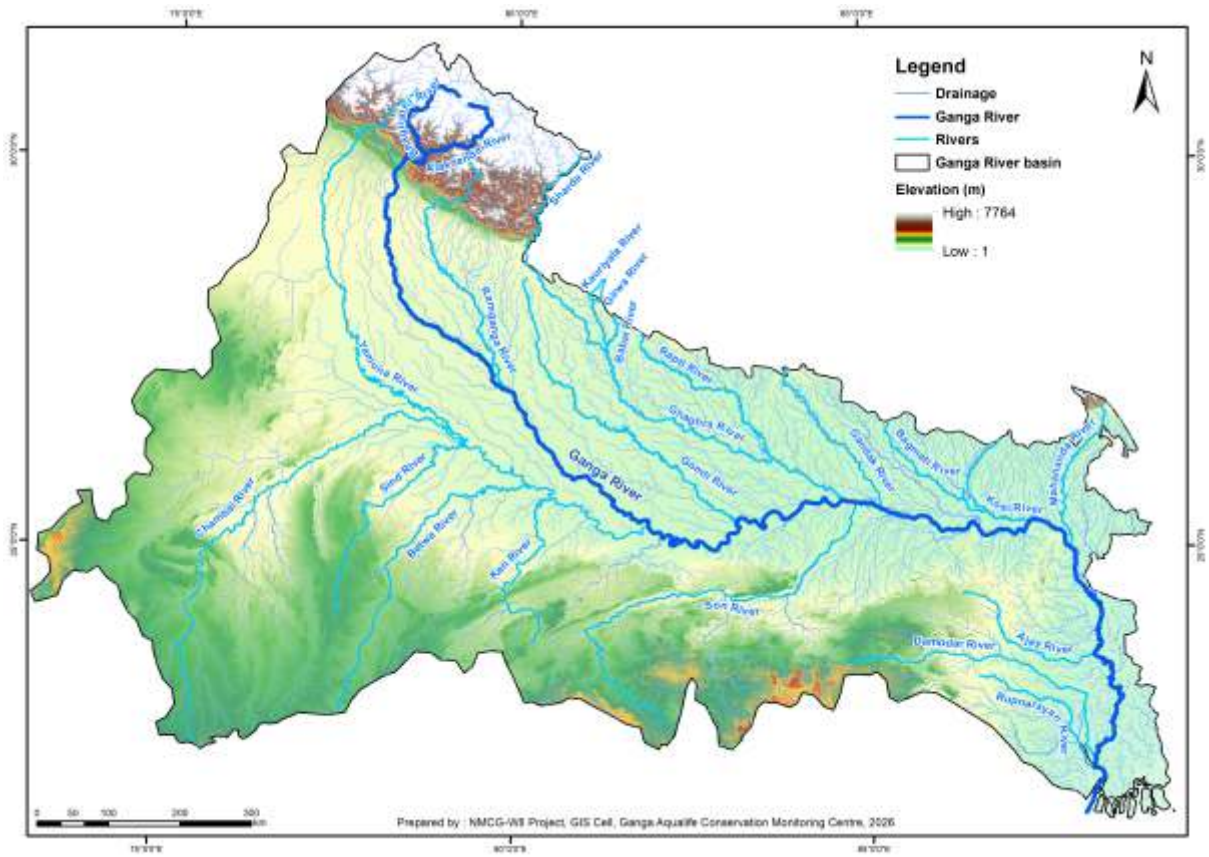


Figure 1.7 Drainage map of the Ganga River basin.

1.8 DEPTH PROFILE

The depth of the Ganga River was measured downstream of Haridwar, using an Acoustic Doppler Current Profiler (ADCP), at a gap of two years from 2018 to 2024. The depth of the river ranged from 0.50 m to 33.40 m in 2018, whereas it ranged from 0.16 m to 23 m in 2020, 0.60 m to 24.10 m in 2022 and 1.17 m to 14.13 m in 2024 (Figure 1.8). The stretch of the river between Haridwar till Prayagraj had an average depth of 2.71 m (SE ± 0.12). The depth of the river increases after the Yamuna River merges with the Ganga at Prayagraj, and hence the average depth from Prayagraj to Revalganj was 5.99 m (SE ± 0.38). At Revalganj, the Ghaghra River meets the Ganga and, thereafter, several tributaries add water to the mainstem Ganga River, hence the average depth in the stretch of the Ganga River downstream of Revalganj was highest at 6.46 m (SE ± 0.27).



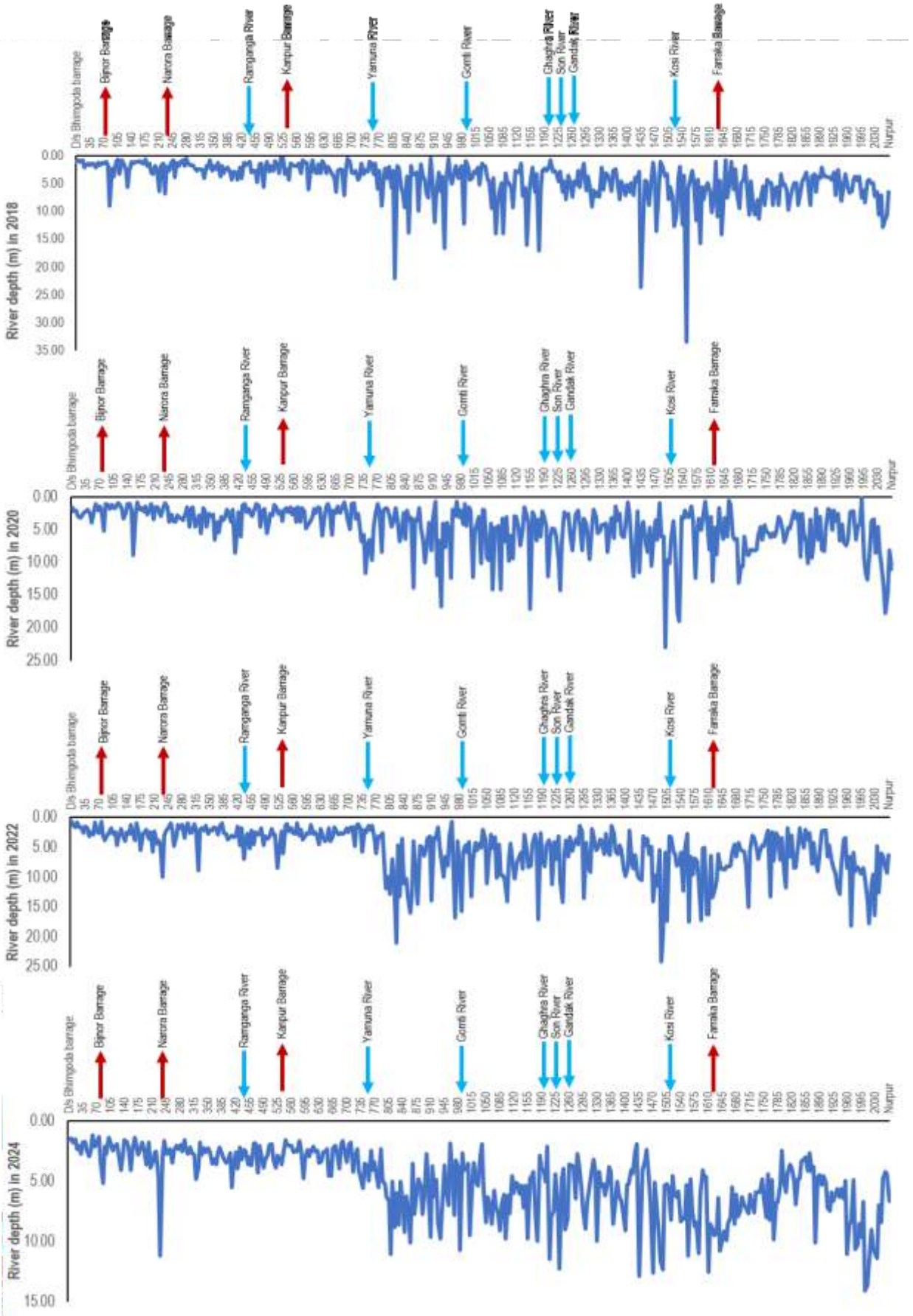


Figure 1.8 Depth profile of the Ganga River from 2018 to 2024, sampled every two years.

In 2018, about 55.8% of the Ganga River was shallow (< 4 m), which gradually declined to 42.1% in 2024. The shallow water stretches were converted to the deeper stretches. The percentage stretches in the 4-7 m category increased from 27% in 2018 to 34% in 2024 (Figure 1.9). Similarly, the stretches with depth of more than 7 m increased between 2018 and 2024 (Figure 1.9).

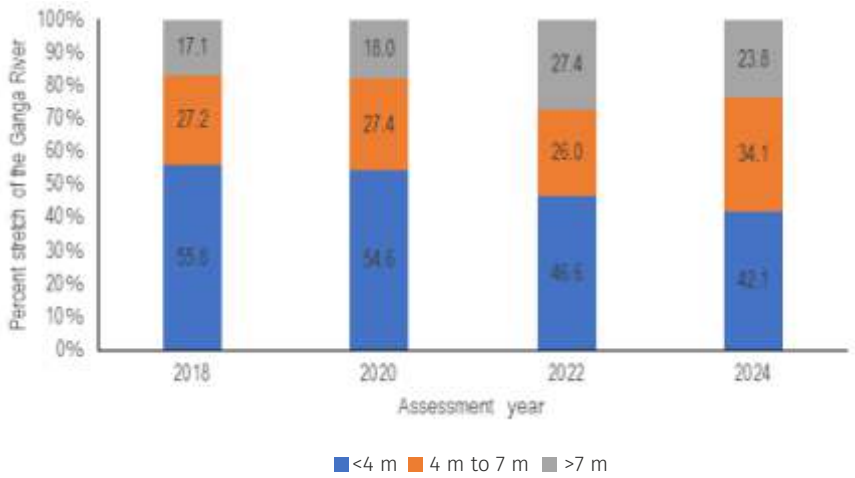


Figure 1.9 Percentage stretch of the Ganga River in various depth categories, from 2018 to 2024, sampled every two years

1.9 BIOGEOGRAPHY

Ganga River basin spans five biogeographic zones and associated provinces, including the Himalaya (West Himalaya - 2B; Central Himalaya - 2C), Semi-Arid (Punjab Plains - 4A; Gujarat Rajputana - 4B), Deccan Peninsula (Central Highlands - 6A; Chotanagpur - 6B), Gangetic Plain (Upper Gangetic Plains - 7A; Lower Gangetic Plains - 7B), and the Coasts (East Coast - 8B) (Rodgers and Panwar, 1988; Rodgers et al., 2000; Kumar et al., 2017) (Table 1.5; Figure 1.10). The basin is predominantly occupied by the Gangetic Plain zone, which accounts for approximately 39.81% of the total area, comprising 24.52% in the Upper Gangetic Plains (7A), covering sub-basins such as the Yamuna, Ramganga, Garra, Gomti, and Ghaghra, and 15.29% in the Lower Gangetic Plains (7B), encompassing the Gandak, Kosi, Mahananda, Son, Ajay, Damodar, and Rupnarayan sub-basins. The Semi-Arid zone constitutes 27.37% of the basin, largely represented by the Gujarat Rajputana province (4B; 24.28%), covering the Chambal, Sind, and Betwa sub-basins, while the Punjab Plains (4A; 3.09%) are primarily associated with the Yamuna sub-basin (in Haryana, NCT of Delhi, and upstream of the Yamuna-Chambal confluence in Uttar Pradesh, on its right bank). The Deccan Peninsula zone contributes 24.67% of the basin area, including the Central Highlands (6A; 15.01%) spanning the Yamuna, Betwa, Ken, and Son sub-basins, and the Chotanagpur Plateau (6B; 9.66%) covering the Son, Ajay, Damodar, and Rupnarayan sub-basins. The Coasts (East Coast - 8B) account for only 2.59% of the basin area and is restricted to the deltaic regions of West Bengal, primarily associated with the Rupnarayan and Haldi sub-basins.

The Himalaya zone occupies a relatively limited extent (5.56%), largely within the West Himalaya (2B), encompassing the Yamuna, Alaknanda, Bhagirathi, and Sharda sub-basins, with a minor contribution from the Central Himalaya (2C; 0.05%) in the Mahananda sub-basin. The delineation by Rodgers and Panwar (1988) includes both the northern and southern slopes of the Himalaya within the basin under the West Himalaya (2B) province.



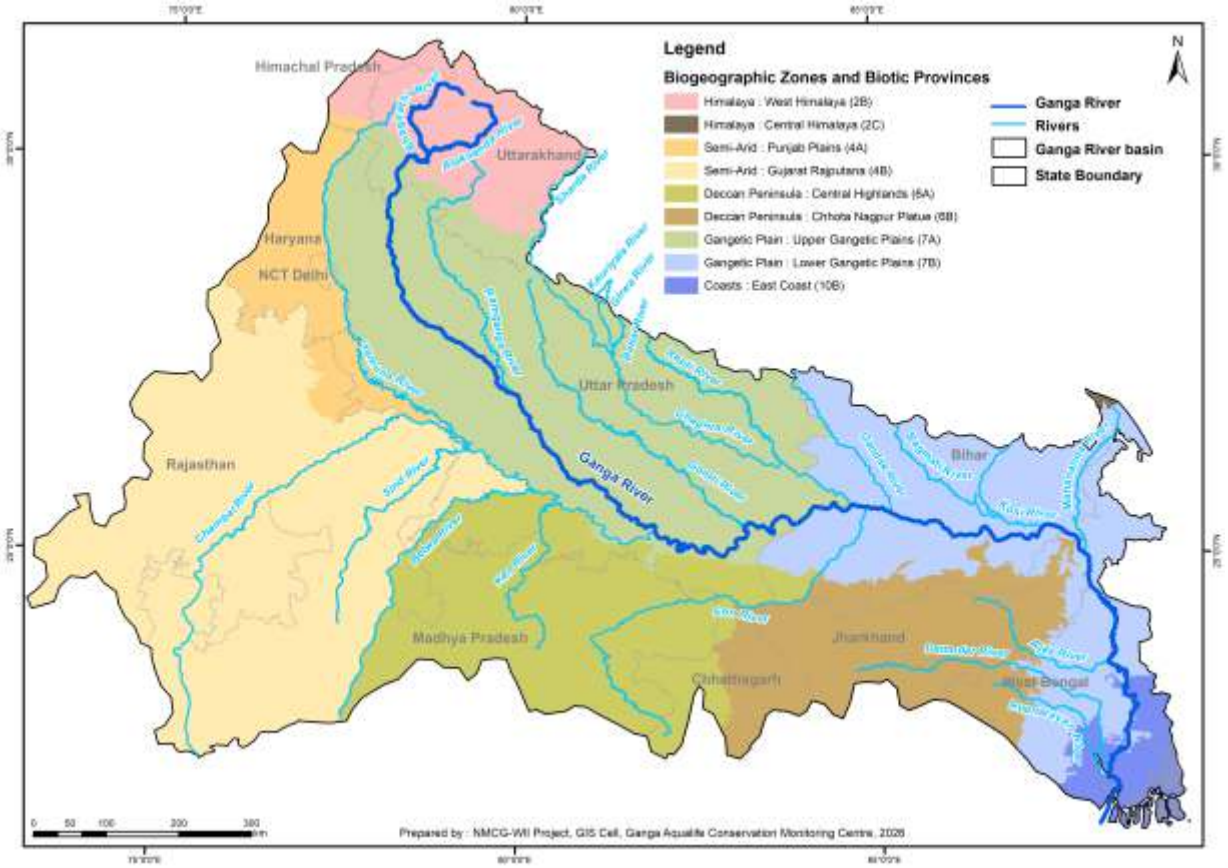


Figure 1.10 Biogeographic zones of the Ganga River basin (Rodgers and Panwar, 1988).



Table 1.5 Biogeographic zones in the Ganga River basin (Rodgers et al., 2000; Rodgers and Panwar, 1988; Kumar et al., 2017)

Biogeographic Zones	Biogeographic Provinces	States/UT
Himalaya		Uttarakhand, West Bengal
	West Himalaya (2B)	Uttarakhand, Himachal Pradesh
	Central Himalaya (2C)	West Bengal (Darjeeling district)
Semi-Arid		Haryana, NCT of Delhi, Rajasthan, Madhya Pradesh, Uttar Pradesh
	Punjab Plains (4A)	Haryana, NCT of Delhi, Rajasthan (Bharatpur district), Uttar Pradesh (parts of Mathura and Agra districts), Himachal Pradesh (southern fringes of Sirmaur district)
	Gujarat Rajputana (4B)	Rajasthan, Madhya Pradesh (North western districts in the Chambal and Sind basin, and left bank side of the Betwa basin), Uttar Pradesh (southern end of Etawah district, and districts between the Sind and Betwa rivers)
Deccan Peninsula		Madhya Pradesh, Uttar Pradesh, Chhattisgarh, Bihar, Jharkhand, West Bengal
	Central Highlands (6A)	Madhya Pradesh (Northern districts in Son basins, and right bank side of the Betwa basin), Uttar Pradesh (Southern fringe districts bordering Madhya Pradesh), Chhattisgarh (Korea, Manendragarh-Chirmiri-Bharatpur and Gaurela-Pendra-Marwahi districts, and eastern fringes of Balrampur-Ramanuganj, Surajpur and Surguja districts), Bihar (Southern parts of Kaimur and Rohtas districts)
	Chotanagpur (6B)	Jharkhand, Chhattisgarh (Balrampur-Ramanuganj, Surajpur, Surguja, Jashpur and Raigarh districts), Bihar (Southern fringes), West Bengal (Purulia district, Eastern parts of Bankura district)
Gangetic Plain		Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, West Bengal
	Upper Gangetic Plains (7A)	Uttarakhand (Southern districts in the Shivalik foothills and Terai), Uttar Pradesh
	Lower Gangetic Plains (7B)	Bihar, Jharkhand (Godda, Sahibganj and Pakur districts), West Bengal (except the south -eastern districts, and Purulia district)
Coasts		West Bengal
		East Coast (8B) the deltaic regions)

Select sub-basins	Area (sq. km)	% of GRB's landmass
Yamuna, Alaknanda, Bhagirathi, Sharda, Mahananda	47,871	5.56
Yamuna, Alaknanda, Bhagirathi, Sharda	47,438	5.51
Mahananda	433	0.05
Yamuna, Chambal, Sind, Betwa	235,785	27.37
Yamuna	26,596	3.09
Chambal, Sind, Betwa	209,189	24.28
Yamuna, Betwa, Ken, Son, Ajay, Damodar, Rupnarayan	212,518	24.67
Yamuna, Betwa, Ken, Son	129,306	15.01
Son, Ajay, Damodar, Rupnarayan	83,212	9.66
Yamuna, Ramganga, Garra, Gomti, Ghaghra, Gandak, Kosi, Mahananda, Son, Ajay, Damodar, Rupnarayan	342,931	39.81
Yamuna, Ramganga, Garra, Gomti, Ghaghra	211,206	24.52
Gandak, Kosi, Mahananda, Son, Ajay, Damodar, Rupnarayan	131,725	15.29
Rupnarayan, Haldi	22,299	2.59
West Bengal (South-eastern districts near the mouth and	Rupnarayan, Haldi	22,2992.59

1.10 FOREST TYPE AND COVER

Forests in the Ganga River basin can be classified into six broad categories, viz. Moist Tropical Forests, Dry Tropical Forests, Montane Subtropical Forests, Montane Temperate Forests, Sub Alpine Forests, and Alpine Scrub (Champion and Seth, 1968), and reflect the basin's diverse biogeographic setting and pronounced altitudinal, climatic, and edaphic gradients (Table 1.6). In the Trans-Himalaya zone (Tibetan Plateau - 1B), vegetation is dominated by dry alpine scrub (16/C1) and moist alpine scrub (15/C1, 15/C2, 15/C3), along with localized riverine forests, and is characterized by sparse, xerophytic vegetation comprising species of *Caragana*, *Artemisia*, *Juniperus*, and riparian *Populus* and *Salix*. The Himalaya zone (Western Himalaya - 2B; Central Himalaya - 2C) exhibits clear altitudinal zonation, transitioning from sub-alpine (14/C1) and alpine scrub (16/C1) forests near the treeline to Himalayan moist temperate (12/C1) and Himalayan dry temperate (13/C1) forests, followed by sub-tropical pine forests (9/C1) in the lower reaches, with dominant species including *Betula utilis*, *Abies* spp., *Cedrus deodara*, *Rhododendron* spp., *Quercus* spp., and *Pinus roxburghii*.

In the Semi-Arid zone (Punjab Plains - 4A; Gujarat Rajputana - 4B), low rainfall conditions support Northern tropical dry deciduous (5B) and Northern tropical thorn (6B) forests, interspersed with dry riverine forests and bamboo brakes, with characteristic species such as *Acacia* spp., *Prosopis* spp., *Ziziphus* spp., and *Dalbergia sissoo*. The Deccan Peninsula zone (Central Highlands - 6A; Chhota Nagpur - 6B) is dominated by North Indian moist deciduous forests (3C) and Northern tropical dry deciduous forests (5B), with occasional riverine forests and localized evergreen patches, represented by *Shorea robusta*, *Tectona grandis*, *Terminalia* spp., and *Butea monosperma*.

In the Gangetic Plain zone (Upper Gangetic Plains - 7A; Lower Gangetic Plains - 7B), forest cover is highly fragmented due to intensive land use and comprises Northern tropical dry deciduous (5B/C1, 5B/C2), North Indian moist deciduous (3C) and Northern tropical thorn (6B/C2) forests, interspersed with patches of riverine forests and edaphic scrub types (ravine and saline scrub). These vegetation types are represented by species such as *Shorea robusta*, *Tectona grandis*, and *Acacia nilotica* in the deciduous and thorn forests, along with riparian species including *Dalbergia sissoo* and *Tamarix* spp., and edaphic scrub species such as *Suaeda* spp. and *Desmostachya* spp. The lower plains further support littoral and swamp (4B/TS1) forests, particularly in the deltaic regions.

The Coasts biogeographic zone (East Coast - 8B) is characterized by littoral and swamp forests (4B/TS1), representing the Sundarbans ecosystem, with species such as *Heritiera fomes*, *Avicennia* spp., *Rhizophora* spp., and *Nypa fruticans*, shaped by tidal influence, salinity, and waterlogged conditions.

Table 1.6. Forest types in the Ganga River basin (Champion and Seth, 1968).

Biogeographic Zone	Biogeographic Province	Major Forest or Vegetation Types
Himalaya	Western Himalaya (2B)	Sub-Tropical Pine (9/C1), Himalayan Moist Temperate (12/C1), Himalayan Dry Temperate (13/C1), Sub-Alpine (14/C1), Moist Alpine Scrub (15/C1)
	Central Himalaya (2C)	Sub-Tropical Pine (9/C1), Himalayan Moist Temperate (12/C1), Sub-Alpine (14/C1), Moist Alpine Scrub (15/C1)
Semi-Arid	Punjab Plains (4A)	Tropical Dry Deciduous (5B), Tropical Thorn (6B), Tropical Dry Scrub (6B/DS), Dry Riverine (5B/DS1), Dry Bamboo Brakes (5B/E9)
	Gujarat Rajputana (4B)	Tropical Thorn (6B), Tropical Dry Scrub (6B/DS), Tropical Dry Deciduous (5B)
Deccan Peninsula	Central Highlands (6A)	Tropical Moist Deciduous (3C), Tropical Dry Deciduous (5B), Riverine Forests
	Chhota Nagpur (6B)	Tropical Dry Deciduous (5B), Tropical Moist Deciduous (3C), Localized Tropical Evergreen (1A/C1)
Gangetic Plain	Upper Gangetic Plains (7A)	Tropical Dry Deciduous (5B/C1, 5B/C2), Tropical Moist Deciduous (3C/C1, 3C/C2), Tropical Thorn (6B/C2), Saline/Alkaline Scrub (8B/DS1), Riverine Forests
	Lower Gangetic Plains (7B)	Tropical Moist Deciduous (3C), Littoral and Swamp (4B/TS1)
Coasts	East Coast (8B)	Littoral and Swamp (4B/TS1)



Dominant or Representative Species
Pinus roxburghii, Quercus incana, Rhododendron arboreum, Machilus odoratissima, Cedrus deodara, Pinus wallichiana, Juniperus spp., *Abies pindrow, A. spectabilis, Betula utilis*
Pinus roxburghii, Quercus spp., *Rhododendron* spp., *Machilus* spp., *Abies* spp., *Betula* spp., *Berberis* spp.
Anogeissus latifolia, Butea monosperma, Acacia catechu, Prosopis spp., *Ziziphus* spp., *Capparis* spp., *Dalbergia sissoo, Tamarix* spp.
Prosopis juliflora, Acacia nilotica, Salvadora persica, Tecomella undulata
Shorea robusta, Tectona grandis, Terminalia spp., *Syzygium* spp.
Butea monosperma, Terminalia pendula, Bombax ceiba; relic evergreen patches
Dalbergia sissoo, Acacia nilotica, Shorea robusta, Tectona grandis, Tamarix spp., *Suaeda* spp., *Desmostachya* spp.
Heritiera fomes, Avicennia spp., *Nypa fruticans, Syzygium* spp.
Rhizophora apiculata, Heritiera fomes, Avicennia spp., *Nypa* fruticans

Forest cover in the Ganga basin is limited, fragmented, and unevenly distributed; with relatively intact forests largely confined to mountainous and plateau regions and highly fragmented or degraded forests in the alluvial plains (Figure 1.11). Very dense forests (1.65%) and moderately dense forests (6.08%) are largely concentrated in the Himalayan region and parts of the Central Highlands and Chhota Nagpur plateau. Open forests (7.17%) form the most widespread forest category, occurring as discontinuous patches across the semi-arid region, central highlands, foothills, and parts of the plains. The Gangetic plains are largely devoid of contiguous forest cover, with only scattered patches of forests confined to the Protected Areas. Scrublands and scrub forests (1.03%) are largely distributed in the semi-arid Chambal basin. Overall, non-forest areas (84.07%) dominate, while forests account for approximately 15.93% of the basin area, reflecting intense anthropogenic pressure and extensive agricultural land use (Table 1.7).

Table 1.7 Description of forest cover classified in terms of tree canopy density classes, and area under each class in the Ganga River basin (FSI, 2022).

SN	Class	Description	Area (sq. km)	Area (%)
1	Very Dense Forest	Tree canopy density ≥ 70%	14,223.37	1.65
2	Moderately Dense Forest	<70% Tree canopy density ≥ 40%	52,362.28	6.08
3	Open Forest	<40% Tree canopy density ≥ 10%	61,766.69	7.17
4	Scrub	<10% Tree canopy density	8,853	1.03
5	Non-forest	Area not included in any of the above classes and includes water	724,198.66	84.07

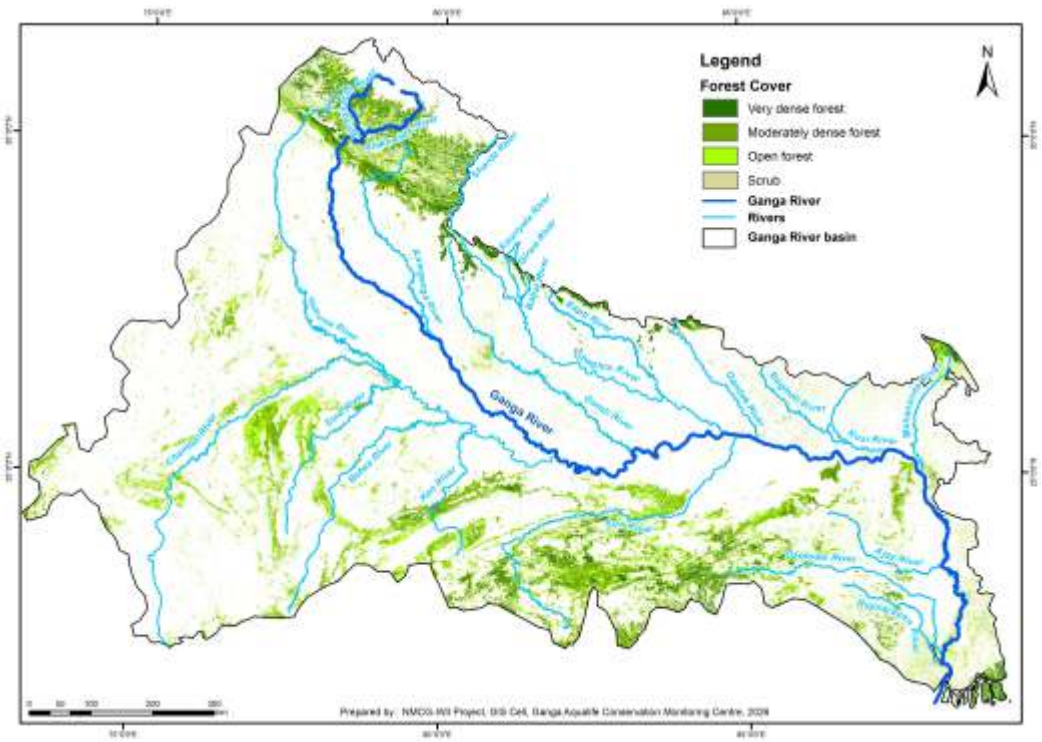


Figure 1.11 Forest cover in the Ganga River basin in 2021 (FSI, 2022).

1.11 FAUNA

Ganga River basin harbours a diverse assemblage of aquatic and water-associated fauna, including a significant number of threatened and Near Threatened species across taxa, as classified in the IUCN Red List of Threatened Species, underscoring the global conservation significance of its freshwater ecosystems (Table 1.8; Table 1.9). The basin harbours five aquatic mammal species, including the Endangered Gangetic dolphin (*Platanista gangetica*) and Irrawaddy dolphin (*Orcaella brevirostris*), as well as the Vulnerable smooth-coated otter (*Lutrogale perspicillata*), Asian small-clawed otter (*Aonyx cinereus*), and Near Threatened Eurasian otter (*Lutra lutra*) (WII-GACMC, 2018; Mallick, 2012).

The reptilian fauna includes three crocodilian species, viz. the Critically Endangered gharial (*Gavialis gangeticus*), Vulnerable mugger (*Crocodylus palustris*), and saltwater crocodile (*Crocodylus porosus*) (WII-GACMC, 2018). With 18 testudine species recorded, comprising 14 aquatic, one semi-aquatic and three terrestrial species (one with

undefined distribution, and one extralimital record), the basin is notable for its high chelonian diversity, a significant proportion of which are globally threatened (ZSI, 1992; Vyas and Singh, 2004; Das et al., 2012; Nair and Krishna, 2013; WII-GACMC, 2018; Thapa et al., 2021). Threatened species include four Critically Endangered species, namely the northern river terrapin (*Batagur baska*), red-crowned roofed turtle (*Batagur kachuga*), three-striped roofed turtle (*Batagur dhongoka*), and elongated tortoise (*Indotestudo elongata*); seven Endangered species, namely the crowned river turtle (*Hardella thurjii*), spotted pond turtle (*Geoclemys hamiltonii*), Indian eyed turtle (*Morenia petersi*), Indian narrow-headed softshell turtle (*Chitra indica*), Indian softshell turtle (*Nilssonia gangetica*), Indian peacock softshell turtle (*Nilssonia hurum*), and tricarinate hill turtle (*Melanochelys tricarinata*); and three Vulnerable species, namely the Indian roofed turtle (*Pangshura tecta*), Indian flapshell turtle (*Lissemys punctata*), and Indian star tortoise (*Geochelone elegans*). Additionally, the brown roofed turtle (*Pangshura smithii*) and Assam leaf turtle (*Cyclemys gemeli*) (undefined distribution) are classified as Near Threatened, while the Indian tent turtle (*Pangshura tentoria*) and Indian black turtle (*Melanochelys trijuga*) are listed as species of Least Concern. The Indian star tortoise has been reported from the Gandhi Sagar Reservoir (Vyas and Singh, 2004), although this record may be extralimital. The distribution of the Assam leaf turtle remains poorly defined, with a single confirmed record from the Darjeeling Hills in West Bengal (Thapa et al., 2021). Fritz et al. (2008) further suggested that a juvenile carapace collected from Sukhna in Mahananda Wildlife Sanctuary (Darjeeling district, West Bengal) in 1987, and a subadult female from Nishangara (Bahraich district, Uttar Pradesh) in 1955/1957, may also correspond to this species.

Avifauna recorded in the basin includes 236 species of water and water-associated birds, belonging to 14 orders and 32 families, including several globally threatened taxa such as the Critically Endangered Baer's pochard (*Aythya baeri*), sociable lapwing (*Vanellus gregarius*), and spoon-billed sandpiper (*Calidris pygmaea*), as well as Endangered species such as the Indian skimmer (*Rynchops albicollis*), black-bellied tern (*Sterna acuticauda*), great knot (*Calidris tenuirostris*), spotted greenshank (*Tringa guttifer*), Pallas's fish-eagle (*Haliaeetus leucoryphus*) and steppe eagle (*Aquila nipalensis*) (Mahar et al., 2025). Historical records indicate the presence of species such as the pink-headed duck (*Rhodonessa caryophyllacea*), now considered Extinct in India, and the Siberian crane (*Leucogeranus leucogeranus*), which is considered Possibly Extinct in India. The white-bellied heron was reported only once from the basin, from Bihar in 1967 (George, 1967). Sushkin's Goose (*Anser neglectus*), an extinct species, was reported only once from the basin (Bihar); however, its taxonomic status at the species level remains uncertain (Inglis, 1905).

Ichthyofaunal diversity is similarly high, with 259 fish species belonging to 24 orders and 61 families documented from the basin (Annexure-III). These include the Critically Endangered Ganges shark (*Glyphis gangeticus*); Endangered species such as the golden mahseer (*Tor putitora*), *Glyptothorax madraspatanus*, and wagur (*Clarias magur*); and Vulnerable species, including the bull shark (*Carcharhinus leucas*), *Botia rostrata*, dark mahseer (*Naziritor chelynoides*), chirruh snowtrout (*Schizothorax esocinus*), asla (*Schizothorax plagiostomus*), snowtrout (*Schizothorax richardsonii*), *Bagarius bagarius*, and *Wallago attu*.



Table 1.8 Number of species under different IUCN Red List threat categories in the Ganga River basin.

IUCN Status	Mammals (aquatic)	Crocodilians	Testudines	Avifauna (water and water-associated)	Ichthyofauna	Total
Critically Endangered (CR)	-	1	4	6	1	12
Endangered (EN)	2	-	7	6	3	18
Vulnerable (VU)	2	1	3	14	8	28
Near Threatened (NT)	1	-	2	25	16	44
Least Concern (LC)	-	1	2	184	189	374
Data Deficient (DD)	-	-	-	-	24	24
Not Evaluated (NE)	-	-	-	-	18	19
Total	**5**	**3**	**18**	**235**	**259**	**520**

Table 1.9 Threatened and Near Threatened species in the Ganga River basin, as classified in the IUCN Red List of Threatened Species.

	Critically Endangered (CR)	**Endangered (EN)**
Mammals (aquatic)		Gangetic dolphin *Platanista gangetica* (Lebeck, 1801), Irrawaddy dolphin *Orcaella brevirostris* (Owen in Gray, 1866)
Crocodilians	Gharial *Gavialis gangeticus* (Gmelin in Linnaeus, 1789)	
Testudines	Northern river terrapin *Batagur baska* (Gray, 1830), Red-crowned roofed turtle *Batagur kachuga* (Gray, 1831), Three-striped roofed turtle *Batagur dhongoka* (Gray, 1832), Elongated tortoise *Indotestudo elongata* (Blyth, 1853)	Crowned river turtle *Hardella thurjii* (Gray, 1831), Spotted pond turtle *Geoclemys hamiltonii* (Gray, 1830), Indian eyed turtle *Morenia petersi* (Anderson, 1879), Indian narrow-headed softshell turtle *Chitra indica* (Gray, 1830), Indian softshell turtle *Nilssonia gangetica* (Cuvier, 1825), Indian peacock softshell turtle *Nilssonia hurum* (Gray, 1830), Tricarinate hill turtle *Melanochelys tricarinata* (Blyth, 1856)
Avifauna (water and water-associated)	Baer's Pochard *Aythya baeri* (Radde, 1863), Sociable lapwing *Vanellus gregarius* (Pallas, 1771), Spoon-billed sandpiper *Calidris pygmaea* (Linnaeus, 1758), Pink-headed duck *Rhodonessa caryophyllacea* (Latham, 1790)[3], Siberian crane *Leucogeranus leucogeranus* (Pallas, 1773)[4], White-bellied heron *Ardea insignis* (Hume, 1878)[5]	Great knot *Calidris tenuirostris* (Horsfield, 1821), Spotted greenshank *Tringa guttifer* (Nordmann, 1835), Black-bellied tern *Sterna acuticauda* (Gray, 1832), Indian skimmer *Rynchops albicollis* (Swainson, 1838) *Rynchops albicollis* (Swainson, 1838), Pallas's fish-eagle *Haliaeetus leucoryphus* (Pallas, 1771), Steppe eagle *Aquila nipalensis* (Hodgson, 1833)
Ichthyofauna	Ganges shark *Glyphis gangeticus* (Müller and Henle, 1839)	Golden mahseer *Tor putitora* (Hamilton, 1822), *Glyptothorax madraspatanus* (Day, 1873), Wagur *Clarias magur* (Hamilton, 1822)

Vulnerable (VU)	Near Threatened (NT)
Smooth-coated otter *Lutrogale perspicillata* (I. Geoffroy Saint-Hilaire, 1826), Asian small-clawed otter *Aonyx cinereus* (Illiger, 1815)	Eurasian otter *Lutra lutra* (Linnaeus, 1758)
Mugger *Crocodylus palustris* (Lesson, 1831)	
Indian roofed turtle *Pangshura tecta* (Gray, 1830), Indian flapshell turtle *Lissemys punctata* (Lacépède, 1788),Indian star tortoise *Geochelone elegans* (Schoepff, 1795)[1]	Brown roofed turtle *Pangshura smithii* (Gray, 1863), Assam leaf turtle *Cyclemys gemeli* (Fritz, Guicking, Auer, Sommer, Wink and Hunsdörfer, 2008)
Common pochard *Aythya ferina* (Linnaeus, 1758), Lesser white-fronted goose *Anser erythropus* (Linnaeus, 1758), Long-tailed duck *Clangula hyemalis* (Linnaeus, 1758), Red-breasted goose *Branta ruficollis* (Pallas, 1769), Horned grebe *Podiceps auritus* (Linnaeus, 1758), Sarus crane *Grus antigone* (Linnaeus, 1758),Grey plover *Pluvialis squatarola* (Linnaeus, 1758) Broad-billedsandpiper *Calidris* sandpiper *Calidris ferruginea* (Pontoppidan, 1763), Wood snipe *Gallinago nemoricola* (Hodgson, 1836), River tern*Sterna aurantia* (Gray, 1831), Eastern imperial eagle *Aquila heliaca* (Savigny, 1809), Greater spotted eagle *Clanga clanga* (Pallas, 1811), Black-capped kingfisher *Halcyon pileata* (Boddaert, 1783)	Ferruginous duck *Aythya nyroca* (Güldenstädt, 1770), Marbled duck *Marmaronetta angustirostris* (Ménétries, 1832), Swamp francolin *Ortygornis gularis* (Temminck, 1815), Lesser flamingo *Phoeniconaias minor* (Temminck, 1815), (Geoffroy Saint-Hilaire, 1798), Beach thick-knee *Esacus magnirostris* (Vieillot, 1818), Great thick-knee *Esacus recurvirostris* (Cuvier, 1829), Eurasian oystercatcher *Haematopus ostralegus* (Linnaeus, 1758), Northern lapwing *Vanellus vanellus* (Linnaeus, 1758), River lapwing *Vanellus duvaucelii* (Lesson, 1826), Asian dowitcher *Limnodromus semipalmatus* (Blyth, 1848), Bar-tailed godwit *Limosa lapponica* (Linnaeus, 1758), Black-tailed godwit *Limosa limosa* (Linnaeus, 1758), Dunlin *Calidris alpina* (Linnaeus, 1758), Eurasian curlew *Numenius arquata* (Linnaeus, 1758), Long-billed dowitcher *Limnodromus scolopaceus* (Say, 1822), Red knot *Calidris canutus* (Linnaeus, 1758), Red-necked stint *Calidris ruficollis* (Pallas, 1776), Ruddy turnstone *Arenaria interpres* (Linnaeus, 1758), Greater adjutant *Leptoptilos dubius* (Gmelin, 1789), Lesser adjutant *Leptoptilos javanicus* (Horsfield, 1821), Asian woollyneck *Ciconia episcopus* (Boddaert, 1783),Dalmatian pelican *Pelecanus crispus* (Bruch, 1832), Spot-billed pelican *Pelecanus philippensis* (Gmelin, 1789), Grey-headed fish-eagle *Icthyophaga ichthyaetus* (Horsfield, 1821), Lesser fish-eagle *Icthyophaga humilis* (Müller and Schlegel, 1841)
Bull shark *Carcharhinus leucas* (Valenciennes in Müller and Henle, 1839) *Botia rostrata* (Günther, 1868), Dark mahseer *Naziritor chelynoides* (McClelland, 1839), Chirruh snowtrout *Schizothorax esocinus* (Heckel, 1838) Asla *Schizothorax plagiostomus* (Heckel, 1838), Snowtrout *Schizothorax richardsonii* (Gray, 1832), *Bagarius bagarius* (Hamilton, 1822) *Wallago attu* (Bloch and Schneider, 1801)	Spadenose shark *Scoliodon laticaudus* (Müller and Henle, 1838), Scaly whipray *Brevitrygon walga* (Müller and Henle, 1841), Cowtail ray *Pastinachus sephen* [Fabricius (ex Forsskål) in Niebuhr, 1775], *Chitala chitala* (Hamilton, 1822) Indian mottled eel *Anguilla bengalensis* (Gray, 1831), *Schistura devdevi* (Hora, 1935), Nandi labeo *Labeo nandina* (Hamilton, 1822), Pangusia labeo *Labeo pangusia* (Hamilton, 1822), Gangetic ailia *Ailia coila* (Hamilton, 1822), *Ompok bimaculatus* (Bloch, 1794), *Ompok pabda* (Hamilton, 1822), *Ompok pabo* (Hamilton, 1822), Gagora catfish *Arius gagora* (Hamilton, 1822), Bombay duck *lizardfish Harpadon nehereus* (Hamilton, 1822), Deocata pipefish *Microphis deocata* (Hamilton, 1822), Highfin glassy perchlet *Parambassis lala* (Hamilton, 1822)

[1] Indian star tortoise - The documentation by Vyas and Singh (2004) from the Gandhi Sagar Reservoir may be an extralimital record; [2] Assam leaf turtle - Recorded by Thapa et al. (2021) from Darjeeling Hills/distribution is under studied; [3] Pink-headed duck is considered Extinct in India; [4] Siberian crane is considered Possibly Extinct in India; [5] White-bellied heron was reported only once from the basin (Bihar in 1967)

Note: Sushkin's goose Anser neglectus (Sushkin, 1897) - Extinct/Taxonomic confusion on species level; One time record in India (Inglis, 1905)

Source: Mahar et al., 2025; Thapa et al., 2021; WII-GACMC, 2018; Nair and Krishna, 2013; Das et al., 2012; Mallick, 2012; Vyas and Singh, 2004; ZSI, 1992; Annexure-VII

1.12 AREAS OF CONSERVATION SIGNIFICANCE

Ganga River basin constitutes one of India's most significant conservation landscapes, supporting an extensive network of Protected Areas (PAs) and internationally significant biodiversity sites (Figure 1.12). A total of 179 PAs, comprising 26 National Parks, 119 Wildlife Sanctuaries, 33 Conservation Reserves, and one Community Reserve, are located within the basin (Table 1.10; Table 1.11). These include five dedicated riverine PAs, namely the Vikramshila Gangetic Dolphin Sanctuary (Ganga River - 60 km), Kachhua Wildlife Sanctuary (Ganga River - 30 km), National Chambal Gharial Wildlife Sanctuary (Chambal River - approx. 600 km; Parbati River - 60 km), Ken Gharial Wildlife Sanctuary (Ken River - 45.20 sq. km), and Son Gharial Wildlife Sanctuary (Son River - 161 km; Banas River - 23 km; Gopad River - 26 km), which play a critical role in conserving flagship aquatic species such as the Gangetic dolphin and gharial. Approximately 11.75% of the Ganga mainstem (296.58 km) receives incidental protection through its passage within five PAs, namely Gangotri National Park (26.47 km), Rajaji National Park (18.21 km), State Animal Barahsingha (Hastinapur) Wildlife Sanctuary (110.13 km), Kachhua Wildlife Sanctuary (30 km), Vikramshila Gangetic Dolphin Sanctuary (61.61 km), and the Sundarban Biosphere Reserve (50.16 km). Additionally, the basin hosts 20 Tiger Reserves (plus the Amangarh buffer) and six Elephant Reserves, underscoring its importance for large mammal conservation (Table 1.12; Table 1.13).

Ganga River basin encompasses several sites of international conservation importance, reflecting its global ecological significance, particularly for wetlands and avifauna. Of the 99 Ramsar Sites designated in India, 32 are located within the basin, highlighting its critical role in sustaining wetlands of international importance (Table 1.14). Similarly, the basin supports 119 Important Bird Areas (IBAs) out of 554 identified in India, underscoring its importance as a key habitat for migratory and resident bird species (Table 1.15). Additionally, three of India's seven UNESCO World Heritage Sites (Natural), namely Keoladeo National Park, Sundarbans National Park, and Nanda Devi and Valley of Flowers National Parks, are located within the basin, reflecting its exceptional biodiversity and natural heritage value (Table 1.16).

Further, the basin includes landscapes recognized under UNESCO's World Network of Biosphere Reserves (WNBR) under the Man and the Biosphere (MAB) Programme, namely the Nanda Devi Biosphere Reserve in the Alaknanda basin, the Sundarban Biosphere Reserve in the Ganga delta, the Panna Biosphere Reserve in the Ken basin, and the Achanakmar-Amarkantak Biosphere Reserve in the Son basin, the latter partly extending into the Ganga basin, with only a portion of its northern buffer and transition zone falling within the basin (Devi and Tiwari, 2024; Table 1.17). These designations highlight the basin's role as a globally significant socio-ecological system, integrating biodiversity conservation with sustainable development.



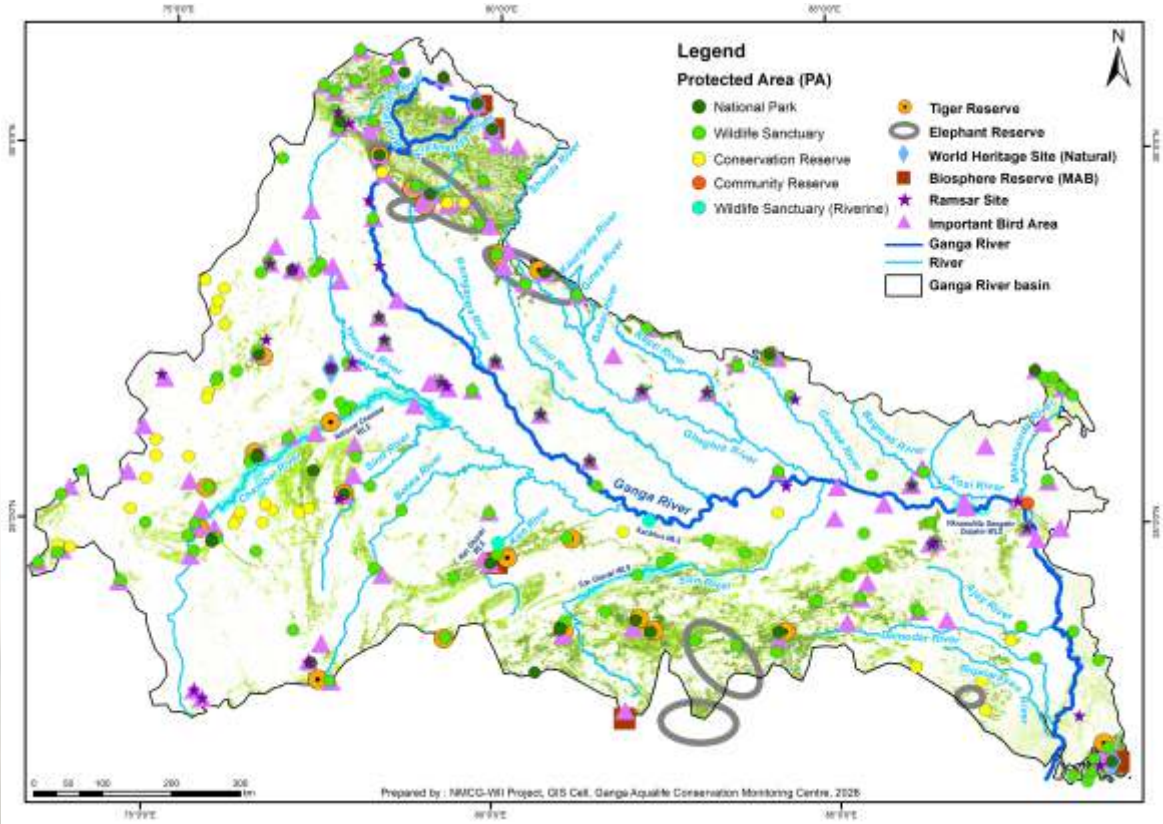


Figure 1.12 Protected Areas, Tiger Reserves, Elephant Reserves, Ramsar Sites, Important Bird Areas, Biosphere Reserves, and UNESCO World Heritage Sites (Natural) in the Ganga River basin.

Table 1.10 Number of Protected Areas, Tiger Reserves, Elephant Reserves, Ramsar Sites, Important Bird Areas, Biosphere Reserves, and UNESCO World Heritage Sites (Natural) in the Ganga River basin States/Union Territory.

State/UT	Protected Area (PA)				Tiger Reserve
	National Park	Wildlife Sanctuary	Conservation Reserve	Community Reserve	
Uttarakhand	6	7	4	-	2
Uttar Pradesh	1	25.33	1	-	4
Bihar	1	13	2	1	1
Jharkhand	1	9	-	-	1
West Bengal	2	14	4	-	1
Himachal Pradesh	1	6	-	-	?
Haryana	2	5	-	-	?
NCT Delhi	?	1	-	-	?
Rajasthan	4	21.33	22	-	5
Madhya Pradesh	7	15.33	-	-	6
Chhattisgarh	1	2	-	-	1
Ganga River basin	26	119	33	1	21

Note: National Chambal Wildlife Sanctuary - tristate, viz. Madhya Pradesh, Rajasthan and Uttar Pradesh; Achanakmar-Amarkantak Biosphere Reserve - bistate, viz. Madhya Pradesh and Chhattisgarh;

WNBR - World Network of Biosphere Reserves

Table 1.11 Protected Areas in the Ganga River basin.

State	National Park (Notification year; Area)	Wildlife Sanctuary (Notification year; Area)
Uttarakhand	Corbett (1936; 520.82 km^2)	Askot Musk Deer (1986; 600 km^2)
	Gangotri (1989; 2390.02 km^2)	Binsar (1988; 47.07 km^2)
	Govind (1990; 472.08 km^2)	Govind (1955; 485.89 km^2)
	Nanda Devi (1982; 624.62 km^2)	Kedarnath (1972; 975.2 km^2)
	Rajaji (1983; 820 km^2)	Mussoorie (1993; 10.82 km^2)
	Valley of Flowers (1982; 87.5 km^2)	Nandhaur (2012; 269.95 km^2)
		Sonanadi (1987; 301.18 km^2)
Uttar Pradesh	Dudhwa (1977; 490.29 km^2)	Bakhira (1990; 28.94 km^2)
		Chandraprabha (1957; 78 km^2)
		Dr. Bhimrao Ambedkar (2003; 4.27 km^2)
		Hastinapur (State Animal Barahsingha) (1986; 1159.16 km^2)
		Jai Prakash Narayan (Surhatal) (1991; 34.32 km^2)
		Kachhua (2020; 30 km)
		Kaimur (1982; 500.73 km^2)
		Katarniaghat (1976; 400.09 km^2)
		Kishanpur (1972; 227 km^2)
		Lakh Bahosi (1988; 80.24 km^2)
		Mahavir Swami (1977; 5.41 km^2)
		National Chambal Gharial (1978; 660 km)
		Nawabganj (Shaheed Chandra Shekhar Azad) (1984; 2.25 km^2)

Elephant Reserve	Ramsar Site	Important Bird Area (IBA)	Biosphere Reserve (WNBR)	World Heritage Site (Natural)
1	1	18	1	1
2	12	33	-	-
-	6	14	-	-
-	1	7	-	-
1	2	6	1	1
-	1	6	-	-
-	2	5	-	-
-	-	-	-	-
-	3	16	-	1
-	4	12	1.5	-
2	-	2	0.5	-
6	32	119	4	3

Conservation Reserve (Notification year; Area)	Community Reserve (Notification year; Area)
Asan Wetland (2005; 4.444 km^2)	
Jhilmil Jheel (2005; 37.835 km^2)	
Naina Devi Himalayan Bird Sanctuary (2015; 111.919 km^2)	
Sitabani (Pawalgarh) (2012; 58.2476 km^2)	
Chand Khamaria Blackbuck (2017; 1.26123 km^2)	

State	National Park (Notification year; Area)	Wildlife Sanctuary (Notification year; Area)
		Okhla (1990; 4 km^2)
		Parvati Aranga (1990; 10.84 km^2)
		Patna (1990; 1.09 km^2)
		Pilibhit (2014; 602.798 km^2)
		Ranipur (1977; 230.31 km^2)
		Saman (1990; 5.26 km^2)
		Samaspur (1987; 7.99 km^2)
		Sandi (1990; 3.09 km^2)
		Shekha (2016; 0.4 km^2)
		Sohagi Barwa (1987; 428.2 km^2)
		Sohelwa (1988; 452.47 km^2)
		Sur Sarovar (1991; 4.03 km^2)
		Vijay Sagar (1990; 2.62 km^2)
Bihar	Valmiki (1990; 335.64 km^2)	Baraila Salim Ali Zubba Saheni (1997; 1.96 km^2)
		Bhimbandh (1976; 681.99 km^2)
		Gautam Buddha (1976; 138.34 km^2)
		Kaimur (1982; 1342 km^2)
		Kanwar (Kabar) Jheel (1989; 63.11 km^2)
		Kusheshwar Asthan (1994; 29.17 km^2)
		Nagi Dam (1987; 1.92 km^2)
		Nakti Dam (1987; 3.33 km^2)
		Rajauli (2019; 27.27 km^2)
		Rajgir (1978; 35.84 km^2)
		Udaypur (1978; 8.87 km^2)
		Valmiki (1978; 545.15 km^2)
		Vikramshila Gangetic Dolphin (1990; 60 km)
Jharkhand	Betla (1986; 226.33 km^2)	Gautam Budha (1976; 121.14 km^2)
		Hazaribagh (1976; 186.25 km^2)
		Koderma (1985; 177.35 km^2)
		Lawalong (1978; 211.03 km^2)
		Mahauadanr Wolf (1976; 63.256 km^2)
		Palamau (1976; 752.94 km^2)
		Parasnath (1984; 49.33 km^2)
		Topchanchi (1978; 12.82 km^2)
		Udhwa Lake (1991; 5.65 km^2)
West Bengal	Singalila (1992; 78.6 km^2)	Ballavpur (1977; 2.021 km^2)
	Sundarbans (1984; 1330.1 km^2)	Bethuadahari (1980; 0.6686 km^2)
		Bibhuti Bhusan (1980; 0.64 km^2)
		Chintamani Kar (1982; 0.07 km^2)
		Halliday Island (1976; 5.95 km^2)
		Jorepokhri Salamander (1985; 0.04 km^2)
		Lothian Island (1976; 38 km^2)
		Mahananda (1976; 158.04 km^2)

Conservation Reserve (Notification year; Area)	Community Reserve (Notification year; Area)
Bhaluni Dham (2021; 0.12 km^2)	Gogabeel (2019; 0.57 km^2)
Gogabeel (2019; 0.3 km^2)	
Deul (2017; 0.105 km^2)	
Garpanchkot (2017; 13.4034 km^2)	
Hijli (2017; 0.155 km^2)	
Mukutmanipur (2017; 0.437 km^2)	

State	National Park (Notification year; Area)	Wildlife Sanctuary (Notification year; Area)
		Pakhibitan (2016; 14.09 km^2)
		Raiganj (1985; 1.3 km^2)
		Ramnabagan (1981; 0.1431 km^2)
		Sajnekhali (1976; 362.4 km^2)
		Senchal (1976; 38.88 km^2)
		West Sundarban (2013; 556.45 km^2)
Himachal Pradesh	Col. Sher Jung (Simbalbara) (2010; 27.88 km^2)	Chail (1976; 16 km^2)
		Churdhar (1985; 55.52 km^2)
		Daranghati (1962; 171.5 km^2)
		Rakchham Chitkul (Sangla Valley) (1989; 304 km^2)
		Renuka (2013; 3.87 km^2)
		Talra (1962; 46.48 km^2)
Haryana	Kalesar (2003; 46.82 km^2)	Bhindawas Lake (1986; 4.1155 km^2)
	Sultanpur (1989; 1.43 km^2)	Chhilchhila (1986; 0.29 km^2)
		Kalesar (1996; 54.36 km^2)
		Khaparwas (1991; 0.83 km^2)
		Nahar (1987; 2.1135 km^2)
NCT Delhi		Asola Bhati (Indira Priyadarshini) (1986; 27.82 km^2)
Rajasthan	Keoladeo Ghana (1981; 28.73 km^2)	Bandh Baratha (1985; 368.5048 km^2)
	Mukundra Hills (Darrah) (2012; 200 km^2)	Bassi (1988; 138.69 km^2)
	Ranthambore (1980; 282.03 km^2)	Bhensrodgarh (1983; 229.14 km^2)
	Sariska (1982; 273.8 km^2)	Darrah (1955; 80.75 km^2)
		Jamwa Ramgarh (1982; 300 km^2)
		Jawahar Sagar (1975; 153.41 km^2)
		Kailadevi (1983; 676.38 km^2)
		Kesarbagh (1955; 14.76 km^2)
		Kumbhalgarh (1971; 608.58 km^2)
		Nahargarh (1980; 50 km^2)
		National Chambal Gharial (1978; 660 km)
		Phulwari Ki Nal (1983; 692.68 km^2)
		Ramgarh Vishdhari (1982; 252.79 km^2)
		Ramsagar (1955; 34.4 km^2)
		Sajjangarh (1987; 5.19 km^2)
		Sariska (1955; 219 km^2)
		Sawai Madhopur (1955; 131.3 km^2)
		Sawai Man Singh (1984; 103.25 km^2)
		Shergarh (1983; 98.71 km^2)
		Sitamata (1979; 422.94 km^2)
		Todgarh Raoli (1983; 495.27 km^2)
		Van Vihar (1955; 25.6 km^2)
Madhya Pradesh	Bandhavgarh (1968; 448.842 km^2)	Bagdara (1978; 478 km^2)
	Kuno (2018; 748.7618 km^2)	Dr. Bhimrao Ambedkar Abhyaran (2025; 258.64 km^2)
	Madhav (1956; 375.23 km^2)	Gandhi Sagar (1981; 368.62 km^2)

Conservation Reserve (Notification year; Area)	Community Reserve (Notification year; Area)
Aasop (2024; 1.184513 km^2)	
Amrakh Mahadev Leopard (2023; 71.468527 km^2)	
Baleshwar (2023; 221.69 km^2)	
Banjh Amli (2023; 146.21 km^2)	
Bansiyal - Khetdi Bagore (2018; 39.66 km^2)	
Bansiyal Khetdi (2017; 70.1834 km^2)	
Beed Muhana -A (2023; 2.0689 km^2)	
Beed Muhana -B (2023; 0.1039 km^2)	
Beed Ghaas Fuliakhurd (2022; 0.8579 km^2)	
Bisalpur (2008; 48.31 km^2)	
Hamirgarh (2023; 5.66 km^2)	
Jhalana-Amagarh (2023; 35.07169 km^2)	
Kharmor (2023; 9.31 km^2)	
Mahseer (2023; 2.06035 km^2)	
Mansa Mata (2019; 102.31 km^2)	
Ramgarh (2023; 38.0864 km^2)	
Shahabad Talheti (2022; 178.84 km^2)	
Shahbad (2022; 189.3961 km^2)	
Sorsan I (2023; 16.1073 km^2)	
Sorsan II (2023; 4.27 km^2)	
Sorsan III (2023; 0.7563 km^2)	
Ummedganj Pakshi Vihar (2012; 2.7247 km^2)	

State	National Park (Notification year; Area)	Wildlife Sanctuary (Notification year; Area)
	Mandla (Ghughwa) Fossil (1983; 0.27416 km^2)	Gangau (1979; 78.53 km^2)
	Panna (1981; 542.6626 km^2)	Ghatigaon (1981; 510.64 km^2)
	Sanjay (1981; 466.657 km^2)	Karera (1981; 202.21 km^2)
	Van Vihar (1979; 4.452 km^2)	Ken Gharial (1981; 45.2 km^2)
		Narsinghgarh (1978; 57.19 km^2)
		National Chambal Gharial (1978; 660 km)
		Noradehi (1984; 1197.04 km^2)
		Orchha (1994; 44.914 km^2)
		Panpatha (1983; 245.842 km^2)
		Ralamandal (1989; 2.345 km^2)
		Ratapani (1978; 910.638 km^2)
		Sanjay Dubri (1975; 347.938 km^2)
		Son Gharial (1981; 210 km)
Chhattisgarh	Guru Ghasi Das (Sanjay) (2001; 1440.71 km^2)	Semarsot (1978; 430.35 km^2)
		Tamor Pingla (1978; 608.51 km^2)

Source: National Wildlife Database Centre, Wildlife Institute of India; MoEF&CC, 2021; Forest Department, Government of Uttarakhand; Forest and Wildlife Department, Government of Uttar Pradesh; Environment, Forest and Climate Change Department, Government of Bihar; Department of Forest, Environment and Climate Change, Government of Jharkhand; Wildlife Wing, Directorate of Forest, Government of West Bengal; Forest Department, Government of Himachal Pradesh; Forest Department, Government of Haryana; Forest Department, Government of NCT of Delhi; Forest Department, Government of Rajasthan; Forest Department, Government of Madhya Pradesh; Forest and Climate Change Department, Government of Chhattisgarh



Conservation Reserve (Notification year; Area)	Community Reserve (Notification year; Area)



Table 1.12 Tiger Reserves in the Ganga River basin.

SN	Tiger Reserve	State	Year of Notification
1	Amanagarh buffer	Uttar Pradesh	2012
2	Bandhavgarh	Madhya Pradesh	2007
3	Corbett	Uttarakhand	2010
4	Dholpur - Karauli	Rajasthan	2023
5	Dudhwa	Uttar Pradesh	2010
6	Guru Ghasidas - Tamor Pingla	Chhattisgarh	2024
7	Madhav	Madhya Pradesh	2025
8	Mukundara	Rajasthan	2013
9	Palamau	Jharkhand	2012
10	Panna	Madhya Pradesh	2007
11	Pilibhit	Uttar Pradesh	2014
12	Rajaji	Uttarakhand	2015
13	Ramgarh Vishdhari	Rajasthan	2022
14	Ranipur	Uttar Pradesh	2022
15	Ranthambore	Rajasthan	2007
16	Ratapani	Madhya Pradesh	2024
17	Sanjay Dhubri	Madhya Pradesh	2011
18	Sariska	Rajasthan	2007
19	Sunderban	West Bengal	2007
20	Valmiki	Bihar	2012
21	Veerangana Durgavati	Madhya Pradesh	2023

Source: National Tiger Conservation Authority (www.ntca.gov.in)

Table 1.13 Elephant Reserves in the Ganga River basin.

SN	Elephant Reserve	State	Districts	Year of Notification	Area (sq. km)
1	Sarguja-Jashpur (Badalkhol - Tamorpingla)	Chhattisgarh	Surguja, Jashpur	2011	1,143.34
2	Lemru	Chhattisgarh	Surguja, Korba, Raigarh	2021	1,995.48
3	Uttar Pradesh	Uttar Pradesh	Saharanpur, Bijnor	2009	744.096
4	Terai	Uttar Pradesh	Lakhimpur Kheri, Bahraich, Pilibhit, Shahjahanpur	2022	3,072.35
5	Shivalik	Uttarakhand	Dehradun, Haridwar, Pauri Garhwal, Nainital, Almora, Udham Singh Nagar, Tehri Garhwal, Champawat	2002	5,405.07
6	Mayurjharna	West Bengal	Paschim Medinipur, Purba Medinipur, Bankura, Purulia	2002	414

Core Area (sq. km)	Buffer Area (sq. km)	Total Area (sq. km)
-	80.6	80.6
716.9	820.03	1,536.93
821.99	466.32	1288.31
599.6406	-	599.6406
1,093.79	1,107.98	2,201.77
2049.232	780.155	2829.387
375.233	1276.154	1651.387
417.17	342.82	759.99
414.08	715.85	1,129.93
576.13	1,021.97	1,598.10
602.79	127.45	730.25
819.54	255.63	1075.17
481.9073	1019.9848	1501.8921
230.31	299.0512	529.3612
1,113.36	297.92	1,411.29
763.812	507.653	1271.465
812.57	861.93	1,674.50
881.11	332.23	1,213.34
1,699.62	885.27	2,584.89
598.45	300.93	899.38
1414.006	925.12	2339.12



Table 1.14 Ramsar Sites in the Ganga River basin (as on 22-04-2026).

SN	Ramsar Site	State	Area (ha)	Date of Designation
1	Asan Conservation Reserve	Uttarakhand	444.4	21-07-2020
2	Bakhira Wildlife Sanctuary	Uttar Pradesh	2,894	29-06-2021
3	Bhindawas Wildlife Sanctuary	Haryana	412	25-05-2021
4	Bhoj Wetland	Madhya Pradesh	3201	19-08-2002
5	East Calcutta Wetlands	West Bengal	12,500	19-08-2002
6	Gogabil Lake	Bihar	86.63	13-05-2025
7	Gokul Jalashay	Bihar	448	13-05-2025
8	Haiderpur Wetland	Uttar Pradesh	6,908	13-04-2021
9	Kabartal Wetland	Bihar	2,620	21-07-2020
10	Keoladeo National Park	Rajasthan	2,873	01-10-1981
11	Nagi Bird Sanctuary	Bihar	205.817	11-10-2023
12	Nakti Bird Sanctuary	Bihar	332.608	11-10-2023
13	Nawabganj Bird Sanctuary	Uttar Pradesh	224.6	19-09-2019
14	Parvati Arga Bird Sanctuary	Uttar Pradesh	722	02-12-2019
15	Patna Bird Sanctuary	Uttar Pradesh	108.86	04-12-2025
16	Renuka Wetland	Himachal Pradesh	20	08-11-2005
17	Sakhya Sagar	Madhya Pradesh	248	07-01-2022
18	Saman Bird Sanctuary	Uttar Pradesh	526.3	02-12-2019
19	Samaspur Bird Sanctuary	Uttar Pradesh	799.371	03-10-2019
20	Sambhar Lake	Rajasthan	24,000	23-03-1990
21	Sandi Bird Sanctuary	Uttar Pradesh	308.54	26-09-2019
22	Sarsai Nawar Jheel	Uttar Pradesh	161.27	19-09-2019
23	Sheikha Jheel Bird Sanctuary	Uttar Pradesh	40.309	19-01-2026
24	Siliserh lake	Rajasthan	315.97	07-07-2025
25	Sirpur Wetland	Madhya Pradesh	161	07-01-2022
26	Sultanpur National Park	Haryana	142.52	25-05-2021
27	Sundarban Wetland	West Bengal	423,000	30-01-2019
28	Sur Sarovar	Uttar Pradesh	431	21-08-2020
29	Udaipur Jheel	Bihar	319	13-05-2025
30	Udhwa Lake Bird Sanctuary	Jharkhand	935.5	08-01-2024
31	Upper Ganga River	Uttar Pradesh	26,590	08-11-2005
32	Yashwant Sagar	Madhya Pradesh	822.9	07-01-2022

Wetland Type
Inland wetlands, M: Permanent rivers/ streams/ creeks, Human-made wetlands, 6: Water storage areas/Reservoirs
Inland wetlands, Tp: Permanent freshwater marshes/ pools
Human-made wetlands, 6: Water storage areas/Reservoirs
Inland wetlands, O: Permanent freshwater lakes, Human-made wetlands, 6: Water storage areas/Reservoirs
Human-made wetlands, 1: Aquaculture ponds, 8: Wastewater treatment areas, Marine or coastal wetlands, G: Intertidal mud, sand or salt flats
Inland wetlands, N: Seasonal/ intermittent/ irregular rivers/ streams/ creeks
Inland wetlands, N: Seasonal/ intermittent/ irregular rivers/ streams/ creeks
Inland wetlands, M: Permanent rivers/ streams/ creeks, Ts: Seasonal/ intermittent freshwater marshes/ pools on inorganic soils, Human-made wetlands, 6: Water storage areas/Reservoirs
Human-made wetlands, 2: Ponds, Inland wetlands, W: Shrub-dominated wetlands
Inland wetlands, Tp: Permanent freshwater marshes/ pools, Ts: Seasonal/ intermittent freshwater marshes/ pools on inorganic soils, P: Seasonal/ intermittent freshwater lakes, Human-made wetlands, 6: Water storage areas/Reservoirs
Human-made wetlands, 6: Water storage areas/Reservoirs
Human-made wetlands, 6: Water storage areas/Reservoirs
Inland wetlands, Ts: Seasonal/ intermittent freshwater marshes/ pools on inorganic soils
Inland wetlands, O: Permanent freshwater lakes
Inland wetlands, Tp: Permanent freshwater marshes/ pools
Inland wetlands, Y: Permanent Freshwater springs; oases, W: Shrub-dominated wetlands, Xf: Freshwater, tree-dominated wetlands, U: Permanent Non-forested peatlands, Xp: Permanent Forested peatlands, Zk(b): Karst and other subterranean hydrological systems
Human-made wetlands, 6: Water storage areas/Reservoirs
Inland wetlands, P: Seasonal/ intermittent freshwater lakes
Inland wetlands, Tp: Permanent freshwater marshes/ pools
Inland wetlands, N: Seasonal/ intermittent/ irregular rivers/ streams/ creeks, Ts: Seasonal/ intermittent freshwater marshes/ pools on inorganic soils, Q: Permanent saline/ brackish/ alkaline lakes, R: Seasonal/ intermittent saline/ brackish/ alkaline lakes and flats, Human-made wetlands, 5: Salt exploitation sites
Inland wetlands, Tp: Permanent freshwater marshes/ pools
Inland wetlands, Tp: Permanent freshwater marshes/ pools
Human-made wetlands, 6: Water storage areas/Reservoirs
Human-made wetlands, 6: Water storage areas/Reservoirs
Human-made wetlands, 6: Water storage areas/Reservoirs
Inland wetlands, P: Seasonal/ intermittent freshwater lakes
Marine or coastal wetlands, F: Estuarine waters, J: Coastal brackish / saline lagoons
Human-made wetlands, 6: Water storage areas/Reservoirs
Inland wetlands, N: Seasonal/ intermittent/ irregular rivers/ streams/ creeks
Inland wetlands, O: Permanent freshwater lakes
Inland wetlands, Tp: Permanent freshwater marshes/ pools, Xf: Freshwater, tree-dominated wetlands, Ts: Seasonal/ intermittent freshwater marshes/ pools on inorganic soils, Human-made wetlands, 9: Canals and drainage channels or ditches, 6: Water storage areas/Reservoirs, 4: Seasonally flooded agricultural land, 3: Irrigated land
Human-made wetlands, 6: Water storage areas/Reservoirs

Table 1.15 Important Bird Areas (IBAs) in the Ganga River basin.

SN	Important Bird Area (IBA)	State
1	Achanakmar Wildlife Sanctuary and Maniyari Reservoir	Chhattisgarh
2	Alniya Dam	Rajasthan
3	Amangarh Reserve Forest	Uttar Pradesh
4	Asan Barrage	Uttarakhand
5	Askot Wildlife Sanctuary and Goriganga Basin	Uttarakhand
6	Bakhira Wildlife Sanctuary	Uttar Pradesh
7	Bandhavgarh National Park	Madhya Pradesh
8	Bardha Dam	Rajasthan
9	Basai wetlands	Haryana
10	Bhindawas Wildlife Sanctuary	Haryana
11	Bhoj wetland	Madhya Pradesh
12	Binog Sanctuary - Bhadraj - Jharipani	Uttarakhand
13	Binsar Wildlife Sanctuary	Uttarakhand
14	Chail Wildlife Sanctuary	Himachal Pradesh
15	Chaurs of North Bihar	Bihar
16	Churdhar Wildlife Sanctuary	Himachal Pradesh
17	Corbett Tiger Reserve	Uttarakhand
18	Danapur cantonment area	Bihar
19	Daranghati Wildlife Sanctuary	Himachal Pradesh
20	Dhanauri wetland	Uttar Pradesh
21	Dighal wetland	Haryana
22	Dihaila Jheel and other wetlands	Madhya Pradesh
23	Dudhwa National Park	Uttar Pradesh
24	Farakka Barrage and adjoining area	West Bengal
25	Gandhi Sagar Wildlife Sanctuary and reservoir	Madhya Pradesh
26	Gangotri National Park	Uttarakhand
27	Ghatigaon Bustard Sanctuary	Madhya Pradesh
28	Gogabil Pakshi Vihar, Baghar Beel and Baldia Chaur	Bihar
29	Govind National Park and Wildlife Sanctuary, Sandra, Kotinad and Singtur ranges (Tons Forest Division)	Uttarakhand
30	Guru Ghasidas Tiger Reserve	Chhattisgarh
31	Halali Reservoir	Madhya Pradesh
32	Hastinapur Wildlife Sanctuary	Uttar Pradesh
33	Hazaribagh Wildlife Sanctuary	Jharkhand
34	Jawahar Sagar Sanctuary	Rajasthan
35	Jehanabad Administrative Area	Bihar
36	Jhilmil Jheel Conservation Reserve	Uttarakhand
37	Kachhudah Lake and Mahananda River Course	Bihar
38	Kajra Dhar and Raniganj Protected Forest	Bihar
39	Kalesar Wildlife Sanctuary	Haryana
40	Katerniaghat Wildlife Sanctuary and Girijapur Barrage	Uttar Pradesh
41	Kawar (Kabar) Lake Wildlife Sanctuary	Bihar
42	Kedarnath Musk Deer Sanctuary and surrounding Reserve Forests	Uttarakhand

IBA Criteria	Key Biodiversity Area (KBA) Classification	Year of Last Assessment
A1, A3	Global/Regional TBD	2016
A1, A4iii	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2016
A1, A4i	Global/Regional TBD	2004
A1, A2	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2004
A1, A3, A4i	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A2	Global/Regional TBD	2004
A3	Global/Regional TBD	2004
A1, A2, A3	Global/Regional TBD	2004
A4iii	Regional	2004
A3	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4i	Regional	2004
A1, A2	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2016
A1, A4iii	Global/Regional TBD	2016
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A3, A4i	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A4iii	Regional	2004
A1, A2	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1, A2	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2016
A1, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2016
A1	Global/Regional TBD	2016
A4i	Global	2016
A1	Global/Regional TBD	2016
A1	Global/Regional TBD	2016
A1	Global/Regional TBD	2016
A1, A3	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1, A2, A3	Global/Regional TBD	2004

SN	Important Bird Area (IBA)	State
43	Keoladeo National Park and Ajan Bande	Rajasthan
44	Kishanpur Wildlife Sanctuary	Uttar Pradesh
45	Kudaiyya marshland	Uttar Pradesh
46	Kulik (Raiganj) Bird Sanctuary	West Bengal
47	Kumbalgarh Wildlife Sanctuary	Rajasthan
48	Kurra Jheel	Uttar Pradesh
49	Kurseala River Course and Diyara Floodplain	Bihar
50	Kusheshwarsthan	Bihar
51	Lagga - Bagga Reserve Forest	Uttar Pradesh
52	Lakh-Bahosi Bird Sanctuary	Uttar Pradesh
53	Madhav National Park	Madhya Pradesh
54	Mahananda Wildlife Sanctuary	West Bengal
55	Mahaveer Swami Wildlife Sanctuary (Lalitpur)	Uttar Pradesh
56	Mokama Taal (Barah) Wetlands	Bihar
57	Nagi Dam Bird Sanctuary	Bihar
58	Naina Devi Himalayan Bird Conservation Reserve	Uttarakhand
59	Nakti Dam Bird Sanctuary	Bihar
60	Nanda Devi Biosphere Reserve	Uttarakhand
61	Nandhour Wildlife Sanctuary	Uttarakhand
62	Narora	Uttar Pradesh
63	National Chambal Wildlife Sanctuary (Agra/Etawah)	Uttar Pradesh
64	National Chambal Wildlife Sanctuary (Bundi/Kota)	Rajasthan
65	Nawabganj Bird Sanctuary	Uttar Pradesh
66	Naya Bandh Wetland Complex	West Bengal
67	New Forest Campus	Uttarakhand
68	North Karanpura Valley	Jharkhand
69	Okhla Bird Sanctuary	Uttar Pradesh, NCT of Delhi
70	Palamau Tiger Reserve	Jharkhand
71	Panna National Park	Madhya Pradesh
72	Parvati Aranga Wildlife Sanctuary	Uttar Pradesh
73	Patna Bird Sanctuary	Uttar Pradesh
74	Pawalgarh Conservation Reserve	Uttarakhand
75	Phulwari Wildlife Sanctuary	Rajasthan
76	Pilibhit Tiger Reserve	Uttar Pradesh
77	Pyagpur and Sitadwar Jheel	Uttar Pradesh
78	Rajaji National Park	Uttarakhand
79	Ramsagar Lake	Rajasthan
80	Rangawa Reservoir	Madhya Pradesh
81	Ranthambore National Park and Tiger Reserve	Rajasthan
82	Ratapani Wildlife Sanctuary	Madhya Pradesh
83	Reservoirs of Chota Nagpur Plateau	Jharkhand
84	Sajjangarh Wildlife Sanctuary	Rajasthan
85	Saman Bird Sanctuary	Uttar Pradesh
86	Samaspur Bird Sanctuary	Uttar Pradesh

IBA Criteria	Key Biodiversity Area (KBA) Classification	Year of Last Assessment
A1, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A4iii	Regional	2004
A1	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A2, A3	Global/Regional TBD	2004
A1	Global/Regional TBD	2016
A1, A4i, A4iii	Global/Regional TBD	2004
A4i, A4iii	Regional	2004
A1	Global/Regional TBD	2016
A4i, A4iii	Regional	2004
A1, A2	Global/Regional TBD	2004
A1	Global/Regional TBD	2016
A1, A4iii	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1, A4iii	Global	2004
A1, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A3	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2016
A1, A4iii	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2016
A1	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2016
A1, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A4iii	Regional	2004
A1, A3	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A4iii	Regional	2016
A1, A3	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004

SN	Important Bird Area (IBA)	State
87	Sambhar Lake	Rajasthan
88	Sandi Wildlife Sanctuary	Uttar Pradesh
89	Sangla (Raksham Chitkul) Wildlife Sanctuary	Himachal Pradesh
90	Sareri Bandh	Rajasthan
91	Sariska Tiger Reserve	Rajasthan
92	Sarsai Nawar Lake	Uttar Pradesh
93	Sauj Lake	Uttar Pradesh
94	Sheikha Jheel	Uttar Pradesh
95	Simbalbara National Park	Himachal Pradesh
96	Singhalila National Park	West Bengal
97	Sirpur Lake	Madhya Pradesh
98	Sitamata Wildlife Sanctuary	Rajasthan
99	Sohagibarwa Wildlife Sanctuary	Uttar Pradesh
100	Soheldev Wildlife Sanctuary	Uttar Pradesh
101	Sonanadi Wildlife Sanctuary	Uttarakhand
102	Sonkhaliya Closed Area	Rajasthan
103	Sultanpur National Park	Haryana
104	Sundarbans Biosphere Reserve (National Park)	West Bengal
105	Sur Sarovar Bird Sanctuary	Uttar Pradesh
106	Surajpur wetland	Uttar Pradesh
107	Surha Tal Wildlife Sanctuary	Uttar Pradesh
108	Talra Wildlife Sanctuary	Himachal Pradesh
109	Tilaiya Dam	Jharkhand
110	Topchanchi Wildlife Sanctuary	Jharkhand
111	Udaipur Lakes Complex	Rajasthan
112	Udhuwa Lake Bird Sanctuary	Jharkhand
113	Upper Pindar Catchment in East Almora Forest Division	Uttarakhand
114	Valley of Flowers National Park	Uttarakhand
115	Valmiki Tiger Reserve and Saraiyaman Lake	Bihar
116	Vijay Sagar Wildlife Sanctuary	Uttar Pradesh
117	Vikramshila Gangetic Dolphin Sanctuary	Bihar
118	Wetlands of Yamuna River	Uttar Pradesh, Haryana
119	Yeshwantsagar Reservoir	Madhya Pradesh

Note: Criterion A1 Globally Threatened Species - the site is known or thought regularly to hold significant numbers of a Globally Threatened species; Criterion A2 Restricted Range Species - the site is known or thought to hold a significant population of at least two range-restricted species; Criterion A3 Bioregion-restricted Assemblages - the site is known or thought to hold a significant component of the group of species whose distributions are largely or wholly confined to one biome-realm; Criterion A4 Congregations - the site is known or thought to hold congregations of ≥1% of the global population of one or more species on a regular or predictable basis (A4i - waterbird species, A4ii - seabird or terrestrial species, A4iii - ≥ 20,000 waterbirds or ≥10,000 pairs of seabird of one or more species).

Source: BirdLife International (2026) Country factsheet: India. Downloaded from https://datazone.birdlife.org/country/factsheet/india on 28/03/2026

IBA Criteria	Key Biodiversity Area (KBA) Classification	Year of Last Assessment
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A2	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2016
A1, A2	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2016
A1, A3	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4i, A4iii	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2016
A1, A4iii	Global/Regional TBD	2004
A1, A2, A3	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2016
A1, A3	Global/Regional TBD	2016
A1, A4i	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A2, A3	Global/Regional TBD	2004
A1	Global/Regional TBD	2004
A1, A3	Global/Regional TBD	2004
A1, A4iii	Global/Regional TBD	2016
A1	Global/Regional TBD	2004
A4iii	Regional	2004
A1, A4i	Global/Regional TBD	2004

Table 1.16 UNESCO World Heritage Sites (Natural) in the Ganga River basin.

SN	World Heritage Site (Natural)	States	Area (sq. km)	Year of Inscription
1	Keoladeo National Park	Rajasthan	28.73	1985
2	Sundarbans National Park	West Bengal	1,330.10	1987
3	Nanda Devi and Valley of Flowers National Parks	Uttarakhand	5,860.67	1988, 2005

Table 1.17 Biosphere Reserves in the Ganga River basin (recognised under UNESCO's Man and Biosphere Programme).

SN	Biosphere Reserve	States	Area (sq. km)	Year of Nomination (WNBR)	Year of Designation (India)
1	Nanda Devi	Uttarakhand *(Alaknanda basin; core area - Nanda Devi National Park and Valley of Flowers National Park)*	6,407.03	2004	1988
2	Sundarban	West Bengal *(Ganga Delta, south of Calcutta and bordering Bangladesh in the east; core area - Sundarban National Park)*	9,630	2001	1989
3	Panna	Madhya Pradesh *(Ken basin; Panna National Park, Gangau Wildlife Sanctuary, reserved and protected forests of the North Panna Forest Division)*	2,998.98	2020	2011
4	Achanakmar-Amarkantak	Madhya Pradesh, Chhattisgarh *(Son and Narmada basin; core area - Achanakmar Wildlife Sanctuary; a part of the northern buffer and transition zone lies in the Ganga basin)*	3,835.51	2012	2005

Note: WNBR - World Network of Biosphere Reserves

Source: UNESCO Man and the Biosphere (MAB) programme (www.unesco.org/en/mab); Ministry of Environment, Forest and Climate Change, Government of India

1.13 DEMOGRAPHY

Ganga River basin spans 280 districts across 11 States and UT, namely Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Himachal Pradesh, Haryana, NCT of Delhi, Rajasthan, Madhya Pradesh and Chhattisgarh (Table 1.18). The basin supports a substantial proportion of India's population, with approximately 539 million people, accounting for 44.53% of the national population, distributed over 861,404 sq. km (26.20% of India's geographical area) (Government of India, 2011). The basin exhibits a relatively high population density of 625.89 persons per sq. km, significantly exceeding the national average (382.41 persons per sq. km). The population density along the Ganga mainstem, which flows through 57 districts across five states (Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal), is even higher, at 952.55 persons per sq. km (Appendix-I).

Population distribution within the basin is highly uneven across states/UT. Uttar Pradesh dominates both in terms of area (27.97%) and population share (37.06%). Madhya Pradesh, which accounts for 20.58% of the basin area (second highest), contributes only 8.47% to the basin's population. Bihar (19.31%) and West Bengal (14.91%) are the second and third most populated states in the Ganga basin, with 10.93% and 8.49% share of the basin's area, respectively. While only 0.17% of the area is in the NCT of Delhi (lowest), it has a population share of 3.11%. Consequently, population density ranges from extremely high densities in the NCT of Delhi (11,320 persons per sq. km) and Bihar (1,105.52 persons per sq. km) to relatively low densities in Himachal Pradesh (132.94 persons per sq. km) and Chhattisgarh (145.20 persons per sq. km) (Figure 1.13; Appendix-I).

The Human Development Index (HDI) and Multidimensional Poverty Index (MPI) values highlight the socio-economic disparities within the basin. States/UT such as the NCT of Delhi (HDI: 0.837), Himachal Pradesh (0.815), and Haryana (0.791) exhibit relatively high levels of human development, while Bihar (0.650), Jharkhand (0.677), and Uttar Pradesh (0.693) have comparatively lower HDI values. Similarly, the MPI indicates higher poverty levels in states such as Bihar (0.16) and Jharkhand (0.131), in contrast to lower levels in the NCT of Delhi (0.014), Himachal Pradesh (0.02), and Haryana (0.031).

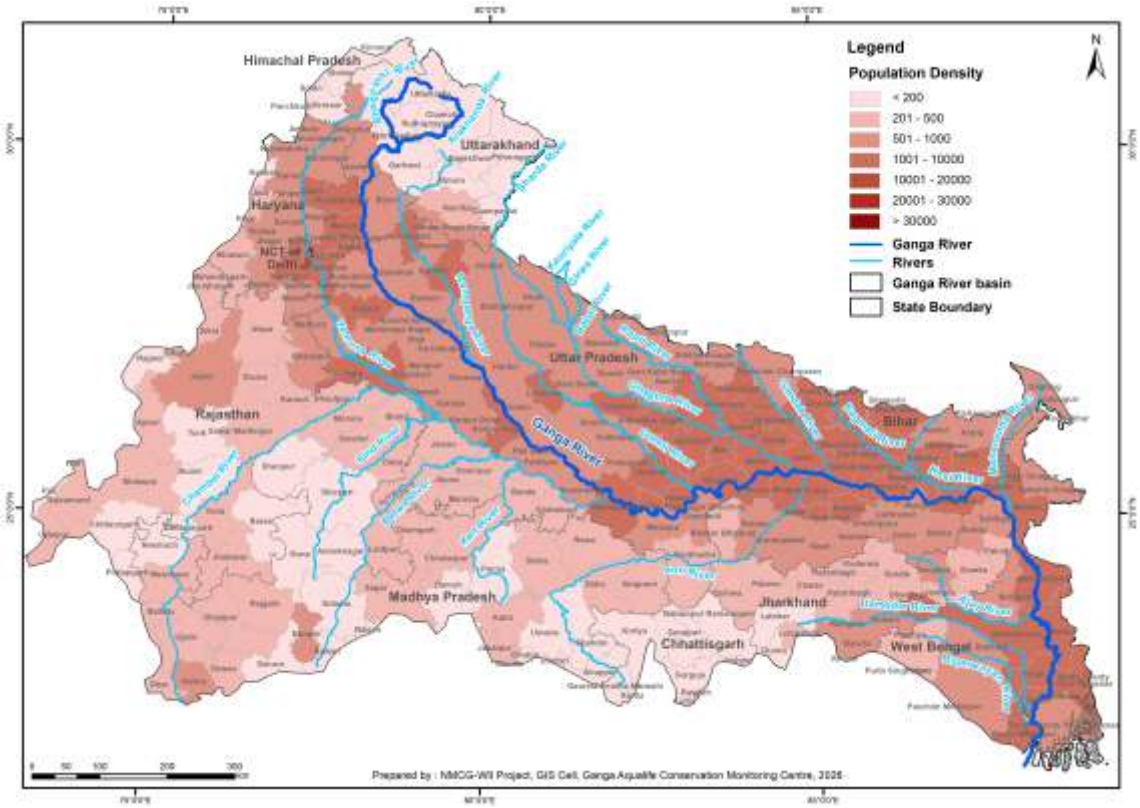


Figure 1.13 District-wise population density in the Ganga River basin (Census of India, 2011).



Table 1.18 State-wise area, population, population density, Human Development Index (HDI), and Multidimensional Poverty Index (MPI) in the Ganga River basin.

SN	State	No. of Districts	Area (sq. km)	Area (% of GRB)	Population
1	Uttarakhand	13	53,484	6.21	10,086,292
2	Uttar Pradesh	75	240,928	27.97	199,812,341
3	Bihar	38	94,163	10.93	104,099,452
4	Jharkhand	20	58,742	6.82	26,984,780
5	West Bengal	21	73,104	8.49	80,390,226
6	Himachal Pradesh	4	7,101	0.82	944,016
7	Haryana	19	25,006	2.90	16,870,626
8	NCT of Delhi*	13	1,483	0.17	16,787,941
9	Rajasthan	26	108,488	12.59	34,363,934
10	Madhya Pradesh	42	177,277	20.58	45,660,264
11	Chhattisgarh	9	21,628	2.51	3,140,297
A	**Ganga River basin**	**280**	**861,404**	**26.20 (% of India)**	**539,140,169**
B	**India**	**-**	**3,287,240**	**-**	**1,210,854,977**

* In December 2025, the Delhi Cabinet approved the reorganization of National Capital Territory (NCT) of Delhi, increasing the number of revenue districts from 11 to 13. New districts include Old Delhi, Central North and Outer North, while Shahdara district has been removed (vide Notification No. F.223/SDM-II(HQ)/Land/2025/285 dated 25/12/2025)

Note: The Human Development Index (HDI) and Multidimensional Poverty Index (MPI) listed are for the entire state, not just the area in the Ganga River basin

Sources: Demographics - Census of India, 2011, Government of India; Area - Census of India, 2011, Government of India; FSI. (2024); Human Development Index (HDI) - Global Data Lab. (n.d.); Multidimensional Poverty Index (MPI) - NITI Aayog. (2023)



Population (% of GRB)	Population Density (persons per sq. km)	HDI (2023)	MPI (2019-21)	Complete/ Partial
1.87	188.59	0.776	0.041	Complete
37.06	829.34	0.693	0.103	Complete
19.31	1,105.52	0.650	0.16	Complete
5.01	459.38	0.677	0.131	Partial
14.91	1,099.67	0.719	0.05	Partial
0.18	132.94	0.815	0.02	Partial
3.13	674.66	0.791	0.031	Partial
3.11	11,320.26	0.837	0.014	Complete
6.37	316.75	0.735	0.065	Partial
8.47	257.56	0.692	0.09	Partial
0.58	145.20	0.707	0.07	Partial
44.53 (% of India)	625.89	-	-	-
-	382.41	0.732	0.066	-



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CHAPTER 2
METHODOLOGICAL FRAMEWORK

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SUMMARY

The study was conducted across the length of the mainstem Ganga River, through a combination of field ecological methods and systematic literature review to assess the current and historical ecological conditions of the Ganga River. Figure 2.1 briefly describes the process followed for the study. The ecological systems of the Ganga River are closely interconnected and influenced by diverse socio-economic structures, and therefore, information on anthropogenic stressors and policy dimensions, including key stakeholders, was also examined.

2.1 REVIEW OF LITERATURE

Extensive literature review was carried out to assess the status of key aquatic and associated terrestrial species of the Ganga River. Online search engines and databases such as Google Scholar (https://scholar.google.com/), JSTOR (https://www.jstor.org/), and OpenAlex (Priem et al., 2022) were used for the collection and compilation of information from peer-reviewed articles, books, and technical reports. Information on the historical and current distribution of species, particularly across major taxonomic groups including flora, invertebrates (with special emphasis on odonates), ichthyofauna, herpetofauna (including amphibians and reptiles), waterbirds and water associated birds, and aquatic and semi-aquatic mammals, was compiled through a comprehensive literature review using appropriate keywords. The checklists of these taxa have been provided in the appendices of relevant chapters.

2.2 FIELD SAMPLING

Field surveys were carried out focusing on different taxa, viz. flora, invertebrates (with special emphasis on odonates), ichthyofauna, amphibians, reptiles, waterbirds and water associated birds, aquatic and semi-aquatic mammals, and ecotoxicological parameters. Considering the diversity of taxa and the spatial scale of the Ganga River, a methodological framework was developed to monitor different elements of biodiversity (Figure 2.1). The river was divided into 5 km segments, designated as Basic/Biodiversity Evaluation Units (BEUs), which were retained throughout the survey and analysis. In addition, 32 intensive monitoring sites were established across different habitat zones along the

river to facilitate detailed sampling of selected taxa and ecotoxicological parameters. Six different habitat zones were classified based on the unique geomorphology, habitat conditions, water availability and physical properties of the Ganga River (WII-NMCG 2019).

Given the variation in sampling requirements across taxa, a combination of methodologies was adopted, including continuous boat-based surveys, vehicle-based surveys, and site-specific intensive sampling. Time-intensive sampling approaches were employed for parameters such as physiochemical characteristics, flora, ichthyofauna, and ecotoxicological assessments, wherein specific sites were selected based on biogeographic representation and accessibility. At these sites, vegetation sampling was conducted using fixed transects in riparian zones, fish sampling involved the deployment of suitable nets with standardized effort, and physiochemical parameters were recorded using portable instruments providing real-time measurements. Parameters that could be measured in situ were recorded in the field, while water samples requiring further analysis were collected and transported to the laboratory for detailed assessment.

In contrast, taxa requiring observation-based monitoring, such as amphibians, reptiles, waterbirds and water associated birds, and aquatic and semi-aquatic mammals, were surveyed using point count methods and continuous transect approaches to minimize biases such as double counting or missed detections. These methods allowed for efficient coverage of larger spatial extents while maintaining consistency in data collection across BEUs and intensive monitoring sites. Within herpetofauna, amphibians were primarily surveyed during dusk and night hours using transect-based approaches, whereas reptiles, including crocodilians and turtles, were monitored during daylight hours using boat-based and point count surveys, with observations recorded based on encounter rates and basking site occurrences along selected river stretches. Avifauna and mammals were surveyed predominantly during daylight hours.

Seasonal variations in species occurrence and detectability were incorporated into the sampling design. Winter migratory waterbird species were monitored during the winter season, whereas breeding and nesting observations, particularly for island and riparian bird species, were undertaken during the summer months. Taxa-wise detailed methodologies have been provided in the respective chapters. Special emphasis was placed on odonates (dragonflies and damselflies) as bioindicators of freshwater ecosystem health. Sampling was conducted along a single accessible bank of the river channel utilizing the point count method. Concurrently, physiochemical parameters, including electrical conductivity, salinity, turbidity, pH, and water temperature, were recorded using portable digital instruments. Surface water, sediment, and fish samples were collected from 39 designated sampling sites along the Ganga River in accordance with standard sampling protocols and established guidelines.

In addition, the hydrological profile and geomorphological variability of the Ganga River necessitated a zone-specific sampling approach. Variations in river depth, flow characteristics, and channel morphology influenced the choice of survey methods across different stretches of the river. In the upper and middle stretches, where shallow depths and accessibility constraints were prevalent, vehicle-based surveys were adopted, and observations were recorded across BEUs and selected monitoring sites. In contrast, the lower stretches of the river, characterized by comparatively deeper channels, were more suitable for continuous boat-based surveys, enabling systematic data collection along extended river segments.

2.3 SPATIAL ANALYSIS

Spatial analysis tools and software were used for delineating and visualizing the Ganga River and its associated stretches. Data collected on species occurrence, habitat characteristics, and associated anthropogenic pressures across different sections of the river, facilitated a comprehensive understanding of spatial patterns in biodiversity and environmental conditions along the Ganga River. In addition, spatial datasets were utilized to understand patterns in land use and to support the interpretation of ecological and socio-environmental dynamics of the Ganga River. Spatial analysis tools such as MaxEnt were also used for predicting Species Distribution Modelling (SDM) of elusive species, which are presented in detail in the relevant chapters including identification of the Conservation Priority Stretches.

2.4 GENETIC ANALYSIS

Genetic analysis was undertaken to assess patterns of genetic diversity, population structure, and connectivity among selected aquatic species along the Ganga River, with the aim of supporting conservation planning and management. The genetic component incorporated information from conservation genetic assessments conducted across multiple taxa associated with the Ganga River. Biological samples were collected from different species across selected locations depending on species-specific feasibility and ethical considerations. Genomic DNA was extracted using standard laboratory protocols, followed by amplification of target gene regions using Polymerase Chain Reaction (PCR). Molecular markers, primarily mitochondrial DNA regions such as cytochrome oxidase I (COI), cytochrome b (Cyt b), and control region sequences, along with nuclear markers such as microsatellites, were utilized to characterize genetic variability.

The generated genetic data were used to evaluate intra- and inter-population genetic diversity, assess gene flow and population connectivity, and identify distinct population units. These analyses provided insights into genetic health and population dynamics of aquatic species.

2.5. RESCUE AND REHABILITATION

For rescue and effective rehabilitation of aquatic species, species of conservation concerns were identified as a primary step, which was followed by identification of potential sites for establishment of the rescue and rehabilitation centres. Identification of potential sites included criteria such as distribution range of species of concern, proximity to secure release sites, administrative control and availability of infrastructure. Detailed methodology is given in the relevant chapter.

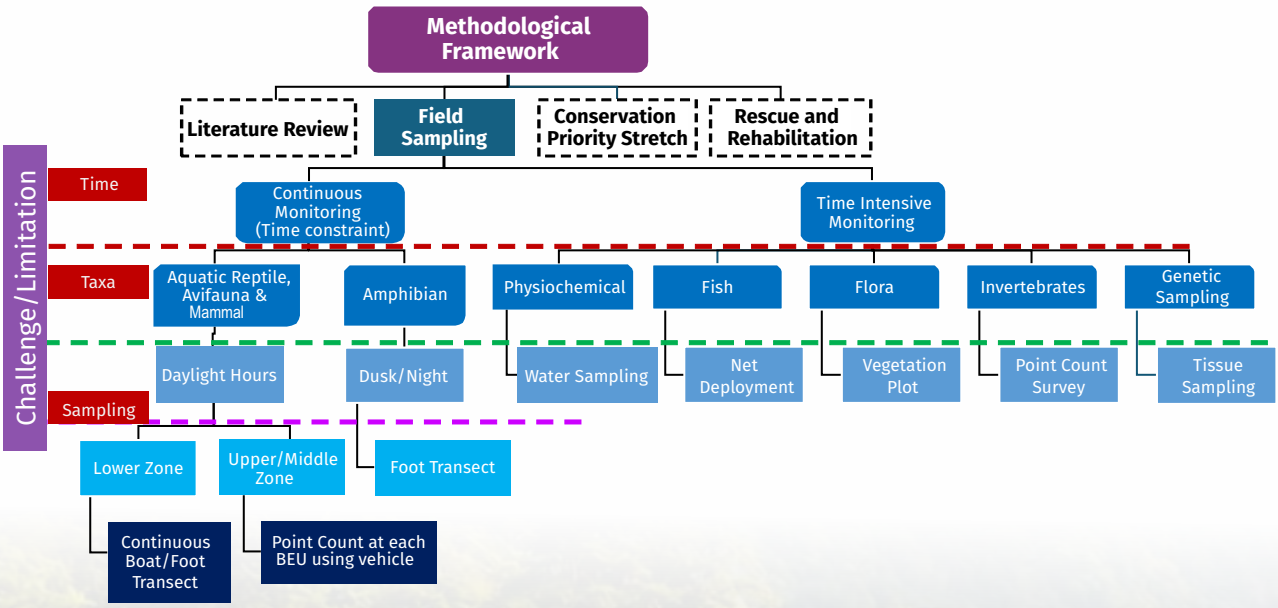


Figure 2.1 Methodological framework for the Field Sampling of the Ganga River

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CHAPTER 3

FLORAL ASSEMBLAGES IN THE GANGA RIVER

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SUMMARY

This chapter presents a comprehensive assessment of riparian vegetation along the Ganga River, analysing species composition, diversity, and ecological gradients from the Himalaya to the delta. It integrates field observations with ecological principles to understand how natural processes and anthropogenic pressures shape riparian plant communities. Riparian vegetation exhibits clear longitudinal and successional patterns driven by hydrology, climate, and human disturbance. In the upper Himalayan reaches, harsh conditions limit species richness, resulting in communities dominated by specialized native species. Moving into the Gangetic plains, increased habitat heterogeneity enhances species richness but also promotes the spread of non-native species due to agriculture and urbanization. In the lower and deltaic regions, species richness peaks under high environmental heterogeneity, though with a significant presence of non-native species reflecting sustained human influence.

Vegetation was sampled using transects and nested plots at 1 m, 500 m, and 1000 m from the riverbank, and analysed using species richness, Shannon diversity index, and Important Value Index (IVI). A total of 747 taxa (735 angiosperms, 7 gymnosperms, and 5 pteridophytes) across 459 genera and 119 families were recorded. Herbaceous species dominated, followed by graminoids, trees, shrubs, and climbers. About 84% of species were native, while 16% were non-native, indicating increasing biotic mixing along the river continuum. Dominant families included Poaceae, Fabaceae, and Asteraceae.

Spatial patterns reveal that the immediate riverbank (1 m) supports dynamic, flood-tolerant herb-dominated communities with relatively higher diversity in middle and lower reaches. At 500 m from the river bank, vegetation reflects a mosaic of semi-natural and human-modified landscapes with moderate diversity. At 1000 m from the river bank, ecological integrity declines markedly, with vegetation largely replaced by agriculture, settlements, and plantation species. The findings highlight the urgent need to conserve remnant habitats, control invasive, and promote native species restoration to sustain ecosystem functionality along this dynamic river system.

3.1 INTRODUCTION

The riparian vegetation along a river reflects the successional stages of plant communities, where fast-growing, flood-tolerant colonizers (sedges, grasses, willow seedlings) stabilize soil, and are gradually replaced by shrubs and trees, while moving away from the river banks and are finally replaced by mature riparian forests (van Andel et al., 1993; Lee & Cho, 2025). The riparian vegetation is known to control runoff, sediment control and improve water quality (Tabacchi et al., 2000). The plant community structure changes along the altitudinal or longitudinal gradient as well as lateral gradient along a riverscape. For a river flowing through varied climatic conditions, the upper reaches of the river have lower species richness, compared to the middle and the lower zones (Surmacz et al., 2024). Anthropogenic disturbances also determine the species richness along the longitudinal gradient of the river, either through loss of habitat or through species introduction (Planty-Tabacchi et al., 1996). Together, these patterns of successional dynamics, spatial gradients, and anthropogenic influences underscore the complexity of riparian vegetation structure in large river systems. Applying this framework to the Ganga River helps to interpret how local edaphic conditions, climatic variability, and human interventions have shaped its riparian vegetation.

The riparian vegetation along the mainstem Ganga River is strongly influenced by the local edaphic, climatic, and anthropogenic conditions. The riverscape has undergone substantial transformation due to intensive agriculture, expanding urbanization, and the establishment of non-native plantations, indicating heightened anthropogenic pressures on riparian ecosystems and consequent alterations in the native community structure and composition. Studies on the vegetation composition along the longitudinal gradient of the River, as it traverses from the Himalaya to the East Coast are scarce and limited in their spatial coverage. Hence, a study was undertaken to assess the vegetation dynamics along the Ganga River. This chapter provides details of the study.

The Ganga River flows across multiple biogeographic zones (Rodgers & Panwar, 1988), resulting in exceptional vegetation heterogeneity. In the upper Himalayan stretches (2B - West Himalaya biotic province), the river flows through alpine scrub (Rhododendron, Berberis, Betula), sub-alpine forests (*Betula utilis*, Abies spp.), and moist/dry temperate forests (Pinus, Cedrus, Quercus, Rhododendron), with extensive subtropical pine forests dominated by *Pinus roxburghii* (Champion & Seth, 1968). Descending into the Gangetic Plains (7A & 7B Upper and Lower Gangetic Plain biotic provinces), vegetation shifts to tropical moist and dry deciduous forests, primarily *Shorea robusta*, *Tectona grandis*, *Dalbergia sissoo*, and *Terminalia arjuna*, interspersed with riparian grasslands, wetlands, and remnant scrub savannahs. Further east, swampy floodplain vegetation is prominent, transitioning into the Sundarbans delta (9B - East Coast biotic province), one of the world's largest mangrove ecosystems dominated by Avicennia, Rhizophora, Heritiera, and Sonneratia (Table 3.1).



Table 3.1 Major forest types in the different biogeographic zones along the Ganga River

Biogeographic zones	Province (Code)	Forest Type		Dominant Species
		Name	Code	
Himalayas				
	Himalaya: West (2B)	Sub-Tropical Pine Forest	9/C1	*Pinus roxburghii*
		Himalayan Moist Temperate Forest	12/C1	*Quercus incana, Rhododendron arboreum*
		Himalayan Dry Temperate Forest	13/C1	*Cedrus deodara, Pinus wallichiana*
		Sub-Alpine Forest	14/C1	*Abies pindrow, Betula utilis*
		Moist Alpine Scrub	16/C1	*Rhododendron* spp., *Berberis* spp.
Gangetic Plains				
	Upper (7A)	Tropical Dry Deciduous Forest	5B/C1-C2	*Dalbergia sissoo, Acacia nilotica*
		Tropical Moist Deciduous Forest	3C/C1-C2	*Shorea robusta, Tectona grandis*
		Ravine Thorn Forest	6B/C2	Tamarix, Capparis
		Saline Scrub	8B/DS1	Suaeda, Sporobolus
	Lower (7B)	Tropical Dry Deciduous Forest	5B/C1-C2	*Dalbergia sissoo, Acacia nilotica*
		Tropical Moist Deciduous Forest	3C/C1-C2	*Shorea robusta, Tectona grandis*
Coasts	East Coast (9B)	Littoral & Swamp (Mangrove) Forest	4B/TS1	Rhizophora, Avicennia, Nypa

3.2 METHODOLOGY

To facilitate study and sampling, the entire river was divided into 5 km sections, each designated as a Biodiversity Evaluation Unit (BEU). The selection of BEUs for sampling was based on factors such as accessibility, species richness (as indicated by previous surveys and literature), overall biodiversity, and the need to cover a broad area to ensure a representative population of plant species along the river.

The study was carried out from April 2023 to June 2025 to assess the vegetation composition along the Ganga River. A total of 35 BEUs were surveyed to assess riparian vegetation. In each Biodiversity Evaluation Unit (BEU), line/belt transects were laid on both banks of the river. A 3 km long line/belt transects were placed at the centre of the BEU. At the beginning and end of the two line/belt transects, perpendicular transects were laid. Thus, in total, six line transects were laid. The four perpendicular transects extended 1 km from the river (Figure 3.1). In each perpendicular transects, three circular plots were established at distances of 1 m, 500 m, and 1000 m from the riverbank to document and collect plant species. Within the circular plots, nested plots of varying radius, 20 m for trees, 5 m for shrubs and 4 quadrats of 1x1m for herbs, were laid. The two line/belt transects of 3 km were walked and the species were noted down.



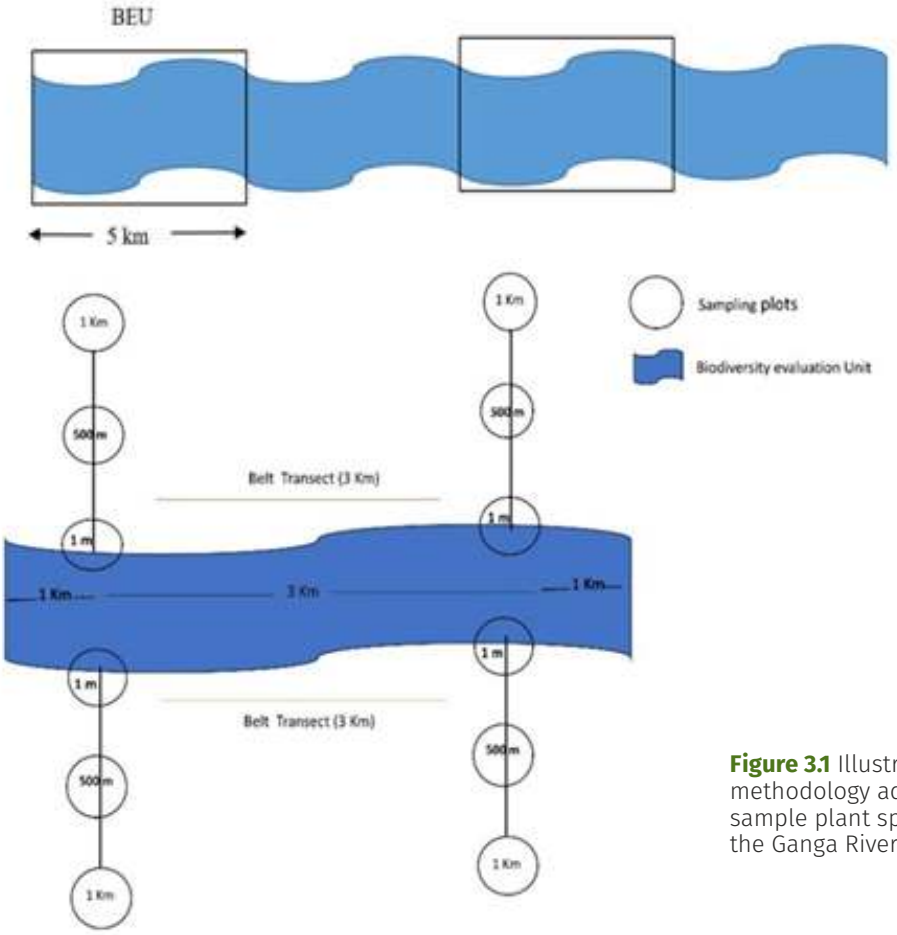


Figure 3.1 Illustrates methodology adopted to sample plant species along the Ganga River



For trees, IVI was calculated using density, frequency and abundance values. For shrubs and grasses percentage cover (species-wise) was recorded. A list of herbs was prepared for each circular plot along the perpendicular transect. Species richness, representing the number of species recorded at each BEU and diversity indices such as the Shannon Index (also known as the Shannon-Wiener or Shannon-Weaver Index) were calculated for all circular plots, as they account for both species' richness and evenness.

In this study, the collected plant specimens, along with their photographs and field notes, were thoroughly examined for identification. Keys and descriptions from local flora and relevant literature from Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal were used for reference. The nomenclature, author citations, and the first place of publication of plant species were determined according to IPNI (n.d.) and POWO (2026). Plant families are classified based on the APG IV system (2016).

3.3 RESULTS

3.3.1. Literature Review

Upper Stretch: Dharasau to Haridwar

In the Himalayan region, the Bhagirathi, the headwaters of the Ganga River, flows with high velocity over a rocky substrate under low temperature conditions, which collectively limit the development of aquatic vegetation (Nautiyal & Nautiyal, 2004; Dobriyal et al., 1999). However, the riparian zones support dense forest vegetation characterized by species such as *Salix tetrasperma*, *Cedrus deodara*, and *Vitex* spp., while the adjoining slopes are dominated by *Pinus wallichiana*, *Bauhinia variegata*, and *Betula utilis* (Champion & Seth, 1968; Singh & Singh, 1992; Gaur, 1999). Shrubs like *Dodonaea viscosa* and *Woodfordia* fruticosa, along with herbaceous species such as *Rumex hastatus*, *Polygonum capitatum*, and *Primula* spp., play a crucial role in stabilizing riverbanks and maintaining biodiversity (Singh & Singh, 1987; Kala, 2010).

As the river descends beyond Devprayag, there is a noticeable shift in species composition within the riparian zone, where tree species such as *Haldina cordifolia*, *Pinus roxburghii*, *Holoptelea integrifolia*, *Ficus racemosa*, *Cordia dichotoma*, and *Salix* spp. become dominant, accompanied by shrubs like *Vitex negundo* and *Pseudocaryopteris bicolor* (Negi & Gaur, 1994; Singh & Rawat, 1999). Further downstream, as the Ganga passes through Rishikesh, the riparian vegetation becomes increasingly dominated by *Shorea robusta* (Sal) and its associated species, reflecting the transition into tropical moist deciduous forests (Champion & Seth, 1968; Puri et al., 1989). Upon entering the Doon Valley, the riparian forest composition becomes more diverse and enriched. The eastern boundary of the Ganga within the Doon Valley supports extensive marshy habitats that are ecologically significant for maintaining biodiversity, enhancing soil stability, and supporting hydrological balance (Negi & Singh, 1992; Joshi et al., 2013; FSI, 2019).

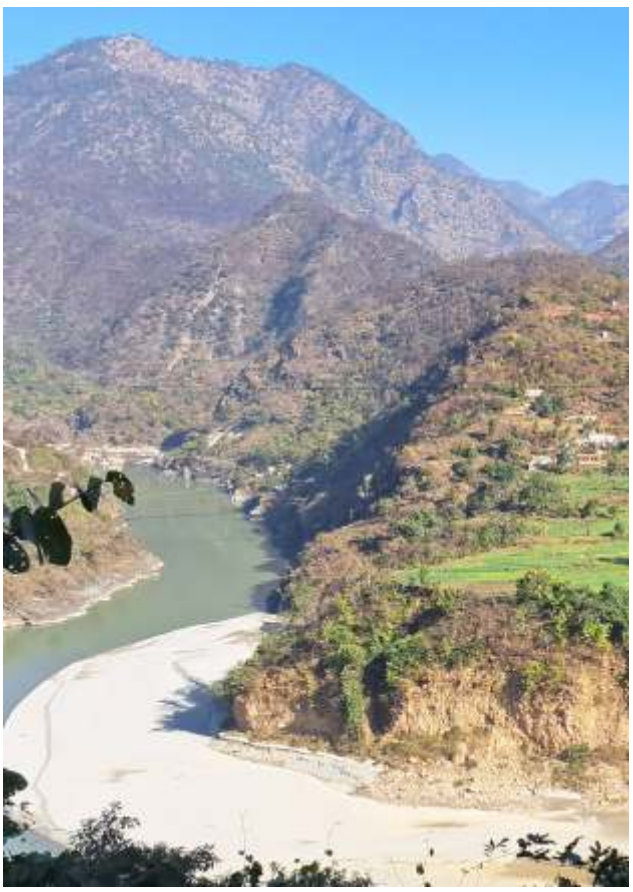


Plate 1: Freshwater swamps and wetlands of Siwaliks (Shahi, 2020)

Types of Wetlands	Characteristics	Location
Riverine	Riverine means 'of the river'- Flowing fresh water. Usually with low vegetation cover. Floodplains also belong to the riverine system.	Assan
Swamps	Wetlands dominated by trees or shrubs. A wide range of vegetation types from grasses, herbs, shrubs, trees. They are often forested.	Mothrawala
Swamps and Marshes	Characterized by aquatic plants, their growth is encouraged by the presence, for a large part of the year, of shallow stagnant water (in the case of a swamp) or muddy waterlogged soil (in the case of a marsh), both never fully dry out.	Maru Siddh, Lacchiwala
Marshes	Wetlands with predominantly grassy vegetation. A frequently or continually inundated wetland characterized by emergent herbaceous vegetation adapted to saturated soil conditions.	Golatappar
Floodplains	Periodic flooding of land between a river channel and raised land on the edge of a valley; areas of low-lying flat ground over which rivers flood during high water.	Nakronda
Flooded Grasslands	Periodically flooded grasslands, herbaceous formations growing on soil that is completely submerged during flooding.	Raiwala
Flooded Forests	Periodically flooded forests, woody formation on ground that is totally submerged during the high-water season, can be found on low, poorly drained lands adjacent to watercourses or swamps.	Teenpani, Lalttappar
Lakes	Developed through several processes, stream action forms oxbow lakes; manmade lakes.	Dakpathar

Swamps of Dehradun and Haridwar Region: Swamps are marshy ecosystems where water percolates into perennial streams, maintaining a constant level throughout the year. These wetlands sustain distinctive vegetation due to specialized soil conditions influenced by continuous water accumulation. The Doon Valley, nestled between the Yamuna and Ganga rivers at the foothills of the Himalayas, once boasted an extensive network of swamps. However, rapid human intervention has led to their alarming decline. The Dehradun landscape still contains freshwater wetlands, primarily on both flanks of the Shivaliks, along with marshy and waterlogged areas that play a crucial role in storing flood and stormwater. These ecosystems are vital for maintaining regional geo-environmental stability and support a rich diversity of flora and fauna. Historically, the valley's low-lying regions were dominated by swamps, but large-scale deforestation, initiated under the pretext of combating the "malarial climate," led to their destruction (Richards, 1987). The clearance of trees created open spaces, accelerating the disappearance of most of these wetland forests (Kanjilal, 1901).

Cane brakes, primarily dominated by *Calamus tenuis*, formed an integral part of the swamp ecosystems in the Doon Valley. These dense thickets were most prominently found in wetlands around Mothronwala and Nakraunda, where shallow streambeds provided ideal conditions for their growth (Gupta et al., 2003). The cane breaks in these swamps thrived in areas with consistent water availability, contributing to the structural complexity of the vegetation.



Middle Stretch: Haridwar to Varanasi

As the Ganga enters the plains, the substrate shifts to sandy-loamy, allowing aquatic species like *Potamogeton crispus*, *Hydrilla verticillata*, and *Vallisneria spiralis* to flourish. After flowing past Haridwar, the Ganga continues its journey towards Muzaffarnagar district, traversing the last remnants of wetland-grasslands mosaic, including the Jhilmil Jheel Conservation Reserve in Haridwar and the Haiderpur Wetland in Muzaffarnagar. Despite extensive agricultural activity in this region, dense grassland patches persist, providing critical habitats for threatened deer species: the barasingha, the Barking deer and the Indian hog deer (Rodgers & Panwar, 1988; WII, 2017). The dominant grass species in this landscape is *Phragmites karka*, which can grow up to 13-14 feet tall if left undisturbed. Other notable grasses coexisting in this ecosystem include *Typha elephantina*, *Saccharum spontaneum*, *Saccharum bengalense*, *Saccharum ravennae*, *Apluda mutica*, *Desmostachya bipinnata*, and *Chrysopogon zizanioides*, with heights ranging between 4 and 15 feet. These grasses serve as vital food sources and shelters for wildlife (Dabadghao & Shankarnarayan, 1973; Singh & Singh, 1992; Shahi, 2022).

As the river flows beyond Muzaffarnagar and Bijnor, the extent of grasslands diminishes, giving way to modified agricultural landscapes. Further downstream, agricultural landscapes dominate, with riparian trees such as *Bombax ceiba*, *Acacia catechu*, *Dalbergia sissoo* and *Terminalia arjuna* persisting amid invasive species like *Eichhornia crassipes* and *Pistia stratiotes*. The riverine habitats beyond Kanpur, Prayagraj and Varanasi have undergone extensive fragmentation. Here, *Saccharum spontaneum*, *Imperata cylindrica*, and *Cynodon dactylon* dominate the vegetation, while taller grasses such as *Saccharum bengalense* and *Saccharum ravennae* grow sparsely along riverbeds but are more prominent near canals and field boundaries (Dabadghao & Shankarnarayan, 1973). The uplands, often referred to as 'Kholas,' are characterized by scrub vegetation, including species such as *Ziziphus* spp., *Clerodendrum infortunatum*, *Phyllanthus reticulatus*, and *Lantana camara*. Dominant trees along the riparian zones include *Bombax ceiba*, *Pithecellobium dulce*, *Mallotus nudiflorus*, *Acacia catechu*, *Acacia nilotica*, *Terminalia arjuna*, *Syzygium cumini*, and *Ficus racemosa* (Champion & Seth, 1968; Singh & Singh, 1992). Surveys in this region revealed a variety of landscapes, from sandy beds used for extensive farming to barren riverbeds with minimal or no vegetation. Invasive species frequently observed in this stretch include *Pistia stratiotes* and *Eichhornia crassipes*, while common herbs include *Erigeron bonariensis*, *Verbascum coromandelianum*, *Dichrocephala integrifolia*, *Glinus oppositifolius*, *Lindernia procumbens*, *Cirsium arvense*, *Nepeta hindostana*, *Spergula arvensis*, *Arenaria serpyllifolia*, *Misopates orontium*, *Operculina turpethum*, *Oenothera rosea*, and *Oenothera laciniata*.

Lower Stretch: Varanasi to Haldia

In Bihar and Jharkhand, increased tributary inflow expands the Ganga River's width, forming oxbow lakes and sandy islands supporting *Phragmites karka*, *Saccharum* spp., and endemic species like *Rorippa cochlearioides*. The Rajmahal Hills region transitions into dry deciduous forests with *Butea monosperma*, *Holoptelea integrifolia*, and *Borassus flabellifer*. As the river nears West Bengal, steep marshy slopes host unique riparian flora like *Pongamia pinnata*, *Acanthus ilicifolius*, and *Typha elephantina*.



3.3.2 Field survey

Based on field surveys conducted and forest types recorded in and along Ganga River in Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal the dominant families representing riparian flora were Asteraceae, Fabaceae, Poaceae, Amaranthaceae, Lamiaceae, Euphorbiaceae, Moraceae, Convolvulaceae, Acanthaceae, Malvaceae, Cyperaceae, Rubiaceae.

During the river survey, 747 taxa (Angiosperms- 735, Gymnosperms- 7 and Pteridophytes- 5 species) were recorded with 459 genera 119 families and 40 orders (Figure 3.2). Poaceae was found to be the most dominant family with 90 species followed by Fabaceae (63 spp.), Asteraceae (56 Spp.), Cyperaceae (42 Spp.), Lamiaceae (26 spp.), Acanthaceae (24 spp.), Malvaceae (23 spp.), Euphorbiaceae (20 spp.), Convolvulaceae (18 spp.), Moraceae (17 spp.), Amaranthaceae, Polygonaceae and Rubiaceae (16 spp. each) (Figure 3.3).

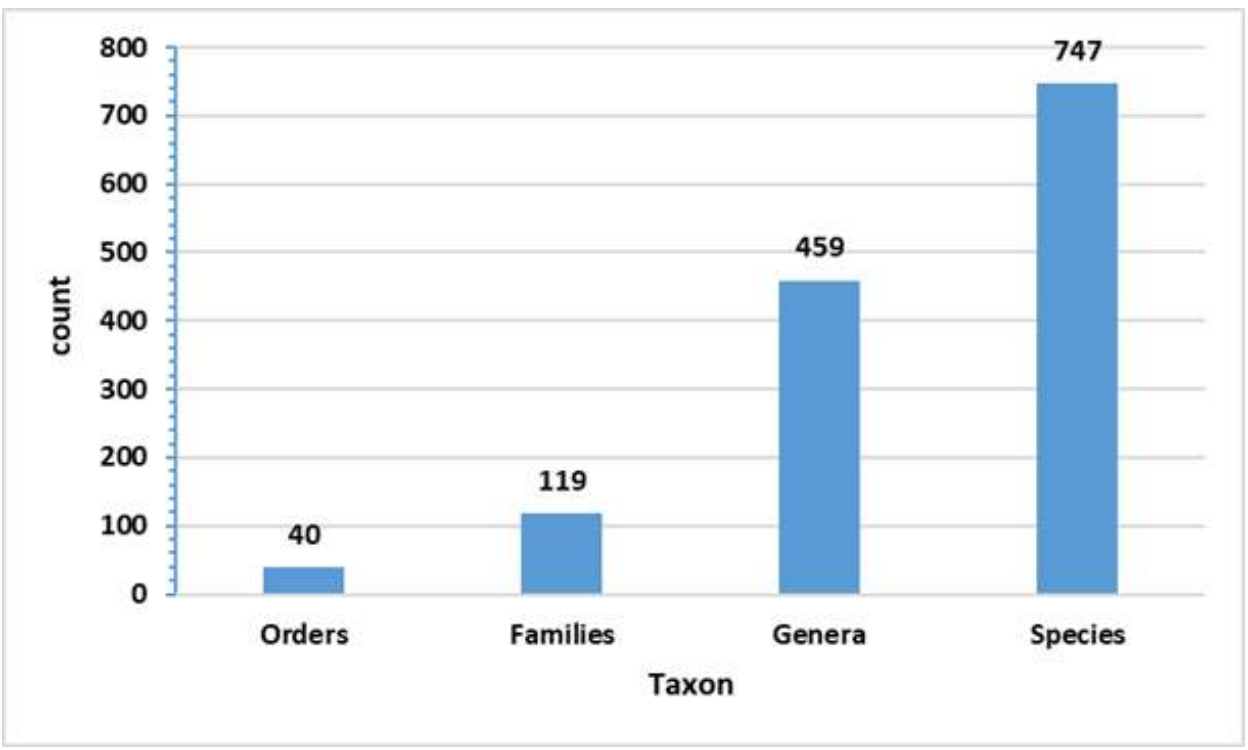


Figure 3.2 Taxonomic classification of plant species recorded during the survey

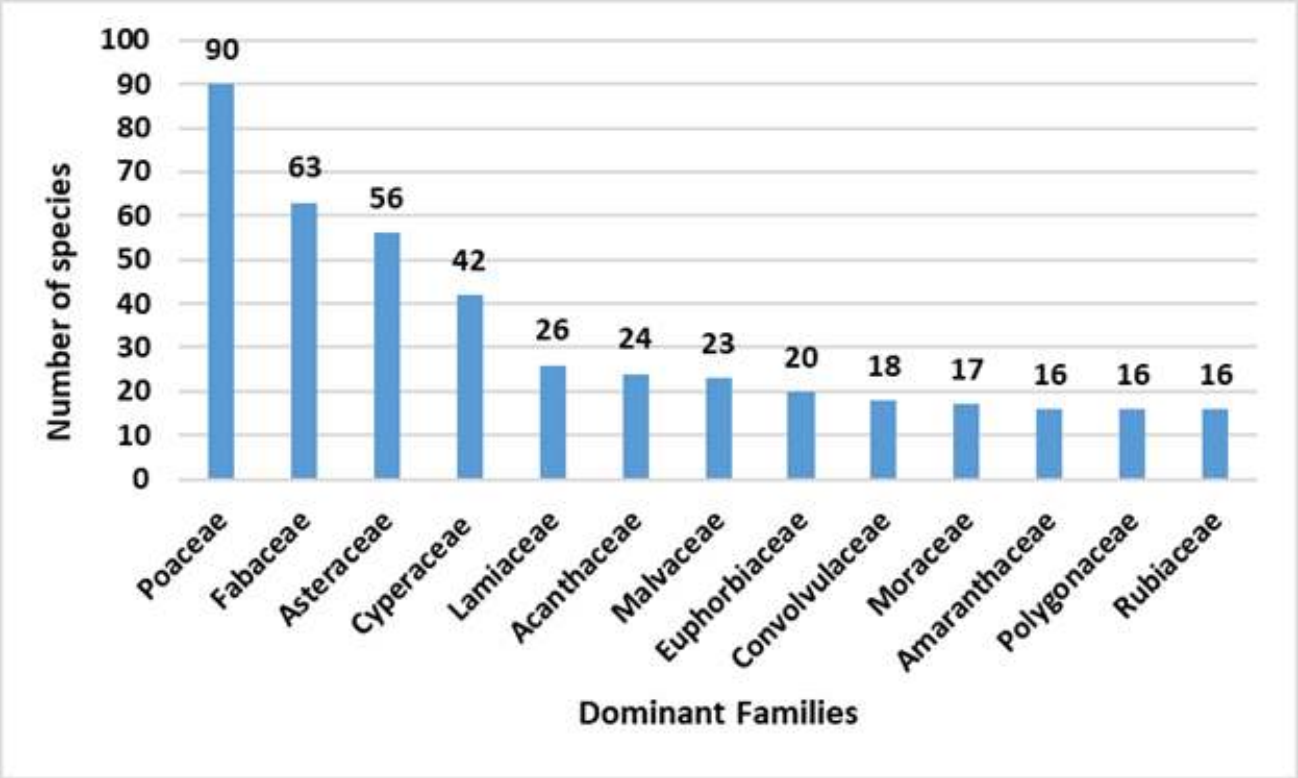


Figure 3.3 Dominant families of plants recorded during the survey

The life form (habit) dominance in the river based on the number of species was dominated by herbaceous flora (378 spp.) followed by graminoids (138 spp.), trees (108 spp.), shrubs (76 spp.), climbers (42 spp.) and climbing shrubs (5 spp.) (Figure 3.4). The habitat preference of species found in the survey was as follows: Aquatic (52 spp.), semi-aquatic (168 spp.), moist-loving (425 spp.), terrestrial (99 spp.) and epiphytic parasites (3 spp.) (Figure 3.5).



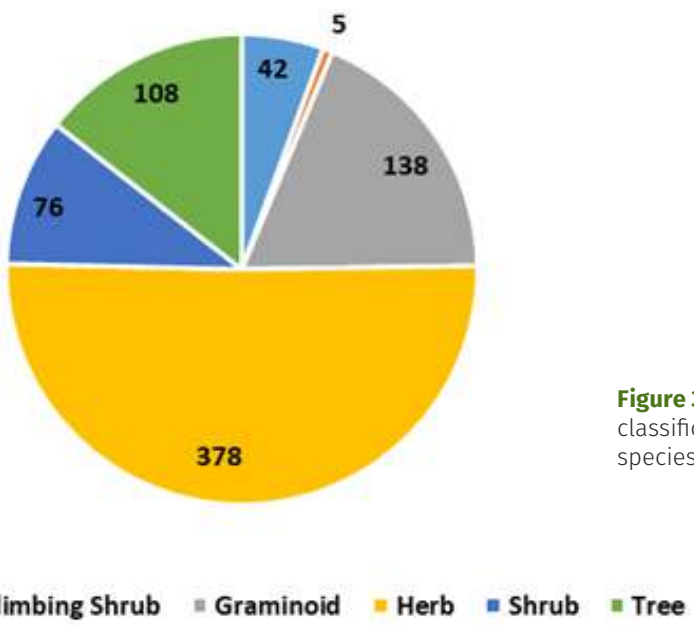


Figure 3.4 Habit-wise classification of plant species

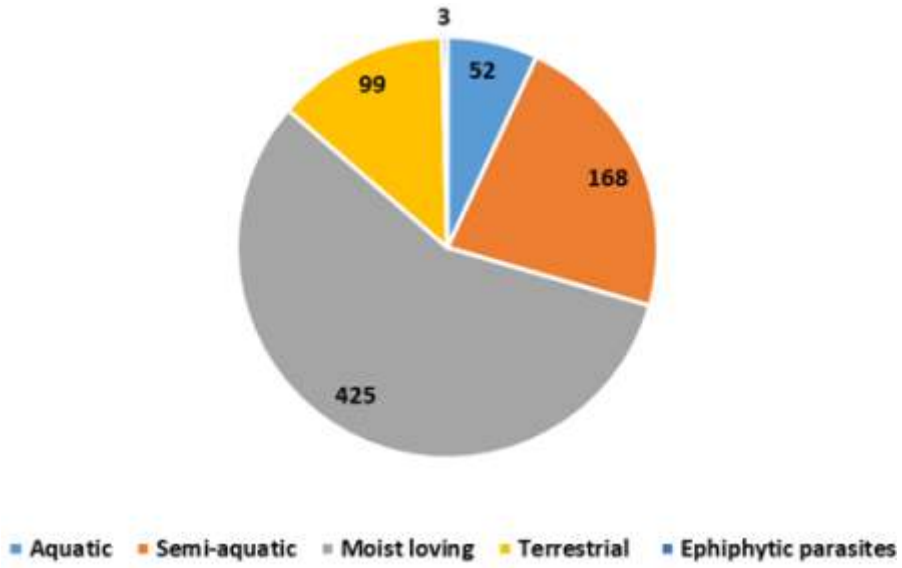


Figure 3.5 Habitat-wise classification of species

Trees reported from the Ganga River are represented by 20 orders, 44 Families, 85 genera and 108 species, of which 90 species are native and 18 species are non-native. Shrubs reported from the Ganga River are represented by 18 orders, 30 families, 54 genera, and 76 species, of which 59 are native and 17 are non-native. Graminoids reported from the Ganga River are represented by 1 order, 5 families, 66 genera and 138 species among which 132 species are native and 06 species are non-native. The term Graminoids is used for grass and grasslike plants including Grasses (90 spp.), Sedges (42 spp.), pipeworts (2 spp.), rushes (2 spp.), Cattails (2 spp.) (Figure 3.6). Herbs reported from the Ganga River are represented by 27 orders, 70 families, 233 genera and 378 species among which 305 species are native and 73 species are non-native.

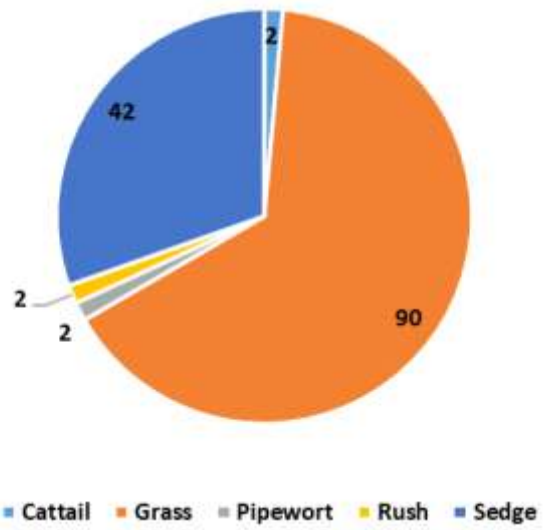


Figure 3.6 Classification of Graminoids at family level



Aquatic and semi-aquatic species recorded in the Ganga River are represented by 28 orders and 60 families, among these plants dominant families are Cyperaceae (41 spp.), Poaceae (31 spp.), Polygonaceae (14 Spp.), Plantaginaceae (9 spp.), Hydrocharitaceae (8 spp.), Araceae (7 spp.) (Figure 3.7). Aquatic plants (n=52) are sub divided into categories like, emergent (16 spp.), free floating (16 spp.), rooted but floating (7 spp.) and submerged (13 spp.) (Figure 3.8). Semi-aquatic plants (n=168) are sub divided into categories like, riparian (26 spp.) and marshy (142 spp.) (Figure 3.9). About 84% (n=627) of the recorded plant species were native to India while the rest are non-native (120 spp.) from different continents of the world (Figure 3.10; Annexure I).



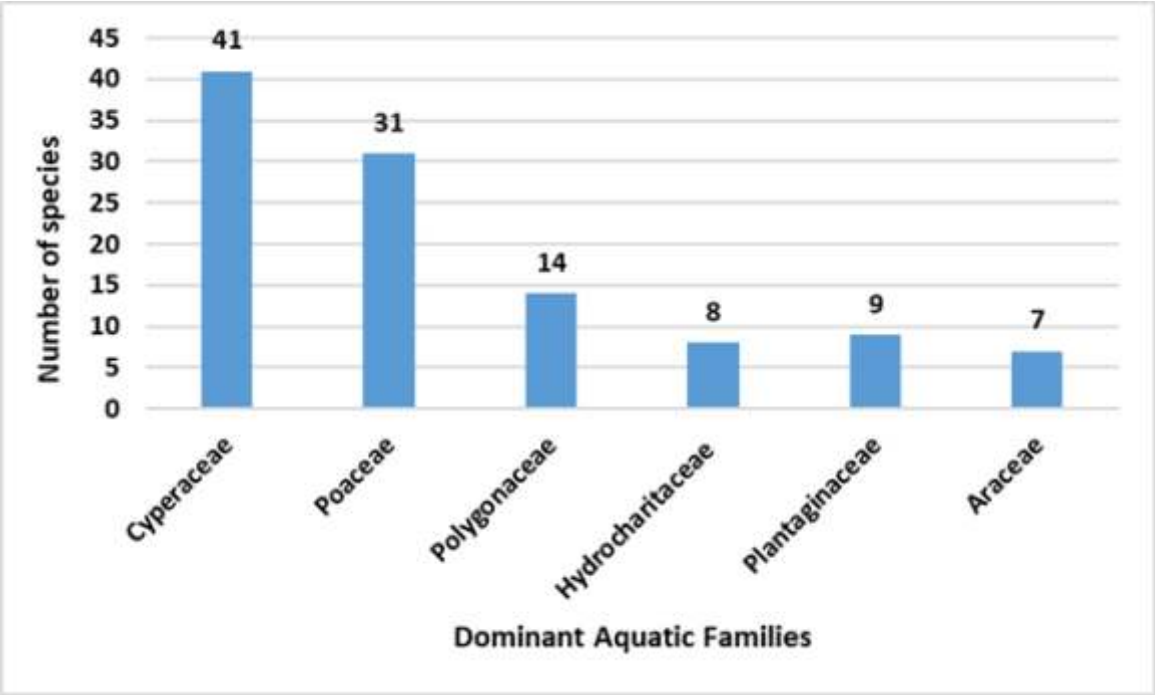


Figure 3.7 Dominant families of aquatic plants species

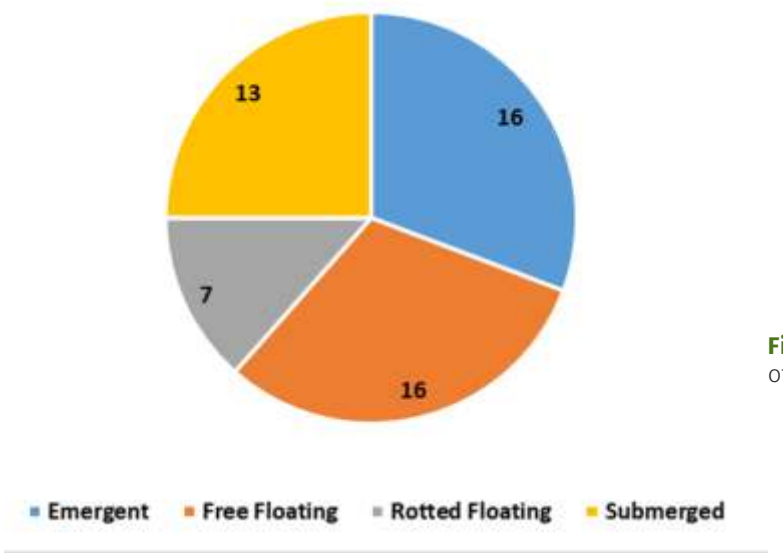


Figure 3.8 Sub-categories of aquatic plants species

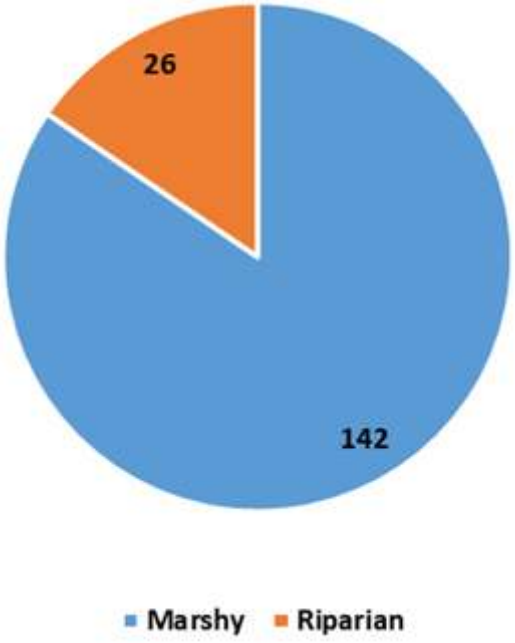


Figure 3.9 Sub-categorisation of semi-aquatic plants

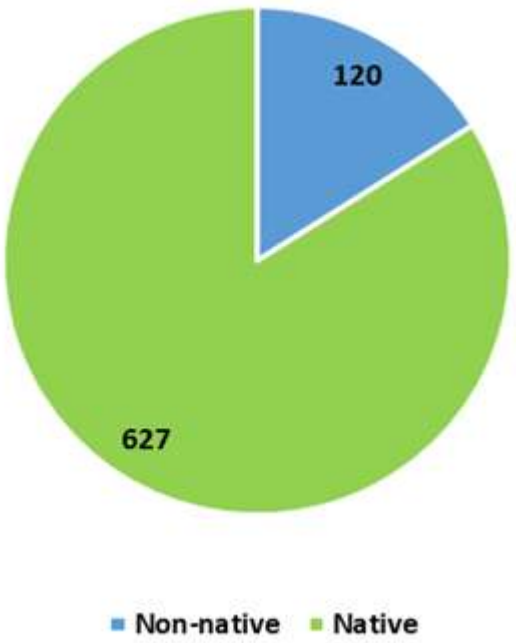


Figure 3.10 Nativity of plant species recorded along the Ganga River

Species Richness and Diversity

The species richness shows notable variation across the different BEUs (Table 3.2). In the upper Himalayan stretch of the Ganga (Harshil to Devprayag), species richness remains low (35-47 species), while nativity is very high (~75-86%). Harsh environmental conditions, low temperatures, steep terrain, and fast-flowing channels restrict vegetation to specialized cold-adapted species, with minimal human disturbance limiting non-native invasion. Dharasu shows a slight increase in non-natives, due to localized disturbance and accessibility.



Table 3.2 BEU wise species richness and nativity

S. No.	BEU no.	Location	Richness	Nativity	
				Native	Non-native
1	1	Harshil	35	30	5
2	26	Dharasu	47	37	10
3	43	Devprayag	45	32	13
4	56	Raiwala	67	49	18
5	71	Bijnor	52	39	13
6	87	Gharmukteshwar	97	74	23
7	102	Narora	77	52	25
8	115	Kacchla	67	55	12
9	132	Farrukhabad	74	46	28
10	147	Kannauj	88	57	31
11	162	Kanpur	90	66	24
12	177	Fatehpur	89	65	24
13	194	Lahedri bridge	78	49	29
14	210	Prayagraj	73	48	25
15	222	Sirsa	67	44	23
16	237	Mirzapur	62	43	19
17	252	Varanasi	67	48	19
18	271	Gazipur	65	43	22
19	282	Buxar	71	47	24
20	298	Revalganj	17	14	3
21	302	Doriganj	55	42	13
22	309	Patna	54	43	11
23	318	Rasalpur Dharnipatti	49	36	13
24	327	Simariya	66	47	19
25	338	Munger	59	42	17
26	347	Sultanganj	41	30	11
27	359	Bateshwarsthan	49	37	12
28	382	Farakka	70	52	18
29	396	Manigram	88	66	22
30	406	Berhampore	102	78	24
31	420	Katwa	85	63	22
32	444	Balagarh	133	95	38
33	450	Bandel	115	89	26
34	468	Purba Basudevpur	123	84	39
35	479	Haldia	95	64	31



As the river enters the foothill-upper plains transition (Raiwala to Bijnor), habitat heterogeneity increases, leading to moderate richness (52-67 species). Non-native species become more noticeable (~24-27%), reflecting expanding settlements, agriculture, and improved accessibility along the riverbanks. In the upper Gangetic plains (Gharmukteshwar to Farrukhabad), richness increases further (67-97 species), supported by fertile floodplains and diverse microhabitats. However, Non-native species also rise substantially (up to ~37%), driven by intensive agriculture, plantations, and anthropogenic disturbances.

The middle Gangetic plains (Kannauj to Mirzapur) maintain moderate to high richness (62-90 species), with non-native representation ranging from 26-38%. Despite the persistence of native vegetation in riparian patches, increasing urbanization and agricultural expansion facilitate the spread of non-native species. From Varanasi to Buxar, richness stabilizes at moderate levels (65-71 species), but nativity gradually declines. Revalganj stands out with extremely low richness (17 species), likely due to severe habitat disturbance or land-use conversion, highlighting localized ecological degradation.

In the lower Gangetic plains (Doriganj to Farakka), richness varies between 41 and 70 species, with non-natives contributing ~20-30%. Although dynamic river processes create diverse habitats, urban centres such as Patna and infrastructural pressures reduce native vegetation continuity. Finally, in the Hooghly-lower delta region (Manigram to Haldia), species richness peaks (85-133 species), particularly at Balagarh and Purba Basudevpur. This high diversity reflects strong environmental heterogeneity; however, non-native species are also prominent (up to ~32%), indicating long-term anthropogenic influence and increasing ecological mixing in downstream reaches.





3.3.3 Trees

Trees reported from the Ganga River are represented by 20 orders, 44 Families, 85 genera and 108 species, among which 90 species are native and 18 species are non-native. Dominant tree species recorded were *Acacia nilotica*, *A. catechu*, *Dalbergia sissoo*, *F. religiosa*, *Bombax ceiba*, *Pithecellobium dulce*, *Terminalia arjuna*, *Azadirachta indica*, *Mangifera indica*, *Holoptelea integrifolia* (Annexure I).

3.3.3.1 Richness and Diversity

Field observations along the Ganga River show clear patterns in tree species richness and diversity (H'), shaped by habitat conditions and human activity (Table 3.3). Upstream BEUs such as Harshil, Dharasu, and Devprayag exhibit moderate species richness (3-16) and relatively low Shannon values (1.09-1.32). These reaches are characterized by narrow valleys and limited riparian zones, where a few species dominate the vegetation structure. In the mid-reaches (e.g., BEUs 56, 71, 87, 117, 132, 147), richness ranges from 3 to 14 species, with diversity indices between 1.03 and 2.52. The variation reflects a patchwork of intact riparian segments interspersed with areas under strong human influence such as agriculture and settlements. Certain segments, including BEUs 298 and 318, richness ranges from 1 to 10 species and no measurable diversity (H' = 0) in Revalganj and Rasalpur Dharnipatti, indicating complete vegetation simplification (sometimes inaccessible locations). In several mid-reach locations (e.g., BEUs 102, 132, 222, 327, 338), richness remains moderately high (1-14) and diversity values range from 1.49 to 2.52, reflecting vegetation that retains structural complexity but includes segments dominated by a few species. Lower and some mid-lower reaches (e.g., BEUs 396, 406, 420, 444, 450, 468, 479) had the highest richness (16-27 species) and the highest Shannon values (2.42-3.20). These stretches are associated with broad floodplains, active meanders, and confluences, which create hydrologically complex and moisture-rich environments. Such areas support diverse and balanced tree communities, with native species well-represented.

Table 3.3 Tree species richness across all BEUs along the Ganga River

S.no.	BEU	Location	Richness (Trees)	SI (*H'*)
1	1	Harshil	16	1.24
2	26	Dharasu	8	1.32
3	43	Devprayag	3	1.09
4	56	Raiwala	3	1.03
5	71	Bijnor	9	1.44
6	87	Gharmukteshwar	13	1.59
7	102	Narora	13	2.45
8	117	Kachla	8	1.8
9	132	Farrukhabad	14	2.52
10	147	Kannauj	7	2
11	162	Kanpur	4	1.49
12	177	Fatehpur	10	1.73
13	192	Lahedri bridge	6	1.74
14	222	Prayagraj	5	2.09
15	207	Sirsa	9	1.8
16	237	Mirzapur	6	1.53
17	252	Varanasi	8	1.74
18	267	Gazipur	9	1.56
19	282	Buxar	5	1.5
20	298	Revalganj	1	0
21	302	Doriganj	10	2.08
22	309	Patna	9	2.04
23	318	Rasalpur Dharnipatti	1	0
24	327	Simariya	10	2.07
25	338	Munger	14	2.25
26	347	Sultanganj	4	1.11
27	359	Bateshwarsthan	7	1.49
28	382	Farakka	18	2.14
29	396	Manigram	20	2.54
30	406	Berhampore	22	2.85
31	420	Katwa	16	2.42
32	444	Balagarh	18	2.69
33	450	Bandel	26	3.11
34	468	Purba Basudevpur	22	2.95
35	479	Haldia	27	3.2



3.3.3.2 Abundance

Based on abundance values across different BEUs, *Acacia nilotica*, *Dalbergia sissoo*, *Mallotus nudiflorus*, *Pithecellobium dulce*, *Azadirachta indica*, and *Ficus* species were the most abundant at 0 m from the river bank. At 500 m, in addition to the species recorded at 0 m, *Morus alba*, *Syzygium cumini*, and *Holoptelea integrifolia* were also found to be abundant. At 1000 m, the abundant species observed at 500 m persisted, with the addition of *Mangifera indica*, *Ficus religiosa*, *Ficus benghalensis*, and other *Ficus* species.

Additionally, species such as *Eucalyptus* spp., *Populus* spp., and *Terminalia arjuna* were recorded in localized plantation patches along the middle stretches of the Ganga River, particularly across Uttar Pradesh, Bihar, Jharkhand, and parts of Uttarakhand (notably observed in areas such as Chidiyapur and in the foothills of Dharasu). These plantations were primarily associated with agricultural landscapes, reflecting their role in agroforestry systems. Eucalyptus and Populus are widely cultivated in Uttar Pradesh for their fast-growing timber, pulpwood, and fuelwood.

Terminalia arjuna was encountered in relatively smaller patches along riverbanks and field margins in Uttar Pradesh and Bihar. In Bihar this tree was sometimes planted on raised mud mounds to withstand periodic flooding. In addition, species such as *Pongamia pinnata* and *Moringa oleifera*, along with *Terminalia arjuna*, were observed as avenue or riverbank plantations in areas such as the Haiderpur wetland (Uttar Pradesh). In Jharkhand, plantation features included *Borassus flabellifer* and *Phoenix sylvestris*, commonly associated with agrarian and rural landscapes, where they are utilized for making ropes, thatching (roofing materials), and brooms. Collectively, these plantation species serve multiple ecological and economic functions, including acting as shelterbelts to reduce wind erosion, providing commercially valuable timber and fuelwood, and contributing to riverbank stabilization

3.3.3.3 Important Value Index (IVI) for Trees

Species with the highest IVI values represent the dominant tree communities within each BEU, contributing significantly to the structural makeup and ecological functioning of those zones.

At 1 m

At this proximity, vegetation is primarily composed of fast-growing, flood-tolerant colonizing species adapted to withstand periodic inundation and substrate instability. These conditions hinder the establishment of long-lived tree species, resulting in the near absence of mature tree cover. Consequently, the area supports sparse vegetation dominated by early successional communities, including herbaceous flora, a few shrub species, and occasional individuals of flood-tolerant taxa occurring in isolated patches. Several native species emerge as key structural components of the riparian forest. *Cedrus deodara*, *Albizia chinensis*, and *Salix tetrasperma* display high IVI values in less disturbed stretches in the Upper stretches of the Ganga River, reflecting stable habitats with intact vegetation. Similarly, *Mangifera indica*, *Azadirachta indica*, *Acacia nilotica*, and *Mallotus nudiflorus* dominate large sections, many of which still retain functional floodplain vegetation (Table 3.4).

Field observations indicate that sites with high native richness and minimal anthropogenic disturbance tend to have single dominant native trees supported by a diverse mix of secondary native species, such as *Ficus religiosa*, *Ficus benghalensis* and *Ficus glomerata*. These areas also show balanced shrub and grass structural indices (SI) with a low proportion of non-native understorey species. Conversely, stretches experiencing heavy anthropogenic pressure, such as urban encroachment, agriculture, grazing, and sand mining, show a shift toward disturbance-tolerant and often non-native dominants. The most notable example is *Prosopis juliflora* in Fatehpur (IVI 235.71), which thrives where native cover has been heavily degraded. The IVI patterns also reflect the influence of site-specific hydrology. Flood-tolerant species like *Mallotus nudiflorus*, *Pongamia pinnata* and *Barringtonia acutangula* appear predominantly in locations with seasonal inundation or tidal influence. In several such areas, field surveys recorded a rich shrub and grass SI, but also a marked presence of non-native trees like *Casuarina equisetifolia*, *Acacia auriculiformis*, and *Neolamarckia cadamba*, often planted for bank stabilization. While these plantations contribute to structural cover, they may limit native regeneration. The riparian or bank flora along the Ganga River at 1 m from the river bank is dominated by *Mallotus nudiflorus*, *Acacia nilotica*, *Pongamia pinnata*, *Dalbergia sissoo*. These are also preferred species for plantation to ensure bank stability. Other species viz. *Ficus religiosa*, *Ficus benghalensis*, *Ficus glomerata*, *Ficus virens*, *Bombax ceiba* were frequently encountered along the river banks.

Overall, the combined dataset underscores a clear ecological gradient influenced more by site-specific disturbance and hydrological conditions than by geographical position alone. Native species dominance persists where disturbance is low, but the intrusion of hardy non-native species in degraded stretches is altering the composition and potentially the long-term ecological resilience of the riparian corridor. The field observations provide crucial context to the IVI data, revealing that richness, nativity, and understorey composition are strongly tied to human activities and floodplain management practices along the Ganga.

Table 3.4 IVI of trees at 1 m from the river bank

BEU	Location	IVI Values		Other contributing species
		Dominant Tree(s) species	IVI	
1	Harshil	*Cedrus deodara*	129.10	*Pinus roxburghii*, *Salix* sp., *Pinus wallichiana*, *Ficus roxburghii.*
26	Dharasu	*Albizia chinensis*	100.57	*Pinus wallichiana*, *Premna* sp., *Salix* sp.
43	Devprayag	*Salix tetrasperma*	183.33	*Ficus religiosa*
56	Raiwala	-	-	-
71	Bijnor	-	-	-
87	Gharmukteshwar	*Ficus palmata*	83.3	*Acacia nilotica*
102	Narora	*Bombax ceiba, Dalbergia sissoo* & *Azadirachta indica*	70	*Ficus religiosa*, *Ficus virens*
115	Kacchla	-	-	-
132	Farrukhabad	*Mangifera indica*	86.7	*Ficus religiosa*, *Ficus benghalensis*, *Ficus glomerata*
147	Kannauj	-		-
162	Kanpur	*Azadirachta indica*	300	-
177	Fatehpur	*Prosopis juliflora*	235.7	*Ficus racemosa*
194	Lahedri bridge	-	-	-
210	Prayagraj	-	-	-
222	Sirsa	*Acacia nilotica*	300	-
237	Mirzapur	*Acacia nilotica*	116.4	*Azadirachta indica*
252	Varanasi	*Azadirachta indica*	91.6	*Dalbergia sissoo*
271	Gazipur	-	-	-
282	Buxar	-	-	-
298	Revalganj	-	-	-
302	Doriganj	-	-	-
309	Patna	*Mallotus nudiflorus*	200	
318	Rasalpur Dharnipatti	-	-	-
327	Simariya	-	-	-
338	Munger	*Azardirachta indica, Pithecellobium dulce*	150	-
347	Sultanganj			-
359	Bateshwarsthan	*Dalbergia sissoo*	300	-
382	Farakka	-	-	-
396	Manigram	*Pongamia pinnata*	133.3	*Barringtonia acutangula*
406	Berhampore	*Pongamia pinnata*	128	*Mallotus nudiflorus*, *Casuarina equisetifolia*
420	Katwa	*Mallotus nudiflorus*	97.0	*Bombax ceiba*
444	Balagarh	*Mallotus nudiflorus*	133.3	*Acacia auriculiformis*, *Neolamarckia cadamba*
450	Bandel	*Mallotus nudiflorus*	110.7	*Borassus flabellifer*
468	Purba Basudevpur	*Mallotus nudiflorus*	125	*Bombax ceiba*, *Borassus flabellifer*
479	Haldia	*Pongamia pinnata*	179.3	*Mallotus nudiflorus*, *Lannea coromandelica*

At 500 m from the river

The riverscape at 500 m from the river bank had human dwellings, sandy banks, riverbed agriculture, grasslands as well as the presence of dominating tree species. Local people grow crops that are adapted to the moisture-retentive yet well-drained conditions through seasonal farming made possible by the rich alluvial soil in these regions. A transitional region between the river and populated areas is provided by sandy banks that are frequently punctuated by vegetation patches. Scattered human habitations are evident across the landscape, alongside naturally occurring tree species such as *Dalbergia sissoo*, *Acacia nilotica*, and *Bombax ceiba*, which play important roles in providing shade, ecological stability, and soil stabilization. This area is a combination of natural vegetation dynamics and human activity, impacted by resource use and recurring flooding. The riparian flora of river Ganga at a distance of 500 m is dominated by *Acacia catechu*, *Dalbergia sissoo*, *Terminalia arjuna*, *Ficus benghalensis*, *Ficus religiosa*, *Borassus flabellifer*, *Pithecellobium dulce* (Table 3.5). Other contributing species of floodplain flora *Phoenix sylvestris*, *Eucalyptus* sp., *Ficus virens*, *Bombax ceiba*, *Leucaena leucocephala*, *Morus alba*, *Holoptelea integrifolia*, *Syzygium cumini* were frequently encountered.

Table 3.5 IVI of Trees at 500 m from the river bank

BEU	Location	IVI Values		Other contributing species
		Dominant Trees	IVI	
56	Raiwala	*Acacia catechu*, *Dalbergia sissoo*	150	-
71	Bijnor	*Dalbergia sissoo*, *Morus alba*	52.5	*Acacia nilotica*, *Phoenix sylvestris*, *Ziziphus* sp., *Bombax ceiba*, *Azadirachta indica*, *Psidium guajava*
87	Gharmukteshwar	*Prosopis juliflora*	91.7	*Acacia nilotica*, *Phoenix sylvestris*, *Ficus racemosa*, *Pithecellobium dulce*, *Eucalyptus* sp.
102	Narora	*Dalbergia sissoo*, *Pithecellobium dulce*, *Prosopis juliflora*, *Acacia nilotica*	41.9	*Eucalyptus* sp., *Ficus virens*, *Bombax ceiba*, *Leucaena leucocephala*, *Morus alba*
115	Kacchla	*Terminalia arjuna*	84.9	*Morus alba*, *Dalbergia sissoo*, *Manilkara hexandra*, *Ficus racemosa*
132	Farrukhabad	*Prosopis juliflora*, *Holoptelea integrifolia*	58.5	*Dalbergia sissoo*, *Syzygium cumini*, *Tectona grandis*, *Polyalthia longifolia*, *Eucalyptus* sp.
147	Kannauj	*Prosopis juliflora*	98.1	*Mallotus nudiflorus*, *Phoenix sylvestris*, *Mangifera indica*
162	Kanpur	-	-	-
177	Fatehpur	*Prosopis juliflora*	76.7	*Ficus racemosa*, *Acacia nilotica*, *Holoptelea* integrifolia, *Dalbergia sissoo*, *Mangifera indica*, *Syzygium cumini*, *Ficus religiosa*
194	Lahedri bridge	*Prosopis juliflora*, *Acacia nilotica*	91.7	*Holoptelea integrifolia*, *Syzygium cumini*
210	Prayagraj	*Ficus benghalensis*, *Mallotus nudiflorus*	66.7	*Prosopis juliflora*, *Melia azedarach*, *Ficus religiosa*, *Ficus racemosa*
222	Sirsa	-	-	-
237	Mirzapur	*Acacia nilotica*	92.7	*Azadirachta indica*, *Dalbergia sissoo*, *Holoptelea integrifolia*, *Ficus racemosa*
252	Varanasi	*Alangium salvifolium*	74.4	*Ficus racemosa*, *Mangifera indica*, *Acacia nilotica*, *Prosopis juliflora*, *Dalbergia sissoo*, *Azadirachta indica*
271	Gazipur	*Acacia nilotica*	64.2	*Ficus racemosa*, *Ficus religiosa*, *Albizia lebbeck*, *Azadirachta indica*, *Holoptelea integrifolia*, *Prosopis juliflora*
282	Buxar	*Mangifera indica*	125	*Holoptelea integrifolia*, *Ficus racemosa*, *Acacia nilotica*
298	Revalganj	*Acacia nilotica*	138.03	*Bombax ceiba*, *Sapium sebiferum*, *Ficus religiosa*
302	Doriganj	*Borassus flabellifer*	105	*Ficus religiosa*, *Bombax ceiba*, *Psidium guajava*

BEU	Location	IVI Values		Other contributing species
		Dominant Trees	IVI	
309	Patna	*Erythrina variegata*	58.3	*Streblus asper*, *Ficus racemosa*, *Dalbergia sissoo*, *Moringa oleifera*, *Mallotus nudiflorus*, *Cocos nucifera*
318	Rasalpur Dharnipatti	*Acacia nilotica*	300	*Dalbergia sissoo*
327	Simariya	Ziziphus sp.	183.3	*Ficus racemosa*
338	Munger	*Azadirachta indica*, *Ficus religiosa*	150	-
347	Sultanganj	*Acacia nilotica*	300	-
359	Bateshwarsthan	*Moringa oleifera*	72.5	*Ficus benghalensis*, *Ficus religiosa*, *Prosopis juliflora*, *Mallotus nudiflorus*, *Bombax ceiba*, *Dalbergia sissoo*, *Acacia nilotica*
382	Farakka	*Polyalthia longifolia*	105.7	*Cordia dichotoma*, *Cascabela thevetia*, *Syzygium cumini*, *Phyllanthus emblica*
396	Manigram	*Moringa oleifera*	45.7	*Neolamarckia cadamba*, *Mangifera indica*, *Acacia nilotica*, Acacia catechu, *Mallotus nudiflorus*, *Dalbergia sissoo*
406	Berhampore	*Acacia catechu*	35.7	*Pongamia pinnata*, *Delonix regia*, *Moringa oleifera*, *Borassus flabellifer*, *Ficus hispida*, *Phoenix sylvestris*
420	Katwa	*Mangifera indica*	55.5	*Leucaena leucocephala*, *Eucalyptus*, *Bombax ceiba*, *Delonix regia*, *Pithecellobium dulce*
444	Balagarh	*Moringa oleifera*, *Borassus flabellifer*	34.2	*Mallotus nudiflorus*, *Azadirachta indica*, *Delonix regia*, *Aegle marmelos*
450	Bandel	*Borassus flabellifer*	39.04	*Diospyros* sp.
468	Purba Basudevpur	*Pithecellobium dulce*	41.2	*Neolamarckia cadamba*, *Azadirachta indica*, *Eucalyptus*, *Borassus flabellifer*
479	Haldia	*Azadirachta indica*	29.3	*Neolamarckia cadamba*, *Ficus benghalensis*, *Mallotus nudiflorus*, *Eucalyptus*

At 1000 m from the river

The riverscape at 1000 m from the riverbank had human settlements, including villages and towns. At this distance, the riverscape is strongly influenced by anthropogenic stressors, such as road networks, built infrastructure and ongoing urban expansion, resulting in a more modified riverscape, that is no longer shaped by the river alone. At this distance the influence of seasonal floods is low and thus the riverscape here is more stable. Native species such as *Ficus religiosa* and *Dalbergia sissoo* are commonly retained or promoted in community spaces, while species like *Mangifera indica* are primarily cultivated in household gardens and along the road network. In urbanized stretches at this distance, tree cover largely comprises avenue and shade trees planted along road sides, residential areas, and public spaces to provide shade, improve aesthetic value, and enhance environmental quality. These planted trees contribute to improvement in air quality, provide habitat for urban biodiversity, and moderate the microclimate. The flora of the Ganga River at this distance is dominated by *Mallotus nudiflorus*, *Dalbergia sissoo*, *Moringa oleifera*, *Azadirachta indica*, *Ficus religiosa*, *Holoptelea integrifolia*, *Azadirachta indica*, *Phoenix sylvestris*, *Pithecellobium dulce* (Table 3.6).

Other contributing species of floodplain flora included the *Ficus religiosa*, *Cordia* sp, *Acacia nilotica*, *Ficus religiosa*, *Dalbergia sissoo*, *Ficus racemosa*.



Table 3.6 IVI of Trees at 1000 m from the river bank

BEU	Location	IVI Values		Contributing tree species
		Dominant tree species	IVI	
56	Raiwala	*Dalbergia sissoo*	207.5	*Mallotus nudiflorus*
71	Bijnor	-	-	-
87	Gharmukteshwar	*Mallotus nudiflorus*, *Dalbergia sissoo*, *Moringa oleifera*, *Azadirachta indica*	75	-
102	Narora	*Acacia nilotica*	133.3	*Ficus religiosa*, *Cordia* sp.
115	Kacchla	*Eucalyptus* sp.	133.3	*Mallotus nudiflorus*, *Dalbergia* sp.
132	Farrukhabad	*Dalbergia sissoo*	103.3	*Acacia nilotica*, *Mallotus nudiflorus*
147	Kannauj	*Dalbergia sissoo*, *Ficus racemosa*	91.7	*Ficus religiosa*, *Mallotus nudiflorus*
162	Kanpur	*Mallotus nudiflorus*	110.7	*Dalbergia sissoo*, *Ficus racemosa*, *Leucaena leucocephala*
177	Fatehpur	*Ficus religiosa*, *Holoptelea integrifolia*, *Azadirachta indica*, *Mallotus nudiflorus*	75	-
194	Lahedri bridge	*Leucaena leucocephala*, *Mallotus nudiflorus*	150	-
210	Prayagraj	*Mallotus nudiflorus*, *Holoptelea integrifolia*, *Azadirachta indica*	100	-
222	Sirsa	*Mallotus nudiflorus*	137.1	*Leucaena leucocephala*, *Ficus racemosa*, *Dalbergia sissoo*
237	Mirzapur	*Azadirachta indica*	147.1	*Acacia nilotica*, *Dalbergia sissoo*
252	Varanasi	*Acacia nilotica*	166.7	*Azadirachta indica*, *Dalbergia sissoo*
271	Gazipur	*Dalbergia sissoo*	191.2	*Ficus racemosa*, *Mallotus nudiflorus*
282	Buxar	*Mallotus nudiflorus*	201.7	*Ficus racemosa*
298	Revalganj	-	-	-
302	Doriganj	*Mangifera indica*	166.7	*Acacia nilotica*, *Bombax ceiba*
309	Patna	*Swietenia macrophylla*	100.3	*Mangifera indica*, *Mallotus nudiflorus*
318	Rasalpur Dharnipatti	-	-	-
327	Simariya	*Mallotus nudiflorus*, *Ficus religiosa*, *Borassus flabellifer*, *Mangifera indica*	50.7	*Ficus benghalensis*, *Cocos nucifera*, *Acacia nilotica*
338	Munger	*Phoenix sylvestris*	94.2	*Mangifera indica*, *Azadirachta indica*
347	Sultanganj	-	-	-
359	Bateshwarsthan	*Swietenia macrophylla*	187.8	*Mallotus nudiflorus*
382	Farakka	*Leucaena leucocephala*	114.7	*Mangifera indica*
396	Manigram	*Acacia auriculiformis*	87.1	*Mallotus nudiflorus*, *Pongamia pinnata*, *Prosopis juliflora*
406	Berhampore	*Pongamia pinnata*	123.3	*Mallotus nudiflorus*, *Bombax ceiba*
420	Katwa	*Eucalyptus*	63.2	*Pithecellobium dulce*, *Acacia auriculiformis*
444	Balagarh	*Phoenix sylvestris*, *Pithecellobium dulce*	60.5	*Borassus flabellifer*, *Ficus benghalensis*
450	Bandel	*Pongamia pinnata*	91.75	*Mallotus nudiflorus*
468	Purba Basudevpur	*Prosopis juliflora*	39.8	*Moringa oleifera*, *Acacia nilotica*, *Pongamia pinnata*
479	Haldia	*Tectona grandis*	39.5	*Mangifera indica*

3.3.4 Shrubs and Grasses

Shrubs reported from the Ganga River are represented by 18 orders, 30 families, 54 genera, and 76 species, of which 59 are native and 17 are non-native. Dominant species recorded were *Ziziphus nummularia*, *Abutilon indicum*, *Calotropis procera*, *Jatropha gossypifolia*, *Justicia adhatoda*, *Ricinus communis*, *Lantana camara*, *Lippia alba* etc (Annexure I). Graminoids reported from the Ganga River are represented by 1 order, 5 families, 66 genera and 138 species among which 132 species are native and 06 species are non-native. The term Graminoids is used for grass and grass like plants including Grasses (90 spp.), Sedges (42 spp.), pipeworts (02 spp.), rushes (02 spp.), Cattails (02 spp.). Dominant grass species recorded were *Saccharum benghalense*, *S. spontaneum*, *Phragmites karka*, *Typha elephantina*, *Cynodon dactylon*, *Cyperus rotundus*, *Fimbristylis* spp., *Desmostachya bipinnata*, *Eragrostis tenella*, *Echinochloa colona*, *Cenchrus ciliaris*, *Bolboschoenus glaucus* (Annexure I).

Species Richness, Nativity and Diversity for Shrubs and Grasses

The Shannon Diversity Index (H') patterns at 1 m, 500 m, and 1000 m along the Ganga River reflect a clear ecological gradient driven by flood disturbance, ravine geomorphology, and land-use intensity. At 1 m, grass diversity peaks in lower deltaic BEUs such as Haldia and Balagarh, where tidal influence, brackish-water conditions, and multi-channel river morphology sustain rich graminoid assemblages. In the upper and middle reaches, sites like Gharmukteshwar and Bijnor exhibit balanced shrub and grass diversity linked to seasonal floodplain grasslands and wetland mosaics, while some Himalayan BEUs show low shrub diversity due to structural dominance by a few riparian species (Table 3.7). At 500 m, shrub diversity declines in many mid-basin agricultural stretches, yet remains high in certain deltaic and semi-rural zones such as Purba Basudevpur and Balagarh, where patchy habitats persist within a modified landscape. Grass diversity at this distance is maintained in sites with mixed land use or residual floodplain vegetation, particularly in the lower basin (Table 3.8). By 1000 m, many BEUs especially in intensively cultivated plains exhibit simplified vegetation and low diversity, with grass assemblages dominated by disturbance-tolerant species (Table 3.9). However, exceptions remain: Raiwala in the upper basin retains high shrub diversity, as this stretch of the Ganga River flows through the Rajaji National Park, while deltaic BEUs like Manigram, Balagarh, and Bandel maintain both high shrub and grass diversity, supported by tidal hydrology and a mosaic of semi-natural habitats. These patterns underline the strong role of land use, hydrological setting, and habitat complexity in structuring riparian biodiversity, and point to the importance of conserving zones where natural processes and remnant vegetation still persist.

At 1 m, Shannon Diversity Index values along the Ganga River reveal distinct biodiversity hotspots at both middle and lower reaches of the river (Table 3.7). BEU 479 (Haldia) registers exceptionally high grass diversity (SI = 2.60) in brackish tidal flats, while BEU 444 (Balagarh) supports the highest shrub diversity (SI = 1.93), reflecting mixed riparian shrub assemblages in a multi-channel setting. Other lower-reach sites such as BEU 450 (Bandel; grass SI = 2.44) and BEU 420 (Katwa; grass SI = 2.12) also sustain high grass diversity, likely influenced by tidal hydrology and successional grassland mosaics. Middle-reach sites such as BEU 87 (Gharmukteshwar) and BEU 71 (Bijnor) exhibit balanced and elevated diversity in both shrubs and grasses, corresponding to floodplain grasslands and seasonal wetland complexes. In contrast, BEUs such as 298 (Revalganj) and 359 (Bateshwarsthan) record very low richness and diversity, indicating highly simplified riparian vegetation due to agricultural expansion and channel modification. These results underscore the role of immediate riverbanks in sustaining both native and non-native plant diversity, with tidal estuarine margins supporting peak richness, middle reaches maintaining balance, and intensively cultivated stretches showing sharp declines.



Table 3.7 Species richness, nativity, and Shannon index values for shrubs and grasses at 1 m from the river bank

BEU no.	Location	Richness	Nativity		SI Shrubs	SI Grasses
			Native	Non-native		
1	Harshil	35	30	5	0.28	0.43
26	Dharasu	47	37	10	0.27	0.016
43	Devprayag	45	32	13	0.06	0.032
56	Raiwala	67	48	19	0	1.16
71	Bijnor	45	35	10	0.48	1.8
87	Gharmukteshwar	91	67	24	0.59	1.74
102	Narora	63	40	23	0.48	1.05
115	Kacchla	66	54	12	0	1.69
132	Farrukhabad	69	42	27	0	0.56
147	Kannauj	73	50	23	0	1.66
162	Kanpur	89	62	27	0.66	1.41
177	Fatehpur	79	56	23	0.23	0.53
194	Lahedri bridge	66	41	25	0	0.91
210	Prayagraj	70	45	25	0.14	0.97
222	Sirsa	67	45	22	0.43	1.16
237	Mirzapur	64	44	20	0.39	0.9
252	Varanasi	64	44	20	0.65	1.2
271	Gazipur	56	34	22	0.25	0.97
282	Buxar	50	31	19	0.25	0.83
298	Revalganj	7	7	0	0	0.85
302	Doriganj	26	18	08	0.7	1.21
309	Patna	26	20	6	0.35	1.15
318	Rasalpur Dharnipatti	29	24	5	0.27	1.19
327	Simariya	29	24	5	0.31	1.29
338	Munger	23	17	6	0.28	0.96
347	Sultanganj	20	17	3	0.62	1.03
359	Bateshwarsthan	8	6	2	0	0.65
382	Farakka	33	28	5	0.46	0.94
396	Manigram	39	33	6	0.85	2.07
406	Berhampore	53	42	11	1.05	1.74
420	Katwa	47	41	6	1	2.12
444	Balagarh	60	46	14	1.93	2.05
450	Bandel	65	53	12	1.08	2.44
468	Purba Basudevpur	64	36	28	0.91	1.73
479	Haldia	52	38	14	0.9	2.6

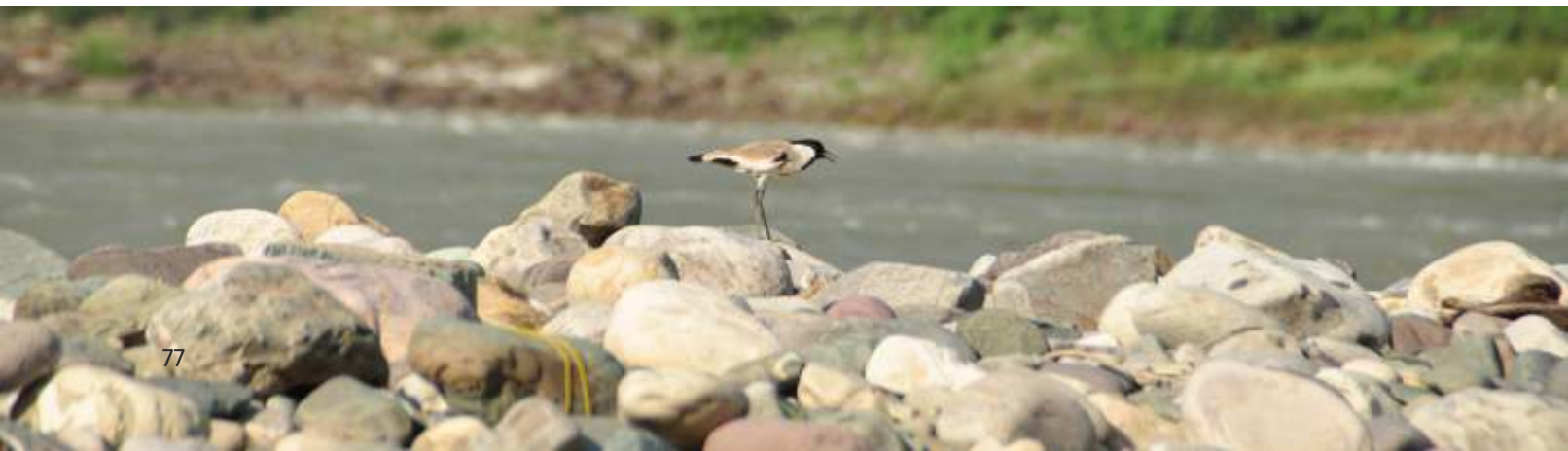


Table 3.8 Species richness, nativity, and Shannon index values for shrubs and grasses at 500 m from the river bank

BEU no.	Location	Richness	Nativity		SI Shrubs	SI Grasses
			Native	Non-native		
56	Raiwala	13	11	3	1.44	1.29
71	Bijnor	21	13	8	0.72	0.93
87	Gharmukteshwar	34	23	11	1.29	1.13
102	Narora	38	24	14	0.97	1.35
115	Kachla	30	25	5	1.01	1.39
132	Farrukhabad	32	20	12	0.79	0.95
147	Kannauj	41	29	12	1.03	1.64
162	Kanpur	37	28	9	1.18	1.67
177	Fatehpur	35	26	9	1.58	0.72
194	Lahedri bridge	28	17	11	0.98	1.08
210	Prayagraj	31	21	10	0.79	0.7
222	Sirsa	22	13	9	0.59	1.05
237	Mirzapur	26	17	9	1.32	1.13
252	Varanasi	37	25	12	1.21	1.37
271	Gazipur	32	19	13	1.18	1.12
282	Buxar	47	36	11	1.13	1.4
298	Revalganj	13	10	3	0.14	0.84
302	Doriganj	34	26	8	0.51	1.23
309	Patna	31	27	4	0.53	1.23
318	Rasalpur Dharnipatti	13	9	4	0.57	0.57
327	Simariya	23	13	10	0.45	0.6
338	Munger	33	26	7	0.42	1.15
347	Sultanganj	38	26	12	0.74	1.19
359	Bateshwarsthan	33	23	10	0.38	1.02
382	Farakka	38	25	13	1.02	1.1
396	Manigram	43	33	10	0.97	2.03
406	Berhampore	47	38	9	0.6	1.93
420	Katwa	33	21	12	1.06	0.98
444	Balagarh	61	46	15	1.16	2.47
450	Bandel	40	30	10	1.35	1.53
468	Purba Basudevpur	58	39	19	2.04	1.9
479	Haldia	45	34	11	1.55	2.04

The Shannon index for shrub and grass along the Ganga River at 500 m from the riverbank, ranged from 0.14 to 2.04, and 0.57 to 2.47, respectively, indicating significant variability across sites (Table 3.8). Grass diversity is generally higher at some locations, but both groups show distinct patterns. BEU 468 has the highest shrub diversity (2.04) and relatively high grass diversity (1.9). BEU 479 leads in grass diversity (2.04) after BEU 444 and shows relatively high shrub diversity (1.55). BEU 479 and BEU 56 also show notable shrub diversity (1.55 and 1.44, respectively). In contrast, BEU 222 and BEU 406 have the lowest shrub diversity (0.59 and 0.6), and site 318 has the



lowest grass diversity (0.57). These findings suggest that shrub and grass diversities vary independently across sites, likely due to differing environmental factors affecting each group differently.

At 1000 m from the riverbank, the Shannon index for shrubs ranged from 0 to 2.34, with BEU 56 showing the highest diversity (2.34) and BEU 132 having the lowest (0.078) (Table 3.9). For grasses, the Shannon index spanned from 0.3 to 2.53, with BEU 444 having the highest diversity (2.53) and BEU 71 having the lowest (0.00) due to inaccessibility. While both shrub and grass diversity varied across sites, the data suggests that their diversities are independent of each other, indicating that different factors may influence the species richness of shrubs and grasses at these sites.

Table 3.9 Species richness, nativity, and Shannon index values for shrubs and grasses at 1000 m from the river bank

BEU	Location	Richness	Nativity		SI Shrubs	SI Grasses
			Native	Non-native		
56	Raiwala	26	18	8	2.34	0.99
71	Bijnor	00	00	00	00	00
87	Gharmukteshwar	32	21	11	0.92	0.087
102	Narora	20	15	5	1.35	0.57
115	Kachla	36	29	7	0.41	1.55
132	Farrukhabad	39	24	15	0.078	0.83
147	Kannauj	29	19	10	0.91	0.83
162	Kanpur	45	28	17	1.29	1.15
177	Fatehpur	44	36	8	1	1.88
194	Lahedri bridge	45	29	16	0.68	1.4
210	Prayagraj	28	22	6	0.6	0.64
222	Sirsa	40	29	11	0.75	0.79
237	Mirzapur	31	20	11	1.32	1.13
252	Varanasi	31	22	9	0.92	1.08
271	Gazipur	31	23	8	1.64	0.3
282	Buxar	37	23	14	1.25	0.93
298	Revalganj	2	2	0	0	0.56
302	Doriganj	22	16	6	0.2	0.34
309	Patna	31	24	7	0.23	1.55
318	Rasalpur Dharnipatti	34	27	7	0.78	1.54
327	Simariya	29	21	8	0.91	1.31
338	Munger	31	17	14	0.8	1.15
347	Sultanganj	19	13	6	0.56	0.34
359	Bateshwarsthan	34	26	8	0.72	0.98
382	Farakka	32	25	7	0.64	0.66
396	Manigram	62	43	19	2.33	2.35
406	Berhampore	49	35	14	1.7	1.69
420	Katwa	32	17	15	0.86	0.91
444	Balagarh	56	39	17	2.03	2.53
450	Bandel	48	32	16	1.51	2.06
468	Purba Basudevpur	40	27	13	0.98	1.41
479	Haldia	46	29	17	1.19	2.31

* At certain locations, the presence of sandy banks, degraded habitat, changing river patterns (Bijnor) or human habitation led to no species being recorded, resulting in a value of zero. Additionally, a few locations were not accessible for sampling, which also contributed to the absence of recorded species at those sites.



In conclusion, vegetation patterns along the Ganga River show a gradual decline in ecological integrity from 1 m to 1000 m. The 1 m zone retains relatively higher diversity, particularly in deltaic and upper floodplain sites where hydrological complexity supports mixed plant communities, though non-native species are common and often dominant. At 500 m, diversity persists mainly in semi-natural patches within agricultural or semi-rural landscapes, but fragmentation is widespread. By 1000 m, large portions of the landscape are converted to cropland or settlements, with natural vegetation restricted to isolated remnants such as protected forest edges or tidal grasslands. Overall, native biodiversity is confined to scattered refuges, emphasizing the urgent need for riparian habitat conservation and restoration along the river's course.

3.3.5 Herbs

Herbs reported from the Ganga River are represented by 27 orders, 70 families, 233 genera and 378 species among which 305 species are native and 73 species are non-native. Dominant herb species recorded were *Alternanthera sessilis*, *A. ficoidea*, *Parthenium hysterophorus*, *Cannabis sativa*, *Tridax procumbens*, *Ammannia baccifera*, *Croton bonplandianus*, *Sida acuta*, *Ageratum conyzoides*, Solanum spp., *Xanthium strumarium*, *Phyla nodiflora*, *Grangea maderaspatana*, *Glinus oppositifolius*, *Glinus lotoides*, *Torenia crustacea*, *Mazus pumilus*, *Aerva lanata*. Along the course of the Ganga River, herbs richness and nativity displayed distinct longitudinal gradients shaped by physiography, habitat diversity, and human influence. In the upper Himalayan reaches (Harshil-Devprayag), richness remained moderate and dominated by native herbs, reflecting relatively undisturbed montane habitats. Non-native herbs were scarce, occurring mainly near settlements and confluences. As the river entered the foothills and middle plains (Raiwala-Kanpur), herb richness rose markedly, peaking at sites such as Gharmukteshwar, Kannauj, and Kanpur. These stretches offered heterogeneous habitats, multi-channel flows, riparian vegetation, and agroforestry mosaics that supported high diversity. However, barrages (Narora) and urban centres (Prayagraj) promoted the spread of non-natives, leading to noticeable shifts in community composition. Further downstream, along the middle Ganga (Prayagraj-Buxar), richness remained relatively high, but non-natives herbs expanded in densely populated and agriculturally intensive zones. Local depressions in diversity occurred at Revalganj and Sultanganj, likely linked to sandy riverbeds and reduced habitat complexity, while sites like Farrakka, with oxbow lakes and hydrological heterogeneity, sustained higher richness. In the lower Ganga and deltaic stretches (Manigram-Haldia), herb richness peaked again, especially at Balagarh and Purba Basudevpur. Yet, native representation declined sharply as non-native herbs dominated disturbed, brackish, and industrialized habitats of the Hooghly (Figure 3.11). This marked a transition from predominantly native-dominated assemblages upstream to mixed and non-native heavy communities downstream. Overall, herb richness along the Ganga River followed a clear gradient: moderate and native-rich in the Himalayas, diverse but increasingly mixed in the plains, and high yet non-native heavy in the delta. Human pressure, hydrological regulation, and land-use change were the main drivers of species turnover, reshaping habitat quality along the river continuum.

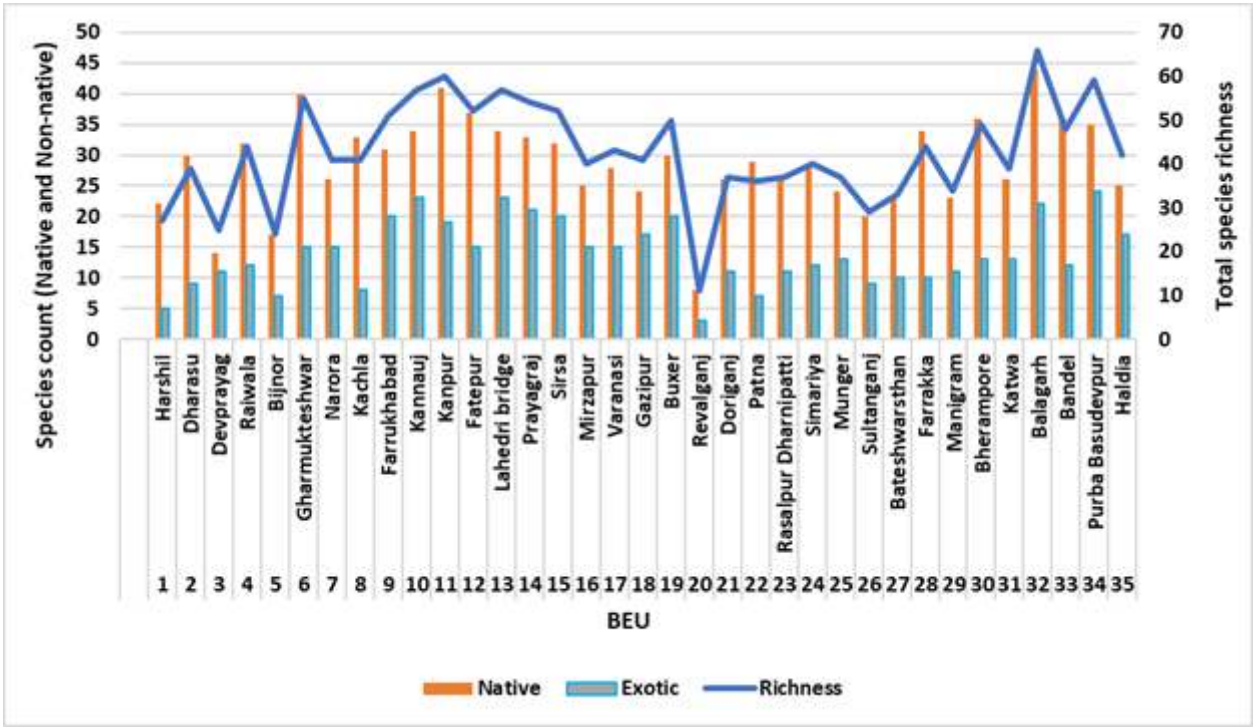


Figure 3.11 Richness and Nativity of herbaceous plants in sampled BEUs of the Ganga River

3.3.6 Invasive and Non-native species

About 84% (n=627) of the recorded plant species were native to India while 120 species recorded are non-native, from different continents of the world). Dominant families with the highest number of introduced plants were Asteraceae (21 spp.), Fabaceae (18 spp.), Euphorbiaceae (11 spp.), Solanaceae (10 spp.) and Amaranthaceae (8 spp.). Dominant non-native tree species recorded in the basin were *Prosopis juliflora*, *Pithecellobium dulce*, *Solanum erianthum*, *Broussonetia papyrifera*, *Leucaena leucocephala*. Dominant non-native shrub species were *Jatropha gossypifolia*, *Ricinus communis* and *Senna occidentalis*, *Lantana camara*, *Lippia alba*, *Solanum chrysotrichum*, *Ipomoea carnea*. Dominant non-native herbs were *Euphorbia hirta*, *Senna tora*, *Alternanthera ficoidea*, *Hyptis suaveolens*, *Ageratum conyzoides*, *Alternanthera paronychioides*, *Alternanthera philoxeroides*, *Amaranthus spinosus*, *Argemone mexicana*, *Calyptocarpus vialis*, *Croton bonplandianus*, *Erigeron bonariensis*, *Portulaca pilosa*. Dominant introduced grasses are *Paspalum dilatatum*, *P. distichum*, and *Urochloa mutica*. *Axonopus compressus*, *Cyperus alternifolius* (Table 3.10). These species were frequently encountered and widely spread across the river basin due to their highly adaptive nature, allelopathic effects, and effective reproductive strategies.



Table 3.10 List of Invasive and Non-native species

Plant group	Species
Trees	*Prosopis juliflora, Pithecellobium dulce, Solanum erianthum, Broussonetia papyrifera, Leucaena leucocephala*
Shrubs	*Jatropha gossypifolia, Ricinus communis and Senna occidentalis, Lantana camara, Lippia alba, Solanum chrysotrichum, Ipomoea carnea*
Herbs	*Euphorbia hirta, Senna tora, Alternanthera ficoidea. Hyptis suaveolens, Ageratum conyzoides, Alternanthera paronychioides, Alternanthera philoxeroides, Amaranthus spinosus, Argemone mexicana, Calyptocarpus vialis, Croton boplandianus, Erigeron bonariensis, Portulaca pilosa*
Graminoids	*Paspalum dilatatum, P. distichum, and Urochloa mutica. Axonopus compressus, Cyperus alternifolius*

Other species recorded

Climbers reported from the Ganga River are represented by 10 orders, 10 Families, 36 genera and 42 species among which 36 Species are native and 6 Species are non-native. Dominant climber species *Cayrtia trifolia*, *Coccinia grandis*, *Mikania micrantha*, *Tinospora cordifolia*. Aquatic species that were dominant along the Ganga River are *Pontederia crassipes*, *Pistia stratiotes*, *Lemna perpusilla*, *Spirodela polyrhiza*, *Najas minor*, *Hydrilla verticillata*, *Vallisneria natans*, *Ludwigia adscendens*, *Nymphaea nouchali*, *Nymphaea pubescens*, *Stuckenia pectinata*, *Trapa natans*, *Ceratophyllum demersum* (Annexure I).

3.4 DISCUSSION

The present study, documenting 747 plant taxa, is broadly consistent with earlier floristic accounts of the Ganga basin while providing important comparative and updated insights. Classical works such as Duthie (1903-1929) and later syntheses by Uniyal and Singh (2014) reported large-scale basin diversity (~2400-2600 species), reflecting cumulative inventories across wide spatial extents. Similarly, comprehensive studies by Kumar (2001) and Balkrishna et al. (2025) recorded 896 and 1117 species, respectively, covering extensive stretches of the Ganga River. In contrast, several stretch-specific or region focused studies, including Krishnamurti (1991; 475 species), Nautiyal & Nautiyal (1993; 211 species), Semwal & Mehta (1996; 252 species), Shruti et al. (2019; 289 species), and Rana et al. (2023; 84 species) reported comparatively lower richness due to limited geographic coverage or habitat-specific focus. Studies from specialized ecosystems such as the lower Gangetic delta (Naskar, 1993; Naskar & Mandal, 1999) further highlight the spatial variability in floristic composition along the course of the Ganga River.

The present study provides a more detailed and fine-scale assessment of riparian vegetation along the Ganga River compared to earlier basin-scale evaluations. While a previous rapid assessment along the Ganga River, documented 289 plant species across 88 families and 219 genera, dominated by herbs (56%), followed by trees (21%), shrubs (10%), climbers (6%), and grasses/reeds/sedges (7%), with 67% native species (Shruti et al., 2019; NMCG-WII), the present study records substantially higher richness with 747 taxa belonging to 119 families and 459 genera. Herbaceous species remain dominant; however, the present study further refines life-form structure by documenting 378 herb species along with significant contributions from graminoids (138 spp.), trees (108 spp.), shrubs (76 spp.), and climbers (42 spp.), reflecting greater structural complexity. A notable contrast is observed in nativity patterns, with the present study reporting 84% native and 16% non-native species, compared to 67% native flora in earlier assessments, indicating stronger persistence of native vegetation when evaluated at finer spatial scales. In terms of spatial patterns, earlier studies identified the Himalayan stretch (Zone I) as the most diverse, whereas the present study



demonstrates a clear downstream increase in species richness, peaking in the middle and lower reaches (up to 133 species in deltaic regions), driven by increasing habitat heterogeneity. However, this higher richness is accompanied by greater non-native species representation, particularly in disturbed plains and deltaic zones, highlighting a trade-off between diversity and ecological integrity. Furthermore, unlike previous zonation-based approaches, the present study incorporates lateral gradients, revealing a decline in diversity and ecological integrity from the riverbank (1 m) to inland areas (1000 m), where natural vegetation is increasingly replaced by anthropogenic land uses. Species exhibiting high prominence values included *Cynodon dactylon*, *Saccharum spontaneum*, *Parthenium hysterophorus*, *Ziziphus nummularia*, and *Eichhornia crassipes*, a pattern that is consistent with observations from the present study, particularly at 1 m from the river bank. The earlier and the present studies consistently identify disturbance as a key driver of vegetation patterns, promoting invasive species such as *Prosopis juliflora*, *Eichhornia crassipes*, *Parthenium hysterophorus*, *Alternanthera philoxeroides* and *Alternantera ficoidea*; however, the present study strengthens this understanding through quantitative indices such as IVI, demonstrating the structural dominance of invasives in degraded habitats. Overall, while earlier assessments provide a broad overview of riparian vegetation, the present study offers a more nuanced understanding by integrating taxonomic richness, life-form composition, nativity, and multi-scale spatial gradients.

When compared to previous studies, the present work provides a systematically sampled, spanning dataset across 35 BEUs, integrating both longitudinal (Himalaya to delta) and lateral (1 m, 500 m, 1000 m) gradients, an approach largely lacking in earlier investigations. While the overall species richness recorded here is lower than cumulative basin-wide estimates, due to lesser geographical coverage, it is comparable to other large-scale field-based studies, reflecting standardized

sampling rather than compiled flora. Importantly, the dominance of families such as Poaceae, Fabaceae, and Asteraceae observed in the present study is in strong agreement with previous reports, confirming their ecological prominence across diverse riparian habitats.

However, the present study advances beyond earlier works by explicitly linking floristic patterns with spatial gradients and anthropogenic pressures. A clear longitudinal trend emerges, with relatively native-dominated assemblages in the Himalayan stretches transitioning to increasingly disturbed and non-native rich communities in the plains and delta. This pattern complements earlier observations of high diversity in the basin but further refines them by demonstrating how species composition shifts under varying degrees of human influence. Additionally, the incorporation of lateral gradients reveals a distinct decline in ecological integrity away from the river, with higher diversity and native representation near the riverbank and increasing homogenization, plantation dominance, and invasive species prevalence at greater distances. Notably, these lateral gradients also reflect successional patterns, with early colonizing and disturbance-tolerant species dominating near the active river edge (mostly herbs, few shrubs and grasses species like *Alternanthera* spp., *Pontederia* spp., *Parthenium hysterophorus*, *Cannabis sativa*, *Croton bonplandianus*, *Sida acuta*, *Ageratum conyzoides*, *Xanthium strumarium*, *Phyla nodiflora*, *Calotropis procera*, *Ziziphus* spp., *Ricinus communis*, *Saccharum* spp., *Phragmites* spp., *Cynodon dactylon*), gradually transitioning to more stable (woody shrubs and tree species like *Dalbergia sissoo*, *Acacia* spp., *Azadirachta indica*, *Ficus* spp., *Borassus flabellifer*, *Phoenix sylvestris*, *Lantana camara*, *Lippia indica*, *Senna occidentalis*, *Mesosphaerum suaveolens*, *Abutilon indicum*, Clerodendrum spp.), managed (Eucalyptus, Terminalia, Populus, Butea, Borassus), or secondary communities farther from the river bank. Unlike most previous studies that focused primarily on species enumeration, the present analysis integrates diversity indices, nativity patterns, and dominance (IVI), thereby offering a more functional understanding of riparian ecosystems along the Ganga River. The substantial proportion of non-native species and their dominance in several stretches highlight an emerging ecological concern that has been only partially addressed in earlier literature. These findings underscore the increasing role of anthropogenic disturbances such as agriculture, urbanization, and plantation forestry in reshaping riparian vegetation across the Ganga basin

CONCLUSION

In conclusion, the river survey recorded 747 taxa (735 angiosperms, 7 gymnosperms, and 5 pteridophytes) across 40 orders, 119 families and 459 genera. Poaceae was the dominant family (90 species), followed by Fabaceae (63) and Asteraceae (56), with notable contributions from Cyperaceae, Acanthaceae, Lamiaceae, Malvaceae, and others, reflecting high floristic diversity. Species richness varies significantly across locations, with Balagarh (BEU No. 444) exhibiting the highest richness, hosting 133 species, while Revalganj (BEU 298) has the lowest at 17 species. Maximum number of non-native species were recorded from Purba Basudevpur, Kanpur and Prayagraj. Tree species diversity along the 1m, 500m, and 1000m distances from the river follows a distinct pattern shaped by hydrological influences and human activities. At 1m, tree species richness is at its peak due to the availability of moisture and nutrient-rich alluvial soils, which favor riparian and moisture-loving species. However, as the distance increases to 500m, tree richness declines as drier conditions prevail, human habitation, resulting in competition from shrubs and invasive species. At 1000 m, richness is at its lowest, suggesting the dominance of drought-tolerant species and significant anthropogenic disturbances, including agriculture and deforestation. Across different locations, richness was found to be lowest in Raiwala, Kanpur, and Prayagraj, while the highest richness was observed in



Manigram and Behrampur. Munger and Fatehpur exhibited moderate richness levels. The dominance of *Acacia nilotica*, *Dalbergia sissoo*, and *Mallotus nudiflorus* was evident across all distances, along with notable contributing species such as *Acacia catechu*, *Ficus* spp., *Mangifera indica*, *Syzygium cumini*, *Bombax ceiba*, *Moringa oleifera*, and *Borassus flabellifer*.

Shrub and grass diversity exhibited spatial variations across different distances from the river. At 1m, shrub and grass diversity were highest in Manigram and Bundel, highlighting the influence of periodic flooding and high moisture availability in shaping vegetation structure. At 500 m, Balagarh and Haldia showed the highest shrub and grass diversity, possibly due to transitional vegetation zones benefiting from intermittent moisture and moderate human disturbances. At 1000 m, Manigram and Raiwala demonstrated the highest shrub and grass diversity, suggesting the presence of resilient species capable of thriving under drier conditions. This variation underscores the role of site-specific factors such as soil composition, hydrological regimes, and human interference in determining the diversity of shrubs and grasses across distances. Overall, tree, shrub, and grass richness followed a gradient influenced by proximity to the river. Tree richness was highest at 1m and declined with increasing distance, while shrub and grass diversity exhibited site-dependent fluctuations. The interplay of moisture availability, soil conditions, and human interventions was key in shaping these vegetation patterns. These findings highlight the necessity of conservation efforts targeting both riparian and transitional zones to maintain biodiversity and ecological stability in the region.

The longitudinal assessment of riparian vegetation along the Ganga River reveals a clear shift from structurally diverse and heterogeneous ecosystems to increasingly simplified and uniform plant assemblages under sustained anthropogenic pressure. Historically, the riverine landscape supported a mosaic of swamp forests, cane brakes, tall grasslands, and Shorea robusta (Sal)-dominated forests, each contributing to high habitat complexity and ecological resilience. However, these systems are now either fragmented or largely replaced. For instance, the swamp ecosystems and associated cane brakes (*Calamus tenuis*) once prevalent in the Doon Valley have drastically declined due to deforestation, drainage, and land-use conversion. Similarly, the extensive tall grasslands of the upper Gangetic plains, which supported species such as *Phragmites karka* and *Saccharum* spp., are now reduced to isolated patches within the protected wetlands like Jhilmil Jheel Conservation Reserve and Haiderpur Wetland. Sal-dominated forests along the foothills (Chidiyapur, Haridwar) and adjoining plains have also undergone significant alteration, often replaced by monoculture plantations (eg., *Eucalyptus*, *Populus*) or agricultural fields, leading to homogenization of vegetation structure. Across much of the middle and lower stretches, diverse riparian assemblages have been substituted by a limited suite of disturbance-tolerant and often invasive species such as *Prosopis juliflora* (replace species of Acacia in the landscape), *Lantana camara*, *Ageratum conyzoides*, *Parthenium hysterophorus*, *Mesophaerum suaveolens* and *Eichhornia crassipes* (all these are under plant species of concern that have replaced India's natural forest systems). This transition reflects not only habitat loss but also a shift in ecological functioning, where native biodiversity, regeneration potential, and ecosystem services are compromised. Overall, the replacement of heterogeneous riparian habitats with simplified, human-modified landscapes indicates a trajectory of biotic homogenization along the Ganga River. This underscores the urgent need for restoring native vegetation mosaics, protecting remnant habitats, and managing invasive species to retain the ecological integrity and resilience of the riverine ecosystem.



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CHAPTER 4

MACRO INVERTEBRATES OF THE GANGA RIVER

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SUMMARY

The benthic macroinvertebrates are important components of the food chain, as they serve multiple functions such as primary consumers, detritivores, predators, and prey in an aquatic ecosystem. They serve as important bioindicators of the freshwater ecosystem due to their limited mobility. In Europe and the United States, the rivers and streams have been monitored using macroinvertebrate community composition since 1970. The International Organization for Standardization has established standards for the use of macroinvertebrates in water quality monitoring. Among the macroinvertebrates, odonates (dragonflies and damselflies) are the most widely studied group, and occupy an important role in assessing conditions of the freshwater ecosystems. Dragonflies and damselflies are one of the dominant invertebrate predators in the freshwater ecosystem and feed on a wide range of aquatic invertebrates. Odonata are known for their diverse distribution and adaptability to various habitats, including the transitional zones or ecotones between different ecosystems. The knowledge of their diversity and distribution provides critical insights into the ecological condition of riverine habitats. In India too, the macroinvertebrates have been used for monitoring the quality of freshwater ecosystems. With regard to the Ganga River, such studies have been conducted throughout its stretch by various scientists and scholars, over varying temporal and spatial scales, however, a comprehensive study providing a baseline on macroinvertebrates for the entire length of the Ganga River, following a similar methodology is missing. This study aims to fulfil this gap by establishing a baseline in 2017-18 and revisiting it in 2024-25 for the odonates.

Through a systematic review of literature, benthic macroinvertebrate communities of the Ganga River were evaluated. The literature published between 1991 and 2023 was studied and changes in the community structure and composition were noted. In addition, primary field surveys of Odonata (dragonflies and damselflies) were conducted during 2017-18 and 2024-25 across 32 sampling sites representing five habitat zones along the Ganga River.

Review revealed that a total of 135 macroinvertebrate families belonging to 33 orders and 10 classes were recorded along the Ganga River's mainstem. Community composition exhibited a pronounced longitudinal gradient, with Arthropoda dominating the upper reaches, while Mollusca and Annelida increased in relative abundance downstream. This shift corresponds to a transition from oligotrophic, fast-flowing headwaters to more organically enriched lowland conditions. A marked decline in pollution-sensitive taxa-particularly Ephemeroptera,



Plecoptera, and Trichoptera (EPT)-and a concomitant increase in pollution-tolerant groups such as Chironomidae and Physidae were observed along the upstream-downstream continuum, indicating progressive degradation in water quality. Altered flow regimes, sedimentation due to hydropower projects on the mainstem River and anthropogenic pollution were identified as key drivers of reduced taxonomic richness, especially in Uttarakhand and Bihar.

Odonate surveys documented 37 species in 2017-18 and 31 species in 2024-25. Habitat Zone II (Bijnor-Narora), located within the Hastinapur Wildlife Sanctuary, consistently supported the highest species richness and diversity across both survey periods. Comparative analysis revealed a significant decline in odonate species richness and Shannon diversity between survey periods, with the most pronounced reductions occurring in the lower reaches of the Ganga River. Analyses indicated that pH, mean discharge, and water temperature were significant predictors negatively associated with species richness and diversity ($p < 0.05$).

These provide evidence of temporal declines in macroinvertebrate diversity along the Ganga River, underscoring ongoing ecological degradation. The study highlights the importance of long-term, standardised biomonitoring frameworks, with Odonata serving as sensitive bioindicators for assessing freshwater ecosystem health.



4.1 INTRODUCTION

The benthic macroinvertebrates are important components of the food chain. They play a crucial role in the aquatic ecosystem, serving multiple functions such as primary consumers, detritivores, predators, and prey (Hauer & Resh 2017). They serve as important bioindicators in the freshwater streams and rivers due to their limited mobility (Mophin Kani & Murugesan, 2014). They are considered a "canary in a coalmine" for water pollution, as their presence and abundance can provide clues about the health of the aquatic environment (Nieto et al., 2017). They can accumulate pollutants from their surroundings and/or food so that an analysis of their tissues provides an estimate of environmental concentrations of the pollutants (Johnson et al., 1993).

Macroinvertebrates are often utilized as an indicator to evaluate the changes in a water environment (Hall et al., 2003, Armitage, 2006; Fabrizi et al 2010; Tampo et al. 2021). In Europe and the United States, the rivers and streams have been monitored using macroinvertebrate community composition as early as 1970, since the passing of the Clean Water Act of 1972 (Barbour et al., 2000). The International Organization for Standardization (ISO) has established standards for the use of macroinvertebrates in water quality monitoring, including ISO 7522:2020, which provides guidelines for the sampling and identification of macroinvertebrates in freshwaters. The Biological Monitoring Working Party (BMWP) is among the most used bioassessment indices for aquatic ecosystem quality assessment, which assigns scores to each macroinvertebrate taxa according to their sensitivity to organic pollution. As the different geographical, ecological, and anthropogenic conditions promote diverse taxonomic compositions, the BMWP scores for each taxon are thus standardized for each ecological region (Paisley et al., 2013). In India, the BMWP scores were calibrated and BWQC (Biological water quality criteria) was developed (CPCB newsletter, 1999), and later BWQC was revised based on the ASPT Score in 2020 (Geol, 2023). Apart from BMWP, there are several indices used worldwide, and the most commonly used indices are the richness and dominance of Ephemeroptera, Plecoptera, and Trichoptera (EPT), Average score per taxon (ASPT), Shannon-Wiener diversity, and feeding traits (Eriksen et al., 2021). BMWP and ASPT are the most widely used indices.

Among the earlier studies on aquatic insects in the Ganga River, Bilgrami et al. (1991) provided a comprehensive account of aquatic insects in the Ganga River between Munger and Farakka. Later, Nesemann et al. (2011) studied benthic macroinvertebrate taxa in the Gangetic Dolphin habitat in Bihar. Kumar et al. (2013) investigated the macroinvertebrate community structure of the Ganga River from Patna to Bhagalpur. Nautiyal et al. (2014) examined the distribution of biodiversity elements, their taxonomic richness, density, and composition in different zones from Badrinath to Varanasi. Kamboj & Kamboj (2021) studied the impact of sand and gravel mining on



the community structure of macrobenthic species in the mining-impacted area of the Ganga River at Haridwar. De et al. (2021) conducted the study from Brij Ghat to Narora, while Jwala et al. (2022) investigated the Ganga River stretch from Bijnore to Badaun. Goel et al. (2021) investigated water quality in upper streams (Digha Ghat and Gandhi Ghat), while there was a decline in water quality and community structure downstream of Patna. Sharma & Behera (2022) studied the distribution of pollution-sensitive and pollution-tolerant families of benthic macroinvertebrates from 33 different locations along the Ganga River in Uttarakhand, Uttar Pradesh, Bihar, and West Bengal. While some studies are restricted to specific locations, very few cover the entire Ganga basin. Most recently, CPCB (2017) investigated the benthic community of the Ganga and its tributaries from Uttarakhand to West Bengal at 93 locations.

Among the macroinvertebrates, odonates are the most widely studied group, and occupy an important role in assessing conditions of the aquatic ecosystems (Golfieri et al., 2016). Odonata is a collective term for dragonflies (Suborder Anisoptera) and damselflies (Suborder Zygoptera). Dragonflies and damselflies are one of the dominant invertebrate predators in the freshwater ecosystem and feed on a wide range of aquatic invertebrates. Odonata are known for their diverse distribution and adaptability to various habitats, including the transitional zones or ecotones between different ecosystems (Chovanec & Waringer, 2001). Their wide distribution among habitats, specific species occurring in each habitat, makes them useful indicators of environmental quality (Silva et al., 2010; Monteiro-Júnior et al., 2013). The knowledge of their diversity and distribution provides critical insights into the ecological condition of riverine habitats.

The Odonates are sensitive towards their surroundings, and changes in their environment may alter their local abundance and distribution. Hence, they are being used in to assess habitat conditions such as water quality (Kutcher & Bried, 2014), habitat modification due to urbanisation (Prescott & Eason, 2018), grazing effects on wetlands (Kinvig & Samways, 2000), climate change (Kalkma et al., 2008). Despite their ecological importance, odonate populations are declining globally due to numerous anthropogenic threats arising from habitat loss, urbanisation, agriculture, and deforestation (Clausnitzer et al., 2009). Studies also show that dragonflies are sensitive not only to the quality of the wetland but also to the major landscape changes, especially changes in the riparian zone (Thomas, 2019).

This study aimed to review the status of macroinvertebrates, including the Odonates. Based on primary data the study also assessed the current status of odonata diversity, distribution, and evaluated the influence of environmental variables on species diversity and richness at selected sites along the Ganga River.

4.2 METHODS

A comprehensive literature review was carried out to know the baseline data, distribution of benthic macroinvertebrate and water quality of the Ganga River and its tributaries. For this study, review was carried out for the studies published between 1991 and 2023. The review included a search of scientific literature, government reports and other relevant literature and these were collected using Google Scholar, ResearchGate and other online search engines. The keywords used to select the scientific material on the topic of interest were "macroinvertebrate", "benthic macroinvertebrate", "macroinvertebrate indices", "BMWP and BWQC", coupled with "Ganga", "tributary name", and "Ganga basins". After pooling all the literature available, the data on the number of species, families, orders were compiled in excel sheet. This data was checked for duplication and errors and processed for visual representation. Here we present state wise distribution of the macroinvertebrate community along the Ganga River.

A post-monsoon survey to assess the Odonata community was conducted at 32 sampling sites across five habitat zones (HZ 2 to HZ 6) along the stretches of the Ganga River during October and March 2017-18, and December and March 2024-25 (Table 4.1, Figure 4.1). Physiochemical parameters, such as electrical conductivity, salinity, turbidity, pH, and water temperature were measured at each site using a Professional Plus digital meter. Adult odonates were surveyed following point count data collection methodology following Buchsbaum et al. (2016). In this method, a 5 km-long river stretch was chosen and 6 sampling points at a distance of 1 km were selected for point count. The observer stood at the observation point for 10 minutes and recorded the counts of odonate that passed within ~5 m of the sampling point (Figure 4.2). Only one bank (either left or right, depending on the accessibility) of the main channel was selected for data collection.



Table 4.1 Geographical coordinates of 32 intensive sampling locations within 6 habitat zones.

HBZ	Name	Description	Longitude	Latitude
Habitat Zone 1	S1	Mukhawa	78.78728	31.040785
	S2	Dharasu	78.32826	30.621249
	S3	Byas Ghat	78.59156	30.084577
	S4	Chila	78.23437	30.006587
Habitat Zone 2	S5	Gangoli Khadar, Bijnor	78.03303	29.434392
	S6	Tigri Ghat	78.15298	28.825642
	S7	Narora	78.36568	28.245238
Habitat Zone 3	S8	Sahwajpur, Kachhla	78.91359	27.866842
	S9	Azizabad, Shamshabad	79.52496	27.543049
	S10	Mehendipur, Kannauj	79.96274	27.109421
	S11	Kanpur	80.29786	26.569625
Habitat Zone 4	S12	Bhitura, Fatehpur	80.7477	26.076239
	S13	Manikpur	81.30711	25.824989
	S14	Prayagraj	81.78004	25.481039
	S15	Tela, Bhadoi	82.19884	25.208651
	S16	Kolhar, Mirzapur	82.60052	25.230269
	S17	Mustafabad Ramchandrapur, Varanasi	83.1382	25.336288
Habitat Zone 5	S18	Gangabarar, Ghazipur	83.53875	25.437415
	S19	Pipra, Ballia	84.04185	25.636455
	S20	Revalganj, Chhapra	84.6264	25.727402
	S21	Raghupr, Patna	85.3131	25.573109
	S22	Maranchi, Begusarai	85.98233	25.398234
	S23	Tilakpur, Munger	86.56944	25.353448
	S24	Kahalgaon	87.17932	25.291065
	S25	Maharajpur, Sahibganj	87.77432	25.244103
Habitat Zone 6	S26	Chandpur, Farakka	87.93215	24.63059
	S27	Jiaganj - Azimganj	88.25379	24.266115
	S28	Katwa	88.19602	23.765048
	S29	Rudrapur, Nabadwip	88.36627	23.462553
	S30	Raninagar, Kalyani	88.45382	23.044451
	S31	Mahesh Tala, Kolkata	88.24024	22.537027
	S32	Haldia, Diamond Harbour	88.18405	22.051548



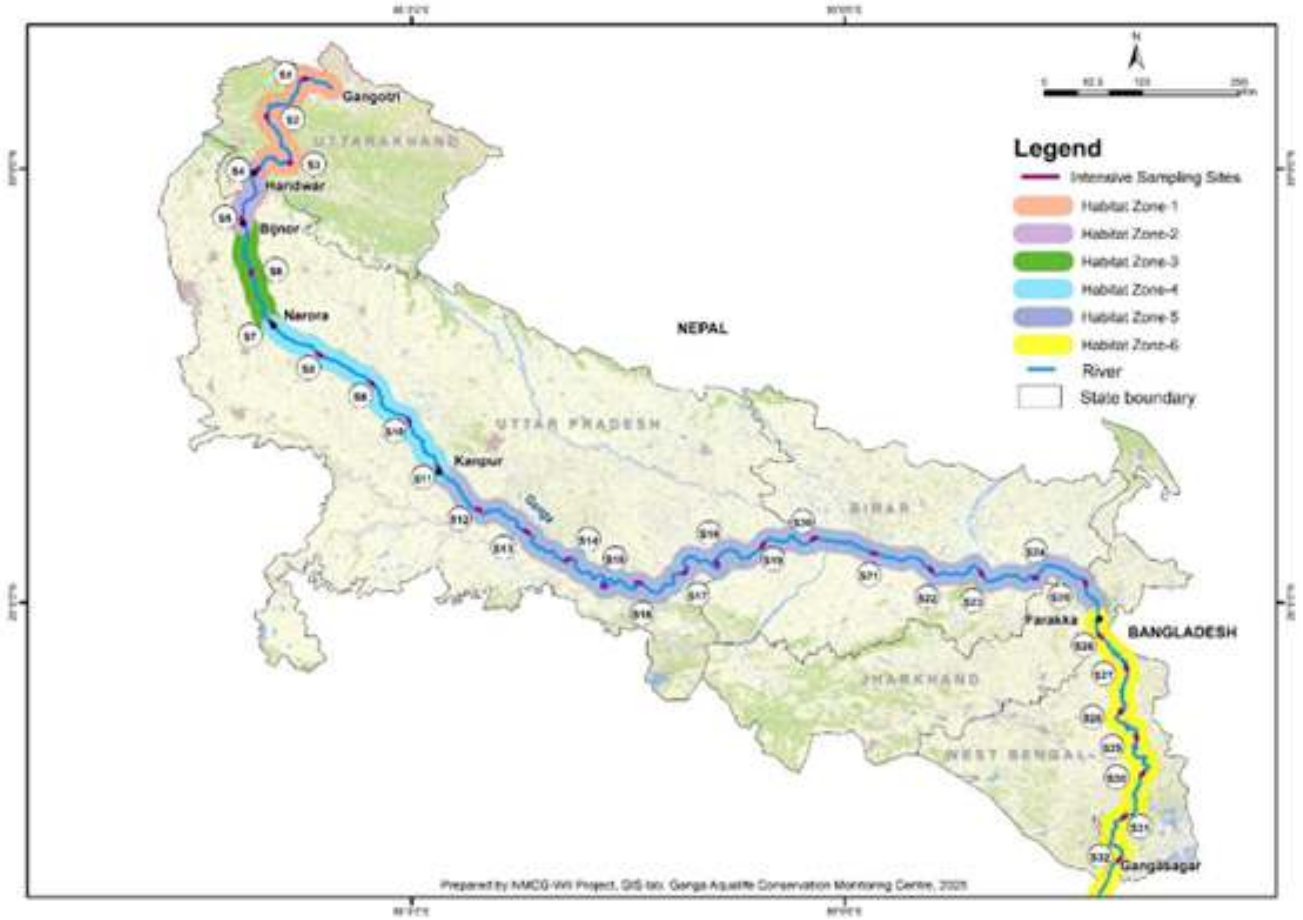


Figure 4.1 The map showing six habitat zones and 32 intensively sampled sites along the Ganga River

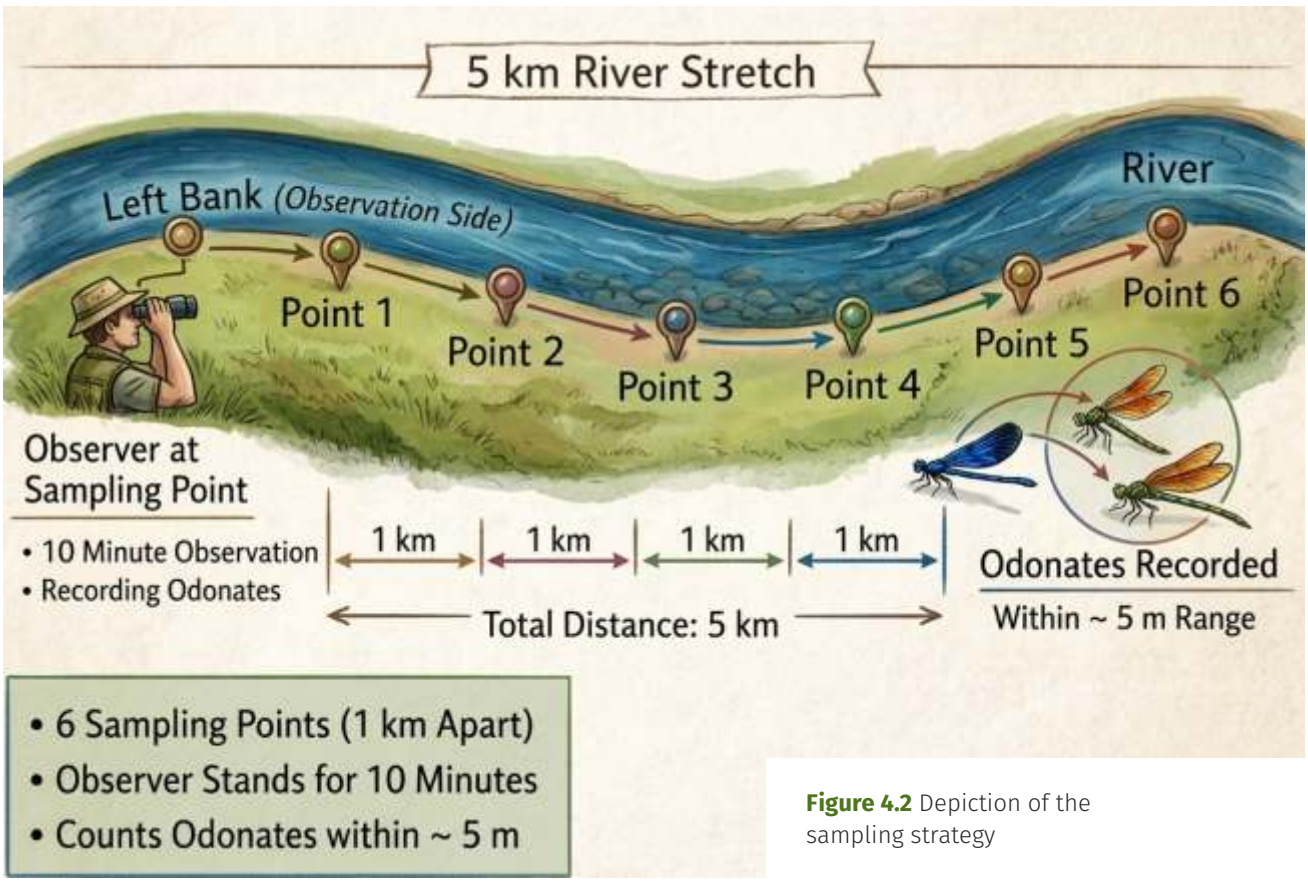


Figure 4.2 Depiction of the sampling strategy

The raw data was filled in excel sheet and the site-wise and zone-wise species richness and Shannon species diversity (H') were computed using SDR (Species Diversity and Richness software version. 4.1.2 (PISCES Conservation Ltd., 2014) from species count data. The mean species richness and Shannon diversity were calculated for five habitat zones. Cluster analysis was performed using R software for grouping the sites based on species diversity. A Pearson's correlation analysis and linear regression model were used to examine the relationship between site-wise species richness and diversity with the selected environmental variables considered in the study. These statistical analyses were performed in an Excel sheet using the Data Analysis Toolpak. Pearson's correlation was used to determine relationships between biodiversity metrics and individual environmental factors for all sites. The linear regression model was applied to assess the predictive capacity of these environmental variables on species richness and diversity across various sites.



4.3 RESULTS

4.3.1 Macroinvertebrates in the Ganga basin

A total of 24 articles on the macroinvertebrate community of the Ganga River mainstem have been published since 1991. A total of 135 families of macroinvertebrates belonging to 33 orders and 10 classes were reported through these studies on the mainstem of the Ganga River. Rao (2001) reported eight species of Coleoptera, four species of Diptera, five species of Plecoptera, and six species of Trichoptera from the Ganga River between Rishikesh and Kanpur. Kumar et al. (2013) identified 47 families from 23 orders in the Ganga River along the State of Bihar, while De et al. (2021) observed the presence of three species of Coleoptera, four Hemiptera, 32 Odonates (14 dragonflies and eight damselflies) from Brijghat to Narora.

4.3.1.a Uttarakhand: Distribution of macroinvertebrate community

The Upper stretch of the Ganga River, from Gangotri to Devprayag, has been examined for altitudinal variations in the composition of macroinvertebrate community and water quality of the river (Singh and Nautiyal, 1990; Singh et al., 1994; Nautiyal, 2010; Semwal and Akolkar 2009). In this stretch, the impact of the hydroelectric project on the macroinvertebrate community was also assessed by Sharma et al. (2008), Kumar and Nautiyal (2019), and Kumar (2021). Some studies have been restricted to the foothill stretch from Rishikesh to Haridwar (eg. Khanna et al., 2001; Bahuguna et al., 2004; Khanna and Bhutani, 2005; Rao, 2001; Kumar et al., 2018; Agrawal et al., 2019).

The review revealed that numerous Arthropods (67 families within 8 orders) populate the mountain section of the Ganga River. Most common are the families of Order Coleoptera, Diptera, Ephemeroptera, Odonata, Plecoptera, and Trichoptera. Of these, the Order Diptera and Ephemeroptera are notably family-rich, while Hemiptera exhibit fewer families (Figure 4.3).

The Chironomidae (Non-biting midges), Baetidae (Small minnow mayflies), and Hydropsychidae exhibited the widest distribution range as they were recorded from all locations from Gangotri to Haridwar, in both past as well in recent investigations. Nemouridae was recorded earlier (Singh et al., 1994) from five stations of mountain stretches. Blephariceridae, restricted to mountain stretches from Ganganani to Devprayag in all the investigations, was not present from Tehri and Devprayag in recent records. Athericidae was also recorded in earlier as well as recent times from the mountain zone of the river (Singh et al., 1994; Kumar, 2021). Similarly, Simullidae was recorded in a recent investigation from most of the studied locations, including Ganganani as well as Ganga Nahar. The widespread presence of these faunal elements indicates their adaptability to both pristine and moderately disturbed rivers.

Some families showed an extended range of distribution. Hydrophilidae, recorded at Dharasu and Tehri in the past (Singh et al., 1994), were recorded from more recent investigations in the foothill stretches of the Ganga in Uttarakhand. Psephenidae recorded from Uttarakashi to Devprayag in earlier records (Singh et al., 1994), was recently recorded from Shivpuri, Laxmanjula, and Haridwar barrage. Limonidae recorded from earlier investigation at Joshiyara Dharasu, Devprayag, Rishikesh (Singh et al., 1994), was later recorded only from Manera,



Haridwar, and Jagjeetpur. Similarly, Heptageniidae reported from Tehri (Agarwal et al., 2003), Gangotri (Nautiyal, 2010), upstream/downstream Maneri Bhali stage 1 (Kumar, 2021), was continuously present in recent records from Haridwar to Kangri. Some families, like Dryopidae recorded upstream of Rishikesh and Haridwar (Nautiyal, 2010; CPCB, 2017), and Tehri (Agarwal et al., 2003) were not noted in earlier records. Gyrinidae was recorded in recent studies at Dharasu, Shivpuri (Kumar & Nautiyal, 2019; Agarwal et al., 2019), while Chaoboridae at some locations of the foothill stretches Bairagi, and Kangri (Kamboj & Kamboj, 2021). Some families show a patchy range in the mountain zone. Dixidae was recorded earlier only from Ganganani and Uttarakashi. Similarly, Deuterophlebiidae was present in recent investigations upstream Maneri Bhali Stage 1 to Manera (Kumar & Nautiyal, 2019; Kumar 2021), while Psychodidae were found in the past from Uttarakashi, Joshiyara, and Dharasu (Singh et al., 1994). Some families are specific to the foothill stretch of the Ganga River. The taxa Siphlonuridae and Neoephemeridae were recorded from Rishikesh barrage to Ganga Nahar (CPCB, 2017; Agarwal et al., 2019). Libellulidae was restricted to foothill stretches from Byasi to Kangri (Kamboj & Kamboj, 2021). Apheloceridae, Coenagridae were observed only at the foothill stretches, while Philopotamidae, Perlidae, and Limneiphilidae were found in the mountain zone of the River (above Devprayag).

Families such as Caenidae, Dytiscidae, Elimidae, Leptoceridae, Glossosomatidae, were reported from past as well as recent investigations, but have patchy distribution. Similarly, Gomphidae was recorded during the recent investigation at the downstream of Maneri Bhali stage 1, Dharasu Shivpuri, and Phoolchatti. In an earlier investigation by Singh et al., (1994), Tipulidae was recorded from Devprayag and Rishikesh. Later studies reported its presence in Gangotri, Maneri Bhali Stage 1, Haridwar, Rishikesh Barrage, and Jagjeetpur (Nautiyal, 2010; Kumar, 2021; CPCB, 2017; Agrawal et al., 2019).

Epheremeridae that was earlier recorded from Joshiyara and Dharasu (Singh et al., 1994) was later found from Byasi to Kangri (Kamboj & Kamboj, 2021). In a recent investigation, Perlidae and Peltoperlidae were recorded from Gangotri (Sharma et al., 2023).

The flatworms, roundworms, and annelid worms prevail in the foothill stretch of the river between Haridwar and Ajeetpur (CPCB, 2017; Agrawal et al., 2019; Kamboj & Kamboj, 2021). A total of 9 families belonging to 5 orders were reported from these stretches. The mountain stretches of the Ganga River are devoid of these worms, as the riverbed comprises large, hard substrate not suitable for burrowing, in contrast to small, soft sediments such as clay, silt, and sand that are suitable for burrowing in the foothill stretch of this river. The stretch from Devprayag to Rishikesh was inclusive of Hirudinidae and Glossiphonidae at Phoolchatti in contrast to the Dugesidae at Laxman Jhula and Rishikesh barrage. It was found at Jagjeetpur also. Annelids were found in the stretch between Haridwar and downstream of Jagjeetpur. Lumbricidae and Glossiphonidae were recorded at Haridwar barrage. Among molluscs, 7 families belonging to 4 orders were recorded from the foothill stretches of the river. In earlier records, only two families were reported (Kishor et al., 1998; Bahuguna et al., 2004), while in the latter investigation, 5 families were reported (CPCB, 2017; Agrawal et al., 2019; Kamboj & Kamboj, 2021).

Changes in the macroinvertebrate community over the years

The highest taxonomic richness was reported from Bhimgoda Barrage, Haridwar, followed by Dharasu, while the least was reported from the downstream of Bhimgoda Barrage, the flow-deficient stretch below the barrage (Fig. 4.4). Taxonomic richness of macroinvertebrates showed a significant declined between 1994 and 2023 at Gangotri, Uttarkashi, Dharasu, and Devprayag (Singh et al., 1994; Nautiyal, 2010; Kumar and Nautiyal, 2019; Sharma et al., 2023).

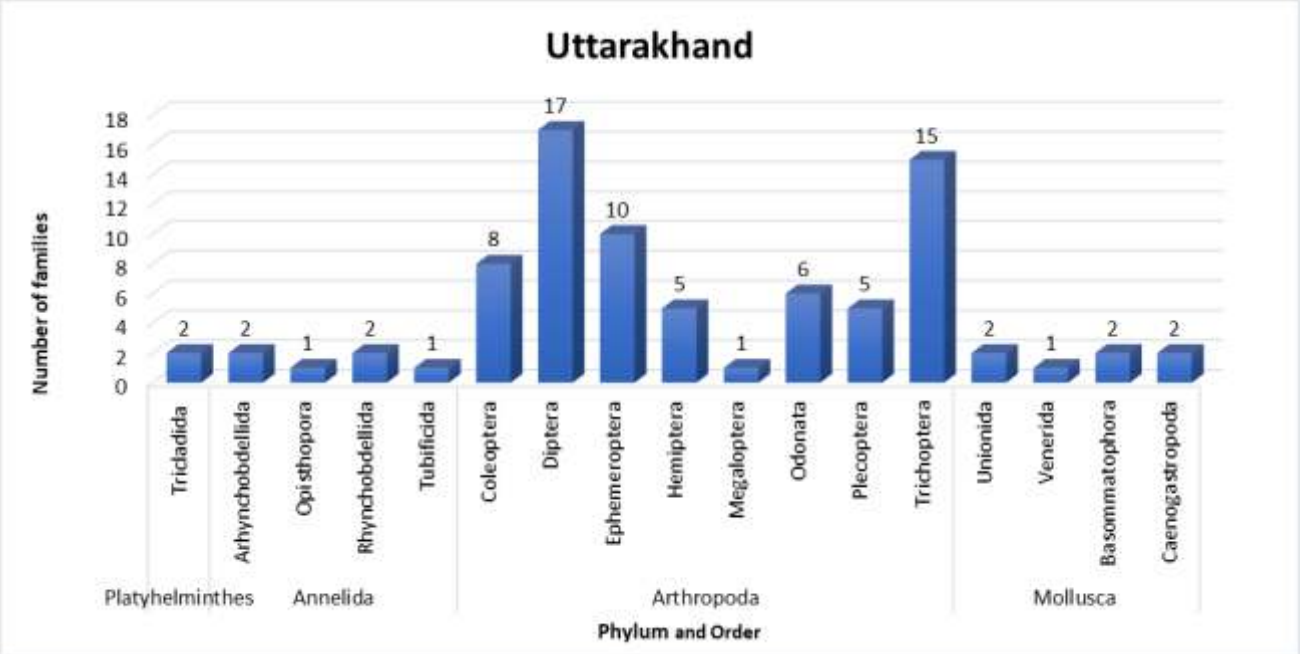


Figure 4.3 Taxonomic distribution of macroinvertebrate families within different orders and Phyla.

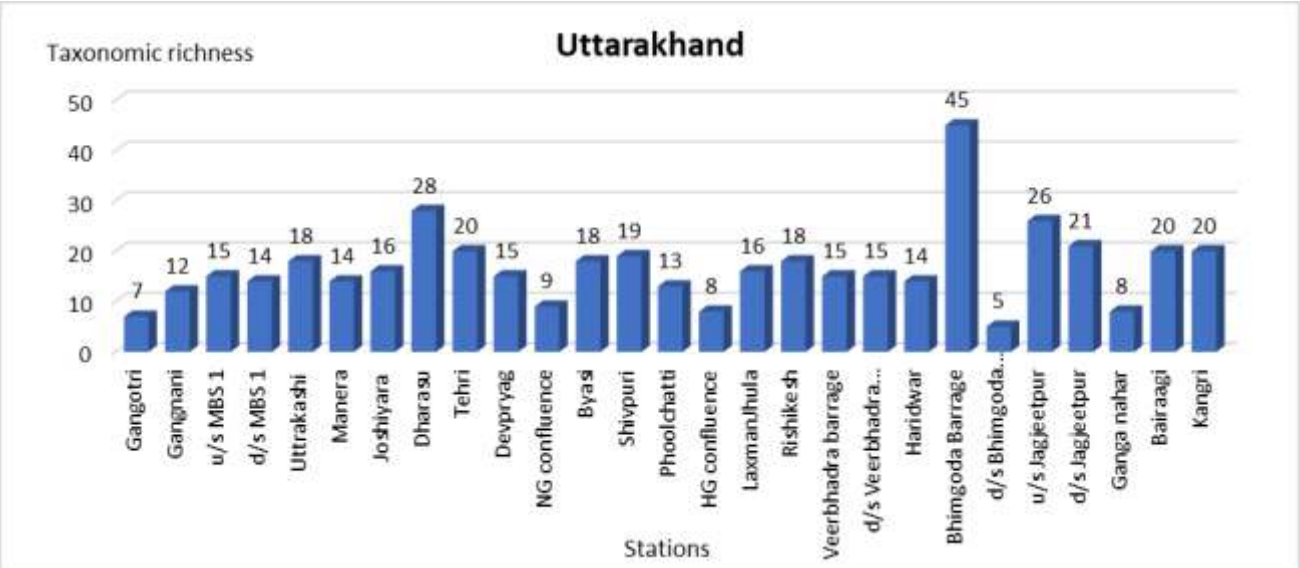


Figure 4.4 Taxonomic richness of macroinvertebrates in the upper part of the Ganga river in Uttarakhand. Acronym: u/s and d/s MBS- upstream and downstream Maneri Bhali Stage, NG- Nayar Ganga, HG- Henwal Ganga

4.3.1.b Uttar Pradesh: Distribution of macroinvertebrates in the Ganga river

In this part of the river, the phylum Arthropoda consisted of the highest number of families, in which Hemiptera, Trichoptera, and Odonata consisted of the maximum number of families, respectively, followed by the phylum Mollusca (Figure 4.5). A total of 9 families of worms belonging to the 7 orders were reported from Uttar Pradesh in the recent investigations. The worms were sparsely distributed in Uttar Pradesh at some locations. Sabellida was sparsely spread upstream from Varanasi to Tarighat in lower Uttar Pradesh and while Tubificidae was noted at Narora and also present at Brijghat, Kanpur, Allahabad, and Varanasi. Hirudinidae and Tubificidae were reported at Brijghat. Salifidae, Glossiphonidae, and Naididae were observed at Tanda.

Among Arthropoda, 62 families belonging to 13 orders were reported. Families such as Baetidae and Chironomidae were commonly observed, although Baetidae and Corixidae show patchy distribution. Ranatranidae, Dytiscidae, Hydrophillae, Nepidae, Gomphidae, Arydiae, and Plaemonidae were distributed from Tanda to Tarighat (CPCB, 2017; Jwala et al., 2022), in which only Dytiscidae were reported later in 2021 from Ajitpur and Tanda (Kamboj & Kamboj, 2021). Some

families such as Ameletidae, Caenidae, Heptageniidae, Neoephemeridae, Gerridae, Hydroptillidae, Helicopsychidae, Glossosomatidae, Rhyacophilidae, Chaoboridae, were present only in the upper stretches of the Ganga River in Uttar Pradesh. Ephemeridae showed a scattered distribution. Noteridae was reported at lower lowermost stations from Varanasi to the downstream of Mirzapur.

Among the mollusc fauna, 17 families belonging to 8 orders were reported. Planoribidae are reported from Ajitpur to Kanpur (CPCB, 2017). Planoribdae, Corbiculidae, Lymnidae, and Physaude reported from Ajitpur to Tarighat in all the investigations show their widespread distribution. Unionidae was reported from Lower Uttar Pradesh, while Viviparidae, Thiaridae, and Bithynidae show scattered distributions that was not reported in the latter investigation.



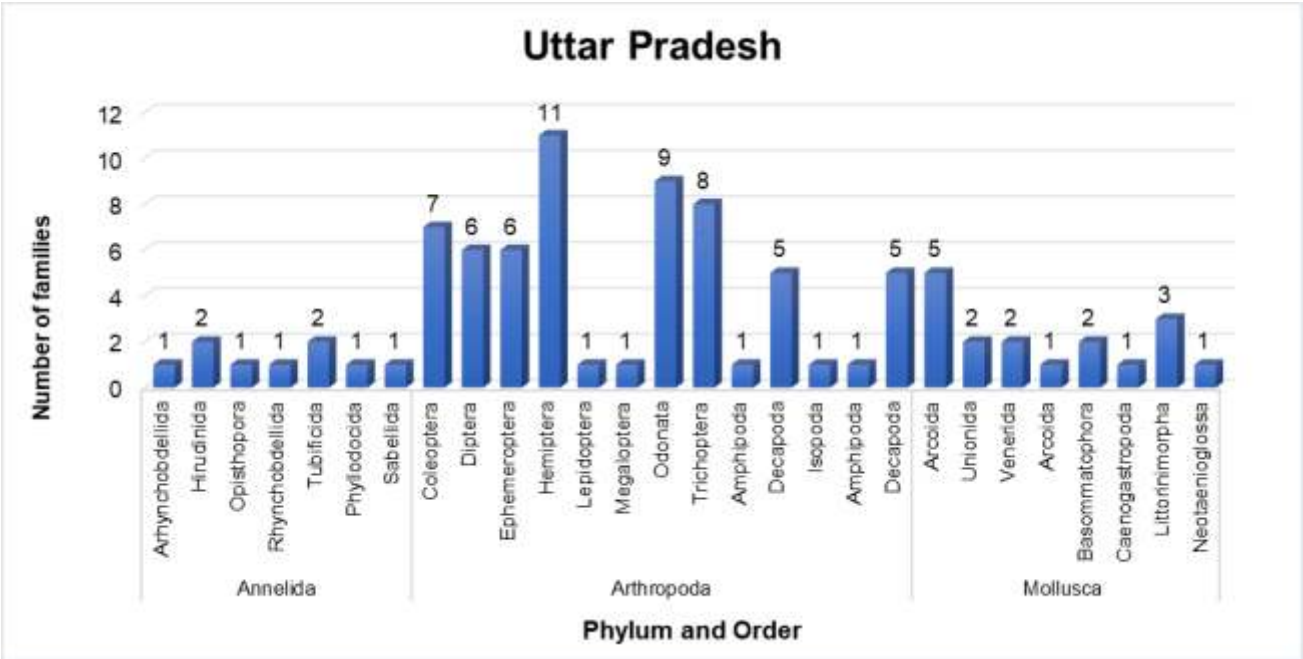


Figure 4.5 Taxonomic richness of macroinvertebrate families among different taxonomic orders in the Ganga River, Uttar Pradesh.

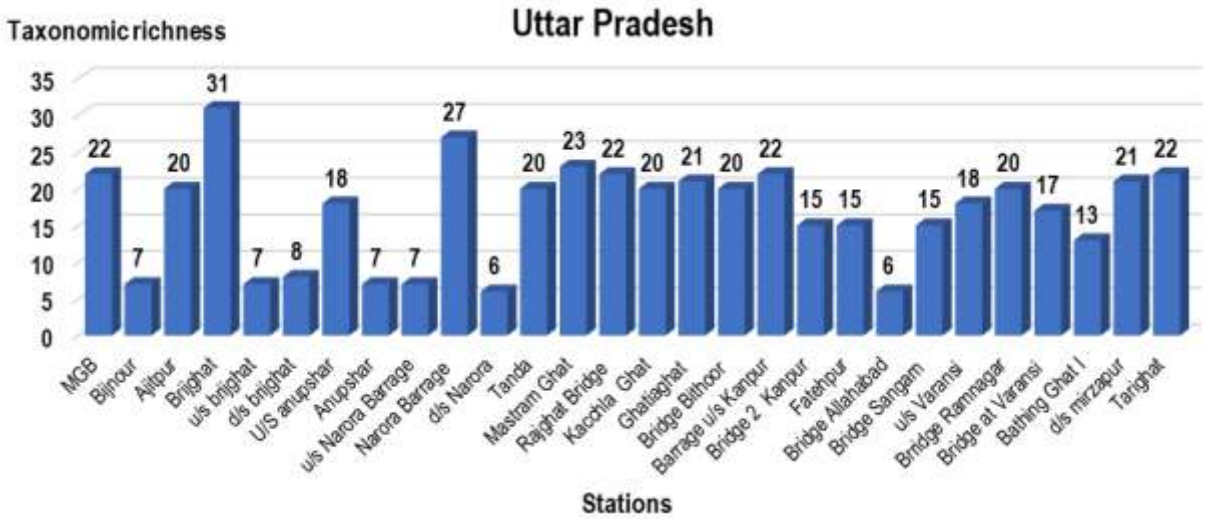


Figure 4.6 Taxonomic richness of macroinvertebrates across different locations in the stretch of the Ganga river in Uttar Pradesh. *Acronym: u/s- upstream, d/s- downstream*

Changes in the macroinvertebrate community over the years

The highest taxonomic richness was reported from Brijghat, while the least was from near the Bridge at Allahabad and downstream of Narora (Figure 4.6). At Madhya Ganga Barrage, 19 families and at Kachla Ghat, 15 families were recorded by CPCB (CPCB, 2017), but later only 8 and 4 families respectively were reported (Jwala et al., 2022), which shows a significant decline within the 3-year time frame.

4.3.1.c Bihar

In this part of the river, the phylum Arthropoda consisted of the highest number of families, in which Hemiptera, Coleoptera, Diptera, and Odonata comprised the maximum number of families, respectively, followed by the phylum Mollusca (Figure 4.7). A total of 14 families belonging to 8 orders, Microchaetidae, Salifidae, and Megascolecidae, were frequently observed from Mahendrughat to Digha Ghat in earlier investigations only (Neseman et al., 2011), while Glossiphoniidae and Nereididae were reported from different locations in all investigations (Neseman et al., 2011; CPCB, 2017; Geol et al., 2021), showing persistence across years. Nereididae showed significant proliferation from Mahendrughat to Old Palace in Bihar. Naididae had a limited distribution. Sabellida was sparsely spread from Gandhi Ghat to Kahalgaon in Upper Bihar, while Lumbricidae and Pisionidae were observed only in 2017 from u/s and d/s Buxar (CPCB, 2017). Several families were not detected in later investigations, despite their widespread presence in earlier investigations.

Within the Arthropoda, 47 families belonging to 11 orders were recorded. Families, Dytiscidae, Chironomidae, Gomphidae, and Hydrophilidae show their consistent presence, in which Dytiscidae, Gomphidae, and Chironomidae were reported from all three investigations from Buxar to Fatuha, showing their widespread distribution. Chironomidae was not reported in earlier investigations. Some families, such as Dryopidae, Stratiomydiae, Ephemerellidae, Polycentropodidae, Gammaridae, and Cirolanidae, were recorded from a recent survey (Geol et al., 2021) at some locations in lower Bihar. They were not recorded from earlier investigations. Few families, Nepidae, Corixidae, and Culicidae, show broad but scattered distribution as they were reported from all three investigations. Gyrinidae, Hymenosomatidae, and Parathelphusidae were restricted to Mehndrughat, to the old Palace, reported from the earlier investigation (Neseman et al., 2011) in which Gyrinidae appeared in the recent survey from Malsalam (Geol et al., 2021). The Mollusca phylum was the second most diverse in Bihar, with 18 families and 11 orders. Planoribidae, Viviparidae, Physidae, Thiaridae, and Lymnaeidae were the most observed and widely distributed families reported from all the investigations and multiple sites. Amblemidae, Unionidae, and Corbiculidae also appeared frequently, particularly in the middle and lower stretches of the river in Bihar. Some families, such as Arcidae, Sphaeriidae, and Succineidae, were documented in earlier studies (Neseman et al., 2011), while Bithyniidae, Solecurtidae, and Stenothyridae were only recorded in later investigations (Geol et al., 2021).

Changes in the macroinvertebrate community over the years

The highest taxonomic richness was reported from the old Palace, while the least was from four locations (Danapur, Nala, Sitakundh, and Sultanganj) (Figure 4.8). The only location, Ghandighat, shows temporal variation in which 23 families were reported in the 2011 survey (Neseman et al., 2011), 9 in 2017 (CPCB, 2017), while a slight increase of 13 was reported in 2021 (Geol et al., 2021). Overall, there is a sharp decline in the number of families at Ghandighat.



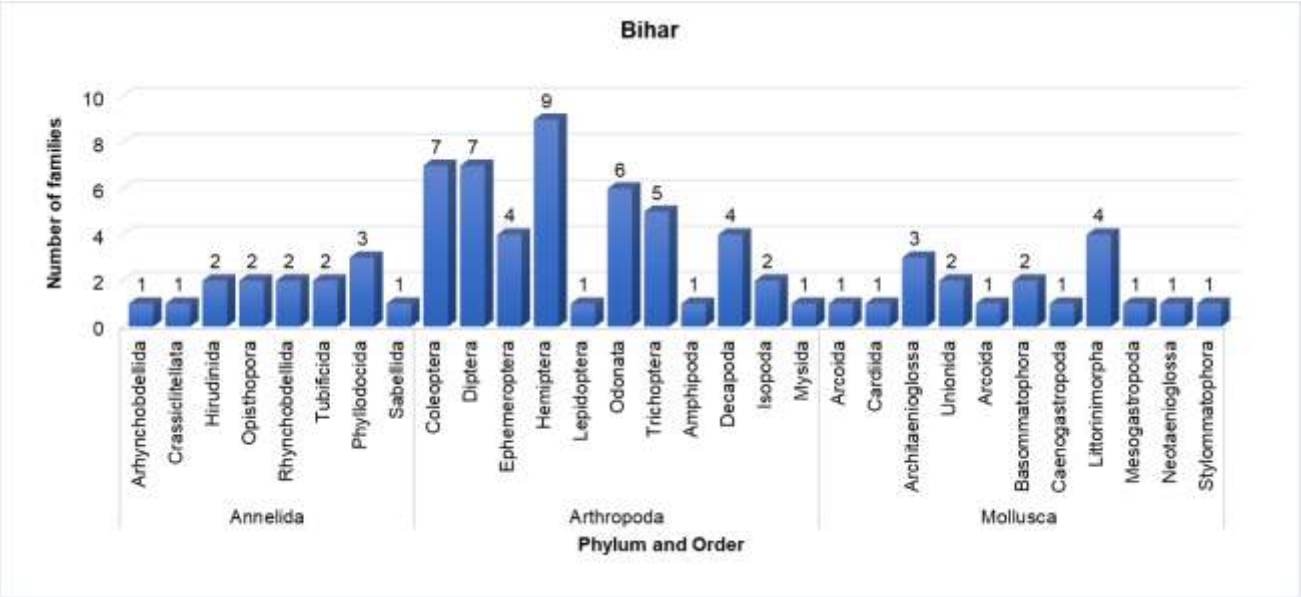


Figure 4.7 Taxonomic richness of macroinvertebrate families among different taxonomic orders in the Ganga River, Bihar.

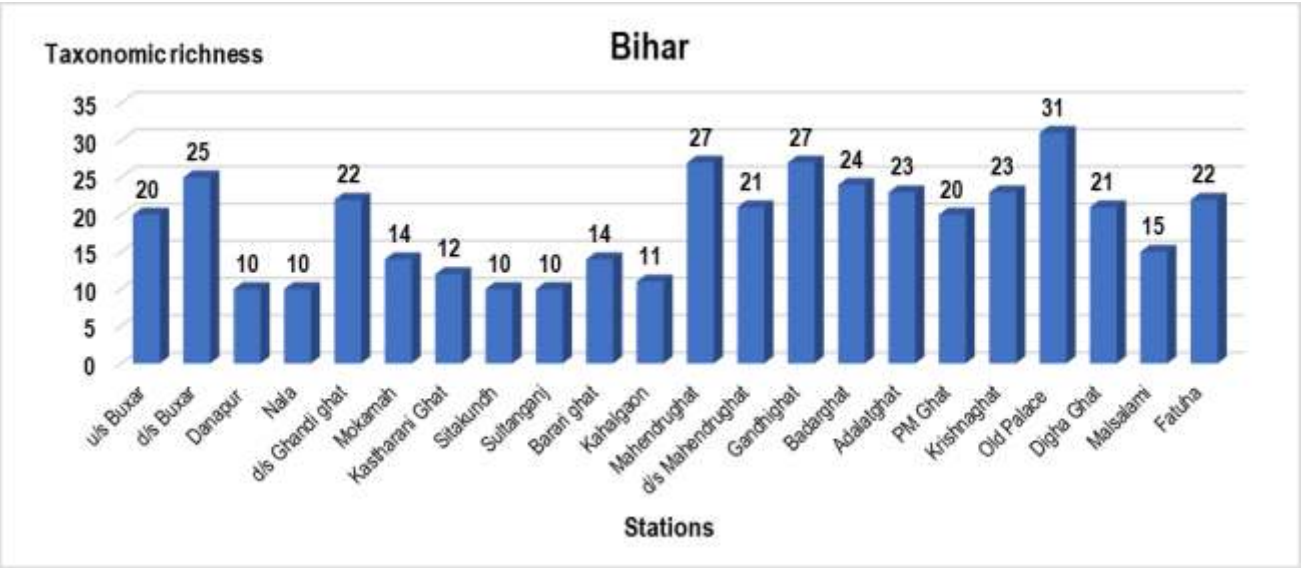


Figure 4.8 Taxonomic richness of macroinvertebrates across various locations along the Ganga River in Bihar.

4.3.1.d Jharkhand and West Bengal

Only one study (CPCB, 2017) is available for this stretch of the Ganga River, showing a significant lack of studies from this stretch. In Jharkhand and West Bengal, the fauna consisted of a total of 25 families from the 8 orders of Arthropoda. Decapoda followed by Hemiptera consisted of a maximum number of families. Mollusca was the second most diverse phylum, consisting of 16 families from 10 orders (Figure 4.9). For the Jharkhand stretch of the Ganga River, the highest taxonomic richness was reported from Brahampur ghat and Mangalhat, while the least was reported from downstream of d/s Sahibganj (Figure 4.10). While for West Bengal, the highest taxonomic richness was reported from d/s the Farakka, while the least was reported from downstream of the Ferryghat (Figure 4.10). Five and six families of Annelids have been reported respectively from Jharkhand and West Bengal, respectively. Only Nereididae was common between Jharkhand and Bengal. Four other families were specific to Jharkhand while five others were specific to West Bengal.

Among the Arthropoda, the family Dytiscidae was the most widely spread Coleopteran beetle in the Jharkhand and West Bengal stretches of the Ganga River. Hydrophilidae was present distantly at Brahampur and Ferryghat in Jharkhand, but was notably present all along the West Bengal segment. The beetle Noteridae was found in the Jharkhand segment at Ferryghat only and in the lower part of West Bengal. The Chironomids occurred in most parts of the Jharkhand segment except the d/s

Sahibganj. In the West Bengal segment, it was recorded at two locations, viz. u/s Farraka barrage and d/s Farakka barrage. The order Ephemeroptera was represented poorly by the families Baetidae and Neoephemeridae at Brahampur and Ferryghat, respectively. Three families of Hemiptera occurred in Jharkhand, Hebridae in particular at Mangalhat. Corixids were relatively well spread in the West Bengal river segment. Belostomatidae and Nepidae occurred distantly. Ranatranidae was present in the whole stretch of West Bengal except the Farakka FTPS. The Odonata were represented by four families that prevailed in the West Bengal segment only. They occurred in a discontinuous manner. Gomphidae was notable for its continuous occurrence in the Jharkhand segment only.

The Decapoda, represented by 6 families, were found in the lower Jharkhand and the total segment of West Bengal, except the Farakka FTPS. This zone is almost devoid of the macroinvertebrate fauna.

Sixteen families of Bivalvia and Gastropoda together characterized the river Ganga in Jharkhand and West Bengal by their total presence in these two states. Annelids and Arthropods were low in occurrence but were diverse, while the molluscs, though high in occurrence, were less diverse. Major stations include Brahampur Ghat, Sahibganj, Mangalhat, and Ferryghat, where a diverse range of molluscs were recorded.

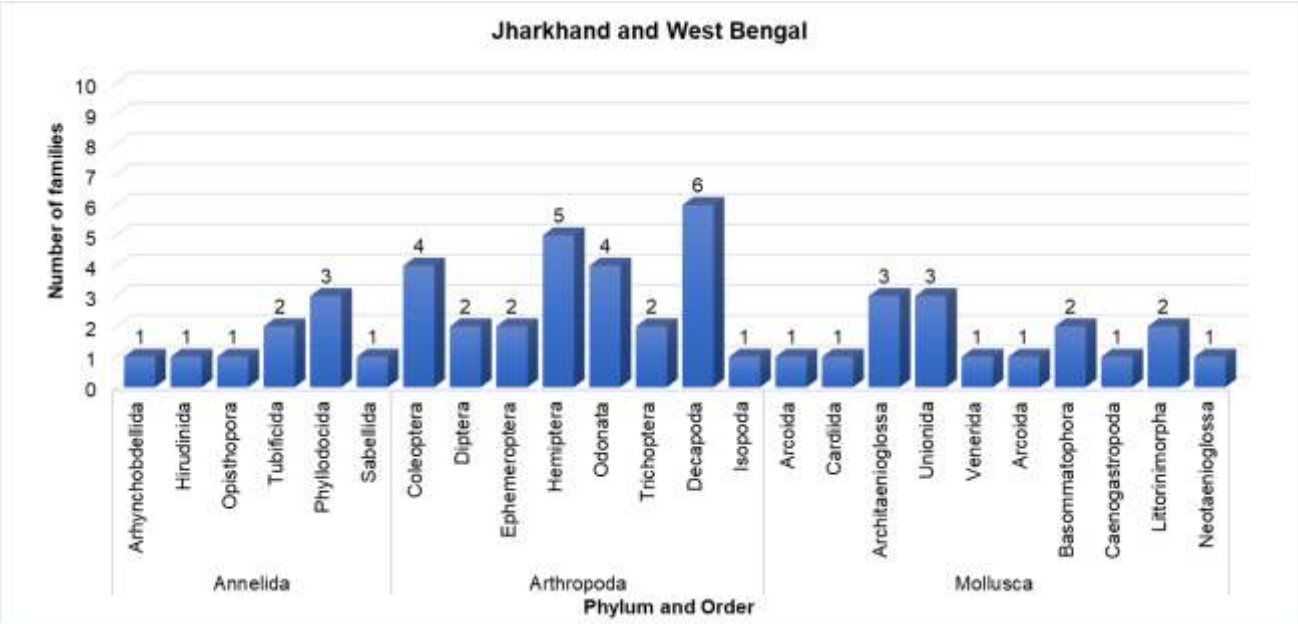


Figure 4.9 Taxonomic richness of macroinvertebrate families among different taxonomic orders in the Ganga River, Jharkhand and West Bengal.

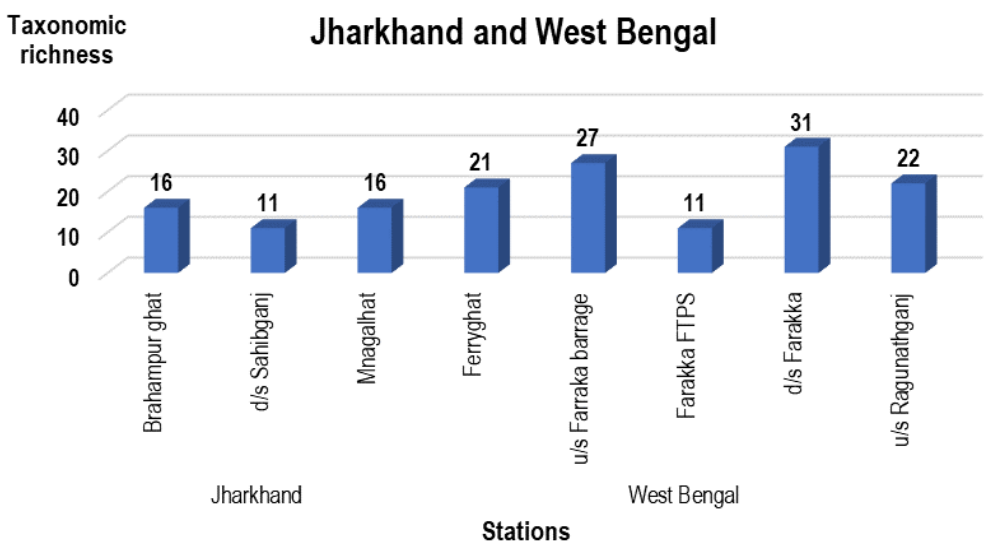


Figure 4.10 Taxonomic richness of macroinvertebrates across various locations along the Ganga River in Jharkhand and West Bengal.

4.3.2 Odonates

4.3.2.a Species Richness and Diversity

During the field survey in 2017-18, a total of 37 species of Odonata, belonging to 26 genera and 6 families were recorded, whereas in 2024-25, a total of 31 species of Odonata belonging to 20 genera and 4 families were recorded (Annexure II).

In 2024-25, the dragonflies (Anisoptera) were represented by 15 species, 13 genera, and 2 families Libellulidae and Gomphidae), and the damselflies (Zygoptera) were represented by 16 species from 7 genera and 2 families (Coenagrionidae and Platycnemididae) (Figure 4.11a). In contrast, during 2017-18, the Anisoptera were represented by 24 species, 18 genera, and 3 families (Aeshnidae, Libellulidae, and Gomphidae), whereas the Zygoptera were represented by 13 species from 8 genera and 3 families (Chlorocyphidae, Coenagrionidae, and Platycnemididae). Libellulidae was the most dominant family and contributed the most species in both years. Aeshnidae was represented by only one species (*Anax guttatus*), which was absent in 2024-25. Within Gomphidae, two species were recorded in 2017-18, whereas only one species was recorded in 2024-25. The suborder Zygoptera comprised three families in 2017-18: Chlorocyphidae, Coenagrionidae, and Platycnemididae, while only two families, Coenagrionidae and Platycnemididae, were recorded in 2024-25. Coenagrionidae dominates the damselfly community, consisting of the highest number of species during both years. Chlorocyphidae was absent during 2024-25 (Figures 4.11a and 4.11b).



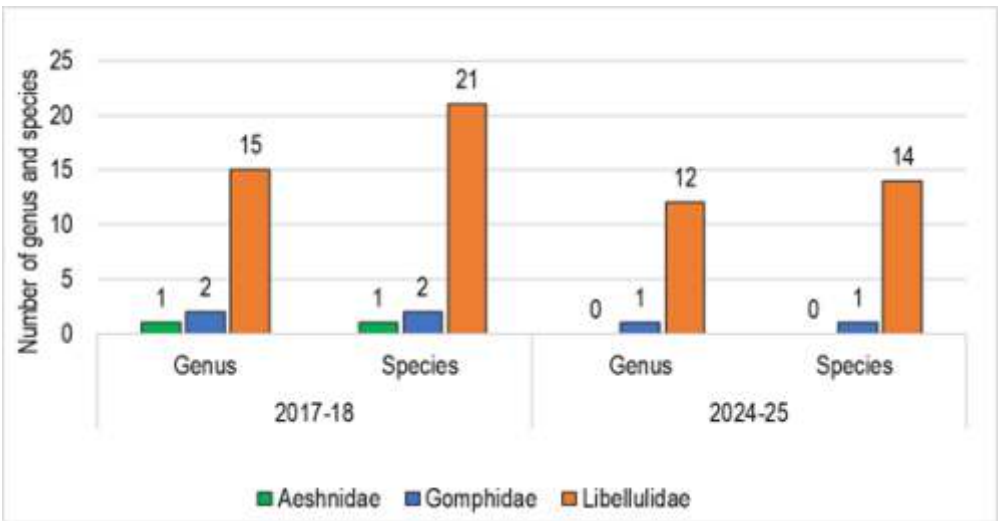


Figure 4.11a Comparative account of the number of genera and species across four families of Dragonflies (Anisoptera) in 2017-18 and 2024-25

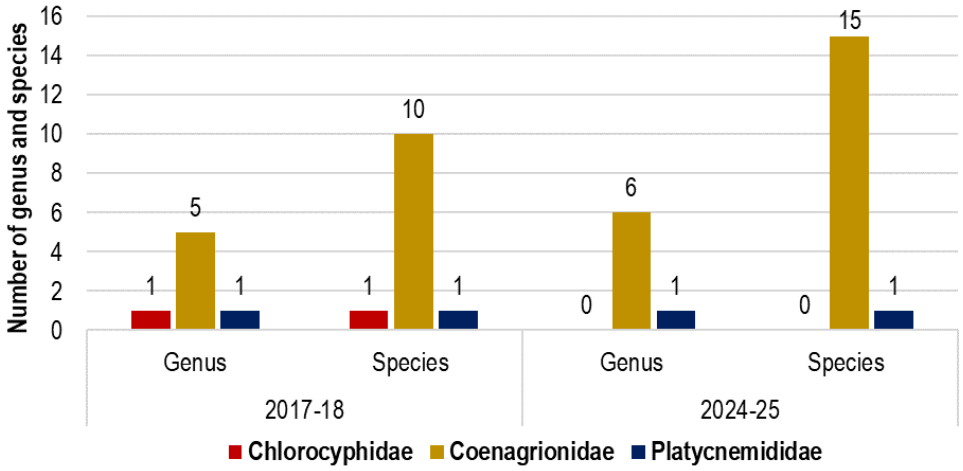


Figure 4.11b Comparative account of the number of genera and species across four families of Damselflies (Zygopetra) in 2017-18 and 2024-25

With respect to species richness across habitat zones, during 2024-25, a total of 23 species belonging to 17 genera were recorded from the habitat zone II, 12 species belonging to 9 genera from habitat zone III, 9 species belonging to 7 genera from habitat zone IV, and only 2 species belonging to 2 genera from habitat zone V were observed, while 5 species belonging to 5 genera were reported from habitat zone VI. In comparison to 2017-18, 27 species belonging to 20 genera were recorded from habitat zone II, 18 species under 14 genera from habitat zone III, 17 species under 12 genera from habitat zone IV, 23 species under 17 genera from habitat zone V, and 22 species from habitat zone VI were recorded. This pattern suggests a decline in species richness across the habitat zones between 2017-18 and 2024-25 (Figures 4.12a and 4.12b). Habitat zone V and Habitat zone VI show a significant decline in species richness, while a moderate decline in habitat zone III and IV occurred during 2024-25. *Crocothemis servilla* and *Trithemis pallidinervis* were the most abundant species of damselfly in habitat zone II, while *Crocothemis servilla* was also recorded as an abundant species in habitat zone IV.



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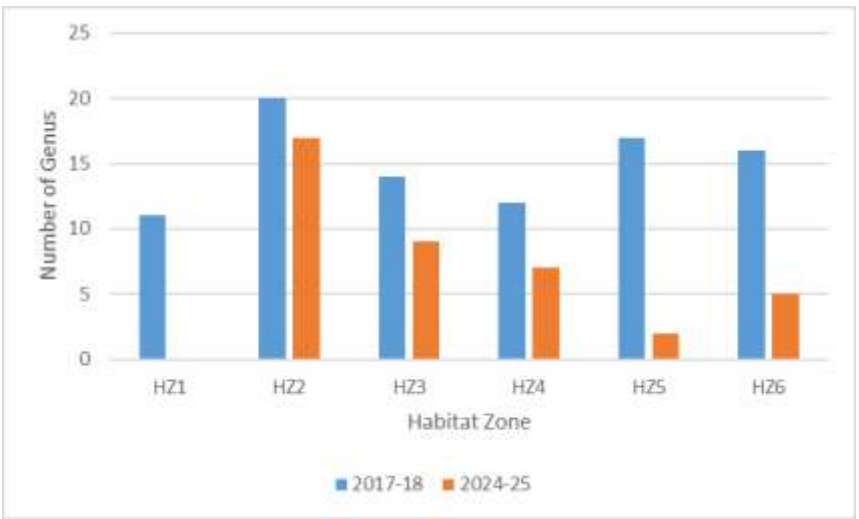


Figure 4.12a Comparative analysis of the number of genera across habitat zones along the Ganga River.

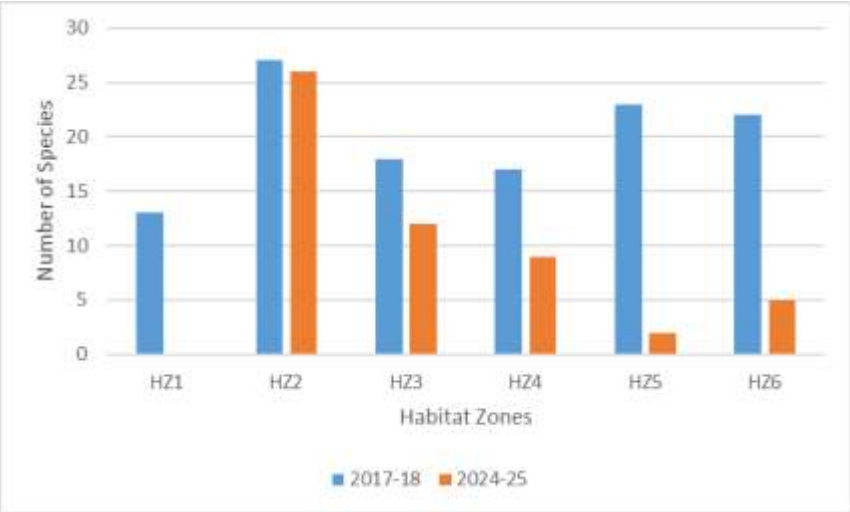


Figure 4.12b Comparative analysis of the number of species across habitat zones along the Ganga River.

During 2024-25, the species richness was lowest at Chila (S4), Haridwar. The mean species richness in the habitat zone III was observed to be 12 ± 8.18, with minimum at S6 (Tigrighat) and maximum at S5 (Bijnor). In the habitat zone III, mean species richness was computed to be 5 ± 2.82, being minimum at S11 (Kanpur) and maximum at S9 (Azibabad) (Figure 4.13). In habitat zone IV, mean richness was found to be 3.25 ± 3.41, and maximum at S13 (Manikpur). The mean species richness was 0.375 ±0.74 in habitat zone V, and maximum at S20 (Ballia) within this zone. In habitat zone 6, the mean was 1.14 ± 1.58, and the maximum was at S28 (Mayapur) (Table 4.2). In 2017-18, the mean species richness was considerably higher across all the habitat zones: 19.67 ± 5.13 in habitat zone II, 9 ± 1.79 in habitat zone III, 8.80 ± 1.83 in habitat zone IV, 10.63 ± 3.85 in habitat zone V, and 9.29 ± 5.19 was recorded from habitat zone VI (Table 4.2). During 2024-25, the diversity was 1.099 at Chilla in Haridwar. The mean Shannon diversity in habitat zone II was 1.845 ±0.64, ranging from a minimum at S6 (Tigrighat) and a maximum at S5 (Bijnor). In habitat zone III, mean diversity was 1.297 ± 0.56; the lowest was at S11 (Kanpur) and the highest at S9 (Azibabad). In habitat zone IV, mean diversity was 0.759 ± 0.78 and maximum at S13 (Manikpur). In habitat zone V, the lowest mean diversity was recorded to be 0.07 ± 0.22, with diversity being 0.636 at S20 (Ballia) within this zone, while in habitat zone VI, the diversity was 0.318 ± 0.44 and maximum at S28 (Azimganj). In contrast, during 2017-18, the mean Shannon diversity index in habitat zone II was 2.76 ± 0.81, in habitat zone III was 1.86 ± 0.30, in habitat zone IV was 1.92 ± 0.20, in habitat zone V 2.11± 0.38, and in habitat zone VI was 1.85 ± 0.59 (Table 4.2). This shows a significant decline in mean diversity between 2017-18 and 2024-25, particularly in the lower stretches of the Ganga River. The species richness and Shannon diversity exhibited a general decline from habitat zone II to habitat zone VI (Table 4.2).



Table 4.2 Summary statistics of species richness and Shannon diversity across the habitat zones of the Ganga River

	Richness (mean ± SD)		Diversity (mean ± SD)	
	2017-18	2024-25	2017-18	2024-25
HZ2	19.67 ± 5.13	11 ± 9.8	2.76 ± 0.30	1.48 ± 1.28
HZ3	9 ±1.83	5 ± 2.83	1.86 ± 0.27	1.29 ± 0.56
HZ4	8.8 ±1.79	3.25 ± 3.4	1.92 ± 0.20	0.76 ± 0.77
HZ5	10.63 ± 3.85	0.38 ± 0.74	2.11 ± 0.38	0.08 ± 0.23
HZ6	9.29 ± 5.19	1.14 ±1.57	1.85 ± 0.59	0.32 ± 0.45

4.3.2.b Hierarchical Cluster Analysis

For 2024-25 survey data, cluster analysis classifies Habitat Zones into two major groups. A small cluster comprises the upper stretch (S5, S7, S9). The remaining sites formed a large cluster consisting of two subclusters, comprising distantly located habitat zones, such as S4-S26, S12-S27, and S11-S18, with S29, which shows similarity in diversity despite spatial separation (Figure 4.13).

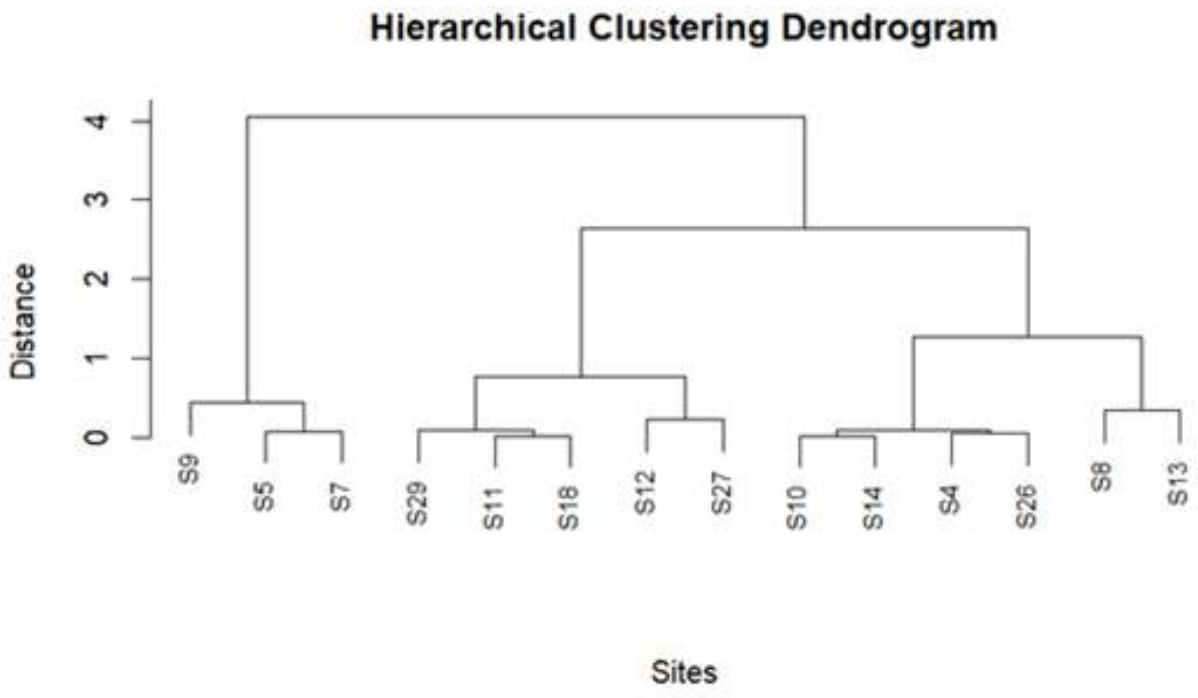


Figure 4.13 The cluster analysis for 2024-25 survey, shows similarity between the stations based on the species diversity.

4.3.2.c Relationship of physicochemical characteristics with Odonate richness and diversity

The correlation coefficient 'r' was examined to understand the influence of selected physical and chemical variables on richness and diversity. The 'r' shows a negative correlation for all the environmental variables, i.e., a decrease in richness and diversity with increasing scale of environmental variables, except conductivity and vice-versa (Table 4.3). The correlation was higher with pH, average flow, water temperature, and average depth, with both richness and diversity, with a stronger correlation observed for diversity.

Richness was found to have a poor relationship with four variables (average width, electrical conductivity, TDS, and salinity) compared with only two variables (average width, electrical conductivity) for species diversity. Among all the variables, pH reflected the strongest negative correlation with both richness (r = 0.565) and diversity (r = -0.669). Average flow (for richness r = -0.44) and (diversity r = 0.5845), Water temperature (r = -0.37 for richness; r = -0.48 for diversity), also showed a high negative correlation. The weaker correlation was observed for average width (r = -0.146 for richness; r = -013 for diversity) and electrical conductivity (r = 0.226 for richness and r = 0.021 for diversity). The relationship of chemical variables with richness and diversity was weak or poor, while it was moderate with physical variables.



Table 4.3 Pearson correlation coefficient (r) between physicochemical characteristics and species richness and diversity (2024-25).

Physical-chemical parameters	Richness (r)	Diversity ®
Water temperature	-0.37	-0.48
Average Flow	-0.44	-0.5845
Average Depth	-0.32	-0.369
Average Width	-0.146	-0.13
Electrical conductivity	0.226	0.021
TDS	-0.123	-0.303
Salinity	-0.15	-0.34
pH	-0.565	-0.669



4.3.2.d Linear Regression

The 'regression coefficient' was positive for electrical conductivity, while negative for other physical and chemical variables (Table 4.4). The regression coefficient (b) was found to be significant for the richness with pH (b = -2.91; R^2 = 0.32; p = 0.003) and average flow (b = - 8.83; R^2 = 0.20; p = 0.027), explaining the variation of 32% and % respectively. Water temperature, average width, depth, conductivity, TDS, and salinity were not significant (p > 0.05) drivers of the richness and each accounted for less than 6% of the variation.

In comparison, species diversity exhibits a stronger relationship with environmental variables than richness. pH (b = -0.56; R^2 = 0.45; p = 3E-04) and average flow (b = -1.89; R^2 = 0.341; p = 0.027), water temperature (b = -0.15; R^2 =0.23; p = 0.015) became a significant negative predictor of diversity and explained the variation of 44.8%, 34.1%, and 23%, respectively. pH was the most influential variable for species diversity compared to richness. The other variables, average width, depth, conductivity, TDS, and salinity, remained insignificant determinants of the diversity and explained less than 13% individually. The linearity was found to increase significantly in the case of diversity, compared to richness. The relationship of some environmental variables included in the analysis is best explained by a polynomial relationship, which shows a lack of significant increase in richness and diversity with the rise in the ionic concentration and physical characteristics. Overall, an increase in pH and average flow results in an increase in richness and diversity, especially in diversity.

Table 4.4 Regression coefficients and significance value (p) for the relationship of species richness and diversity dependent variable with physical and chemical variables as explanatory variables for 2024-25.

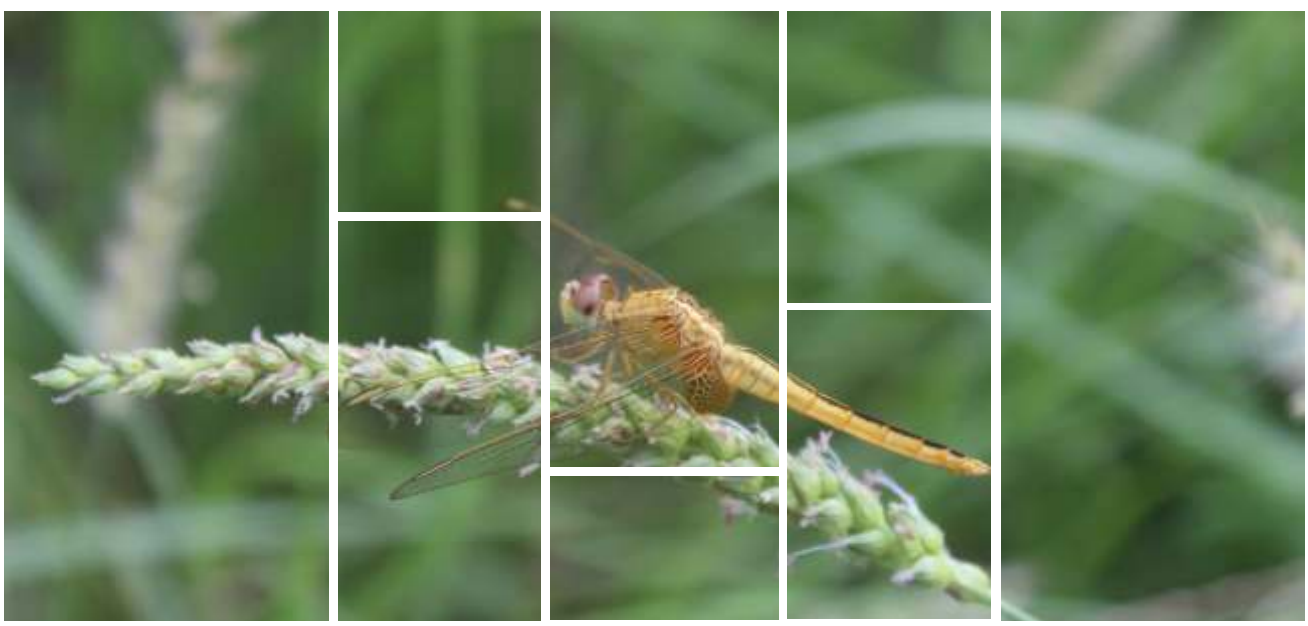
Environmental Variables	Species Richness				Species Diversity			
	Coefficient 'b'	R^2	Std Error	p-value	Coefficient 'b'	R^2	Std Error	p-value
Water Temp	-0.74	0.137	0.386	0.067	-0.15	0.23	0.059	0.015
Average Width	-0.003	0.021	0.004	0.483	-0.000	0.017	0.001	0.526
Average Depth	-0.25	0.103	0.155	0.118	-0.046	0.129	0.024	0.077
Average Flow	-8.83	0.195	3.743	0.027	-1.889	0.341	0.546	0.002
pH	-2.91	0.32	0.885	0.003	-0.556	0.448	0.129	3E-04
Conductivity	0.011	0.051	0.01	0.278	0.000	0.000	0.001	0.919
TDS	-0.01	0.015	0.015	0.559	-0.003	0.092	0.002	0.141
Salinity	-1.53	0.023	207	0.47	-55.8	0.12	31.8	0.09

*Statistically significant predictors ($p < 0.05$) are presented in bold.

For both the survey time periods, the pH was the only parameter which significantly affected the species richness and diversity (Table 4.6). Whereas, in 2017-18, electrical conductivity, TDS, and salinity had significant linear relationship with the species richness and diversity (Table 4.5).

Table 4.5 Comparative regression coefficients and significance value (p) for the relationship of species richness and diversity dependent variable with physical and chemical variables for 2017-18 and 2024-25 surveys

Physical-chemical parameters	Species Richness				Species Diversity			
	2017-18		2024-25		2017-18		2024-25	
	R^2	p value	R^2	p value	R^2	p value	R^2	p value
Temperature (°C)	0.02	0.29	0.137	0.067	0.03	0.43	0.23	0.015
pH	0.39	0.003	0.32	0.003	0.30	0.01	0.448	3E-04
Electrical conductivity	0.27	0.02	0.051	0.278	0.20	0.05	0.000	0.919
TDS (mg/L)	0.28	0.02	0.015	0.559	0.21	0.04	0.092	0.141
Salinity (ppt)	0.29	0.01	0.023	0.47	0.23	0.03	0.12	0.09





4.4 DISCUSSION

Among the invertebrates, arthropods, followed by molluscs, are the most diverse aquatic fauna of the Ganga River. The distribution of benthic macro-invertebrates from the entire stretch of the Ganga River from Gaumukh to Farakka indicated the dominance of Arthropoda gradually reduced from upstream to downstream. Contrarily, the percentage of Mollusca and Annelids increased from upstream to downstream reaches of the River. Baetidae, Chironomidae, Dytiscidae, Corbiculidae, Physidae, Gomphidae, Corixidae, and Hydrophilidae are the most widespread families. Baetidae are restricted to the upper and middle stretches of the river. Chironomidae are the most prevalent, found at 64 stations in the Ganga river from Uttarakhand to West Bengal.

The increasing taxonomic richness of annelids and molluscs in the foothill stretches of Bhagirathi-Ganga reported from recent investigations indicated the suitability of their habitat in this section of the river. It means that the habitats of Ephemeroptera, Plecoptera, and Trichoptera gradually diminish in this section. The annelid and mollusc are soft-bodied animals that are mainly burrowers and typically inhabit soft sediments (silt, clay, and sand). In mountain rivers such as the Bhagirathi-Ganga, the hydro-power projects impede the flushing of fine sediments and create a bed of soft sediments in the impounded stretch, suitable for colonization by worms and molluscs. Thus, the modified hydrological regime caused by a series of dams can facilitate the upward ascent of these invertebrates.

In the mountain zone, there is considerable similarity in the fauna among the stations over the years. However, there is a decline in the taxonomic richness between 1994 and 2023 at Gangotri, Uttarkashi Dharasu, and Devprayag. The mountain zone of the Bhagirathi-Ganga has witnessed mega-development over the last three decades and these locations have been under direct stress. Gangotri experienced a significant reduction and variation in richness from 6 taxa in 2010 to 3 taxa in 2023 (Nautiyal, 2010; Sharma et al., 2023). In recent years, entirely different families (Sharma et al., 2023) were reported at Gangotri. The presence of Baetidae at Gangotri and Devprayag during recent years is noteworthy. Baetidae is a widespread and abundant family. However, the Baetidae family has been given a BMWP score of 4, which indicates that this group is moderately tolerant towards organic pollution. This points to a general decline in water quality. At Uttarkashi, 15 families were recorded during 1994, while only 5 families were reported during 2021.

Currently, Uttarkashi receives variable flow throughout the year due to regulation by Maneri Bhali Stage II Powerhouse, thus causing desiccation and flooding in this stretch of the river. Similarly, at Dharasu, there is a decrease from 21 taxa in 1994 to 13 taxa in 2019, in which Ephemerellidae, Ephemeridae, Perlodidae, etc., were absent in recent years. Devprayag shows the most dramatic shift, with a steep decline from 13 taxa in 1994 to only 2 taxa in 2019 (Singh et al., 1994; Kumar & Nautiyal, 2019). The consistent presence of Chironomidae and Baetidae families across all stations during most of the investigations shows increasing general organic enrichment in the river. Singh & Nautiyal (1990) reported



enhanced Chironomidae larvae due to sewage from urbanized Uttarkashi. In foothill stretches, taxonomic richness declines from 29 to 23 at Haridwar barrage.

In the Bhagirathi Maneri-Bhali Stage, I became operational at Maneri in 1984. Tehri Dam and Maneri Bhali Stage II became operational by the year 2006. The reduction in taxonomic richness of the macroinvertebrate community is the consequence of hydropower development in the upper section of the Ganga. The river habitat became fragmented, leading to a disturbed hydrological regime. The river downstream the dam was deprived of flow, and impounded sections were modified into deep water columns, disturbing the continuum of flow, nutrients, sediments, and dissolved oxygen so necessary for biota and its diversity. The flushing function of the river is severely hampered. The section with a deepwater column is characterized by deposits of soft sediments not suitable for flora and fauna with clinging or adhesive habits. Here, the burrowing forms tend to flourish. In the case of the stretch below the dam, the swift-turbulent (riffles) sections turn into flow-deficient sections consisting of shallow pools characterized by slow-moving water. Here, the bottom is mostly represented by the large-sized hard substrate. In the case of the foothill stretch of the river in Uttarakhand from Rishikesh to Haridwar the river is fragmented by two barrages, while the flow is the main concern in the Ganga from Gangotri to Haridwar, the presence of Naucoridae and Physidae indicates high organic pollution in this section of the river from recent investigation (CPCB, 2017).

The presence of an insect community such as the Baetidae, Heptageniidae, Chironomidae, and Ephemerellidae characterizes the upper stretches of the river. Some of them and other families, such as Brachycentridae and Perlodidae, are indicative of clean and less polluted waters. However, in this segment, a decline in taxonomic richness and an increase in tolerant families over decades reflect the impact of flow regulation and habitat fragmentation due to irrigation and hydroelectric projects. The foothill stretch from Rishikesh to Haridwar shows an increase in the number of annelid and molluscan families, attributable to sedimentation and increasing organic load in this segment.

In the middle stretches of the river, tolerant families such as Chironomidae appeared more frequently. In this stretch, sensitive families such as Heptageniidae, Ephemerellidae, and others decrease slightly, while tolerant families within Mollusca (Lymnaeidae, Physidae, Planorbidae) and Annelids (Glossiphonidae, Lumbricidae), and in insects such as Dytiscidae, Corixidae, Gerridae, begin to appear frequently, compared upper stretches of the Ganga river. This is attributable to the wide alluvial Plains where soft sediments form the river-bed compared with the stony bed in the mountains. Thus, the forms that can burrow increase in number, leading to an increase in the annelid diversity. The soft sediments are rich in organic matter, thus providing a variety of food resources to the molluscan fauna, which leads to a more terrestrial rather than aquatic mode of life. The invertebrate fauna shows organically enriched waters indicated by the presence of Chironomids.

The lower stretches of the river, Bihar, Jharkhand, Gomphidae, constitute the common insect fauna in this stretch of the river. A significant reduction in the insect families of Ephemeroptera, Diptera, and Trichoptera was observed, while the families of Plecoptera were completely absent compared to the upper and middle stretches of the river. The lower part of the plains is characterised by the abundance of Corbiculidae and Physidae. The composition of fauna indicates habitat degradation due to anthropogenic stressors from multiple sources.

The studies on macroinvertebrates in the Ganga River, particularly in the middle and lower stretches, remain limited compared to studies in Uttarakhand (upper stretches of the Ganga river). Although some investigations have been carried out, they are often fragmented and location-specific. The conclusions can





only be suggestive with the available information on macroinvertebrate fauna. In the absence of knowledge on temporal variations, it would be unwise to draw sound conclusions for the middle and lower segments of the Ganga in the alluvial Plains. The significant lack of studies in the lower stretches of the river suggests further investigations in this stretch of the river, particularly for macroinvertebrate fauna.

During the recent survey (2024-25) 31 species of Odonata were recorded, compared to 37 species reported in the previous survey (2017-18) at the same sampling locations. Despite the slight reduction in the total number of species, the Bijnor and Narora segments of the Ganga River still reflect the relatively high biodiversity. These two sites are part of the Hastinapur Wildlife Sanctuary. Protected stretches thus provide a better habitat for the Odonate community, reflecting the ecological importance of Protected Areas for supporting high biodiversity. This is also consistent with the previous studies conducted during 2017-18 in the Ganga River, which reported high diversity in this stretch of the river.

The diversity was found to be moderate at three stations, Kacchla Ghat (1.487), Azibabad (1.97), and Manikpur (1.71), in the Bijnor and Narora segments of the Ganga River. This diversity was possibly influenced by the presence of backwaters around Azibabad and Kacchla ghat, and riparian habitats around Manikpur, which are known to play an important role in shaping Odonate communities (Elango et al., 2021; Cheri & Finn, 2023). However, ubiquitous species prevail in disturbed or temporary waters, while sensitive, often localised species are found in pristine streams, seepage, and swamp forests (Clausnitzer et al., 2009).

A decline in diversity was observed downstream of Azibabad, including cities of Kanpur, Kannauj, and Prayagraj, known for high-level anthropogenic disturbances and severe pollution. A noticeable decline occurred in the species richness from Bijnor to Prayagraj. Further, the downstream section was devoid of Odonata fauna.

The cluster analysis highlights this ecological gradient by grouping Bijnor and Narora, both protected sites, into a single cluster, while pairing ecologically distant locations into common clusters. This shows a disruption in the longitudinal continuum in the downstream section of the river, likely due to disturbed riverine gradients, particularly at locations with increased human interference. Several studies linked the decline in richness and diversity due multiple factors, such as flow alterations due to barrages and dams, increasing pollution, and loss of riparian habitat (Kalkman et al., 2008; de Oliveira-Junior et al., 2017; Adu et al., 2022; Manu et al., 2023). However, seasonal variation could also be an important factor contributing to the low diversity at these sites (Tuhin, 2019). As the timing of surveys greatly influences species count and diversity estimate, the seasonal samples should be given careful consideration when assessing the long-term trends.

Environmental variables play a crucial role in shaping odonate diversity and distribution. In this study, the coefficient of linear regression was found to be positive only for the electrical conductivity. Hence, species

diversity and richness tend to increase with an increase in electrical conductivity, though not significantly. Contrastingly, all other environmental variables show a negative correlation with these community features, indicating a decrease in richness and diversity with increasing scale of environmental variables and vice versa. Among these, the relationship was significant for water temperature, pH, and average flow. Similar trends were observed for the correlation coefficient. The level of significance was higher for species diversity compared to species richness. This suggests that while the number of species may remain relatively stable under changing conditions, the species diversity patterns are more sensitive (Simaika & Samways, 2012). These are important variables for the Odonate community and are hence identified as key drivers of the community. These findings are consistent with previous studies that have demonstrated the sensitivity of the Odonate community to water thermal and chemical gradients in freshwater ecosystems (Ndaruga et al., 2004; Popoola & Otalekor, 2011; Ishak et al., 2021).

Among the reported families, Libellulidae and Coenagrionidae were found to be abundant in the study area. These families are well known for their tolerance to disturbed habitats, often occupying a wide range of habitats (Vick 2003; Suhling et al., 2004; Adu et al., 2022). In this study, *Crocothemis servilla* and *Orthetrum sabina* of the family Libellulidae were recorded across nearly all the habitat zones. These species are known for their wide distribution across India and adaptability to a range of habitat conditions are well documented (Singh et al., 2017; Kumar et al., 2018; Aghade et al., 2022). Notably, *Trithemis pallidinervis* was the abundant species in the habitat zone II, this species was not recorded from previous findings. Mokaria & Jethva (2019) recorded this species from open water with emergent vegetation, which may explain its presence, particularly in Bijnor. Within Coenagrionidae, *Agriocnemis pygmaea* was common across habitats and known for its widespread distribution (Nicolla et al., 2021), while *Ceriagrion cerinorubellum* was also recorded at several sites, particularly from Bijnore to Kannuj, although in low abundance. This species was reported to be an indicator of degraded water quality (Jacob et al., 2017).

In contrast, only one species (*Ictinogomphus rapax*, *Calicnemia eximia*) of the family Gomphidae and Platycnemididae respectively, was accounted for during the study. The species of the family Gomphidae rarely occur in large numbers (Acquah-Lamptey et al., 2013). Clausnitzer (2003) noted that they hunt above streams and along forest paths at dusk, possibly contributing to their low encounter rates.





CONCLUSION

This comprehensive review report will create a baseline for future investigations by consolidating the knowledge and identifying key trends, while bio-assessment could reveal the precise nature of stress, such as industrial pollution, organic load, irrigation, and hydropower operations. Odonates inhabit a variety of aquatic environments, including seeps, brooks, streams, pools, ponds, reservoirs, lakes, marshes, and ephemeral pools (Beaune & Sellier, 2021). Most odonate larvae are found in still or slow-moving waters, like lentic-littoral and lotic-depositional habitats. Fewer occur in fast-flowing, lotic-erosional habitats. While some families are highly adaptable and thriving in nearly all the aforementioned habitats, others require a more selective habitat preference (Adeleke et al., 2024). Despite a well-documented adult taxonomy of the Indian odonate fauna, its ecology and distribution remain poorly known (Chandran et al., 2025).

The concerns over the conservation status of Odonata are gradually growing in India. The current IUCN Red List Assessment (2026) categorizes two Endangered, fifteen Vulnerable, and eight Near Threatened species from India, emphasizing the vulnerability of these taxa to habitat loss and environmental degradation. Although all the species reported in this study fall into the category of Least Concern (LC).

In light of their ecological importance, the Odonata can serve as bioindicators of freshwater ecosystem health. Decline in species richness and diversity signals broader ecological stress within riverine systems such as the Ganga. Therefore, long-term, wide-scale monitoring of odonate diversity and distribution is critical for preserving not only these species, but the broader ecosystems as well. Long-term conservation of Odonata and other freshwater biota can be achieved through an appropriate freshwater biodiversity conservation programme

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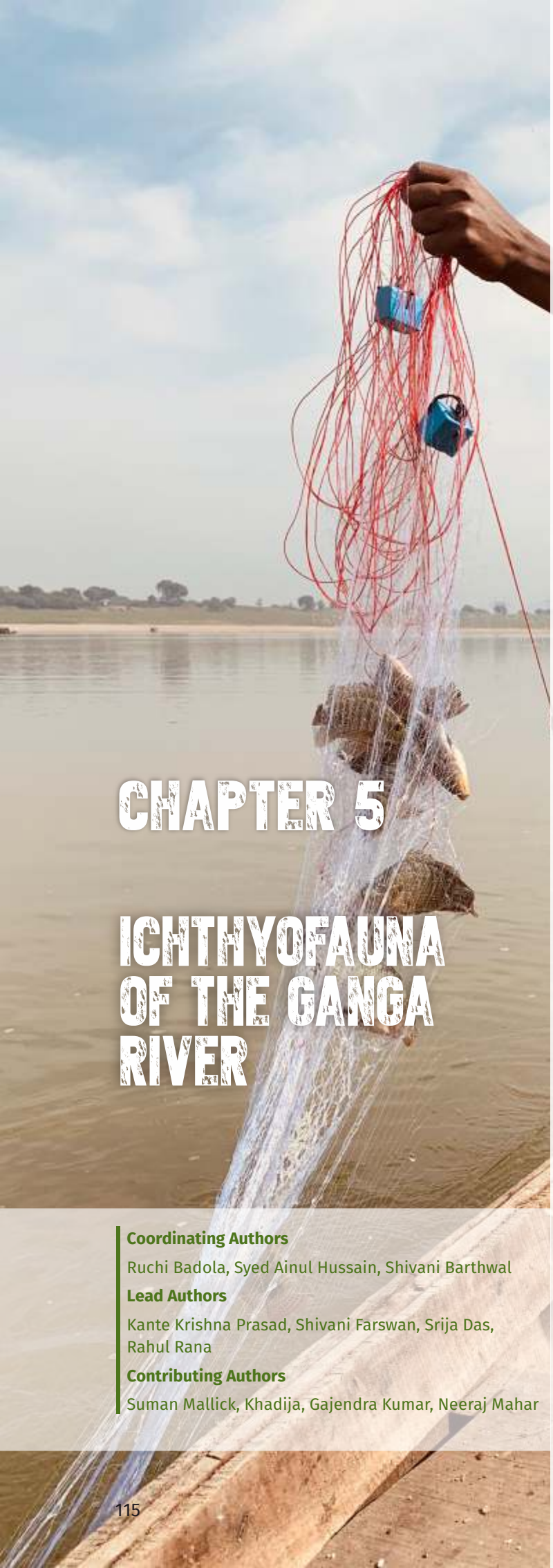
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CHAPTER 5

ICHTHYOFAUNA OF THE GANGA RIVER

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SUMMARY

Fishes are known to respond rapidly to alterations in water quality, habitat structure, and flow regimes through physiological and behavioural adaptations, making them reliable indicators of ecosystem health. In the Indian context, riverine ecosystems form a critical component of biodiversity conservation, and among these, the Ganga River stands out as one of the most ecologically, culturally, and economically significant river systems. Historically, the ichthyofaunal diversity of the Ganga River has been extensively documented, with early accounts reporting over 270 species, and subsequent studies indicating fluctuations in species richness due to methodological differences, spatial coverage, and anthropogenic pressures. Over time, evidence suggests not only variation in species richness but also shifts in community composition, including a decline in commercially important species and an increase in invasive species.

The present study provides a comprehensive assessment of fish diversity along the mainstem Ganga River, covering a gradient from Mukhba (Uttarakhand) to Haldia (West Bengal). The river was stratified into six habitat zones based on topographical and ecological characteristics, enabling a systematic evaluation of spatial patterns in fish diversity. Sampling across 32 sites using standardized fishing methods, including gill nets, cast nets, and drag nets, ensured robust data collection. The integration of field sampling with market surveys further enhanced species detection, particularly for rare or elusive taxa. Quantitative measures such as Catch Per Unit Effort (CPUE), alongside different diversity indices provided insights into community structure and ecological stability. The results revealed significant spatio-temporal variability in fish diversity across the three survey years (2019, 2023 & 2024). In 2019, the Ganga River exhibited relatively high biodiversity, with 125 species recorded, dominated by native taxa, which was characterized by low dominance, high diversity, and high evenness across most zones, indicating stable and healthy ecological conditions. Cypriniformes and Siluriformes emerged as the most species-rich orders, with Cyprinidae being the dominant family—consistent with the known ecological dominance of carps in Indian rivers. However, the 2023 survey indicated a marked decline in species richness (56 species), accompanied by increased dominance and reduced diversity in several zones. The decline in diversity indices and evenness indicated ecosystem stress and reduced resilience during this period. However, the 2024 survey demonstrated partial increase in richness, with 114 species recorded and improved

diversity metrics in several zones. Although not fully restored to 2019 levels, the observed increase in species richness and CPUE suggests a degree of ecological resilience and recovery. This recovery may be attributed to improved environmental conditions, management interventions, or natural system dynamics.

Dominance patterns changed across years and zones, with different species emerging as abundant in different periods. Such shifts may reflect changes in habitat quality, resource availability, or competitive interactions. Environmental variables played a variable role in shaping fish diversity. In 2019, water temperature was the only significant predictor of diversity, whereas no significant relationships were observed in 2023. In 2024, variables such as flow, depth, and elevation showed stronger associations with diversity, of which elevation had significantly negative associated with diversity. The occurrence of endangered species such as *Tor putitora* in the upper stretches highlights the ecological importance of these habitats. Similarly, the detection of vulnerable species and the presence of apex predators such as the bull shark in the estuarine zone emphasize the ecological connectivity of the river system. However, the restricted distribution of many threatened species indicates habitat specialization and vulnerability to environmental changes. The proliferation of invasive species represents an additional concern. Species such as *Cyprinus carpio* and *Oreochromis niloticus* were widely distributed and abundant, potentially competing with native species for resources. The expansion of invasive species across multiple habitat zones highlights the need for effective management measures. Overall, the study demonstrates that the Ganga River supports a rich but dynamic ichthyofaunal community shaped by both natural gradients and anthropogenic influences. These findings underscore the importance of long-term monitoring, habitat conservation, and sustainable management to preserve the ecological health of the Ganga River system.

5.1 INTRODUCTION

Aquatic ecosystems are essential natural assets that support unique biotic communities, including aquatic plants, ichthyofauna, macroinvertebrates, and microbial communities. Ichthyofauna are particularly sensitive to habitat changes and serve as effective bioindicators of aquatic ecosystem health, responding physiologically and behaviourally to environmental disturbances (Schiemer, 2000; Kang et al., 2009). Apart from a diverse coastline (Nayak, 2017), the Indian landscape is intersected by numerous rivers that flow east and west (Jain et al., 2007; Singh, 2018). Recognized as a biodiversity hotspot, India significantly contributes to aquatic ecosystems through its extensive river networks (Lakra et al., 2010). The Ganga River, the country's largest river system, exemplifies this ecological importance by preserving cultural heritage and supporting socioeconomic activities through its rich diversity of endemic fish populations and ecosystem services. The rich ichthyofaunal diversity of the Ganga River is dominated by various families of freshwater fish such as Cyprinidae, Bagridae, Schilbidae and Sisoridae (Das et al., 2013; Koushlesh et al., 2021). The Ganga River descends from the glaciers of Gangotri, flows through the alluvial plains, and finally drains into the Bay of Bengal through the delta of the Sundarbans (Rudra, 2018) offering diverse habitats which contributes to rich ichthyofaunal diversity of the river.

The first detailed study of fish diversity in the Ganga River was published by Hamilton (1822), documenting 272 fish species (Table 5.1). Later, Francis Day (1888) catalogued 1,340 fish species in 342 genera from India, many of which were linked to the Ganga River. Menon (1974) through his consolidated efforts, listed 207 fish species from the upper Ganga to the downstream estuary of the Ganga River (Hooghly). Venkateswarlu & Menon (1979) compiled a taxonomic checklist of 264 fish species found in the Ganga River. Bilgrami (1991) reported 97 freshwater fish species across three stretches of the Ganga River- from Kalankar to Phaphamau, Buxar to Barh, and Munger to Farakka. A comprehensive study by Talwar (1991) recorded 375 species, including both freshwater and brackish-water species, across the entire Ganga River. In the same year, Talwar & Jhingran (1991) listed 266 species in the entire Ganga basin, of which 158 were freshwater and 108 marine species. Sinha et al. (1998) recorded 140 fish species from the Ganga River along the Rishikesh-Dakshineshwar stretch.

In the 21st century, Payne et al. (2004) reported 161 fish species from the Ganga River (Table 5.1). Vass et al. (2008) identified 140 commercially important fish species, whereas Vass et al. (2010) noted a decline in fish diversity, reporting only 47 commercially significant species. Their study also highlighted shifts in species composition, favouring non-major carps and miscellaneous species, as well as an increasing presence of exotic species in the river stretch. Thereafter, Das et al. (2010) listed 147 fish species from the Ganga River, while a subsequent study by Pathak and Tyagi (2010) reported 95 fish species from the glacier fade headwater zone of the Ganga River. A detailed description and biogeographic distribution of 143 fish species belonging to 72 genera and 32 families were reported by Sarkar et al. (2012), extending from Gangotri to Hooghly, emphasising the river's freshwater zone. Mathur et al. (2012) identified 294 fish species along the Ganga River, including 181 freshwater fish species from Gangnani to Farakka belonging to 89 genera and 37 families, 103 brackish water fish species from the Hooghly-Matlah estuary belonging to 67 families of Osteichthyes, and 13 species belonging to 7 families of Chondrichthyes.

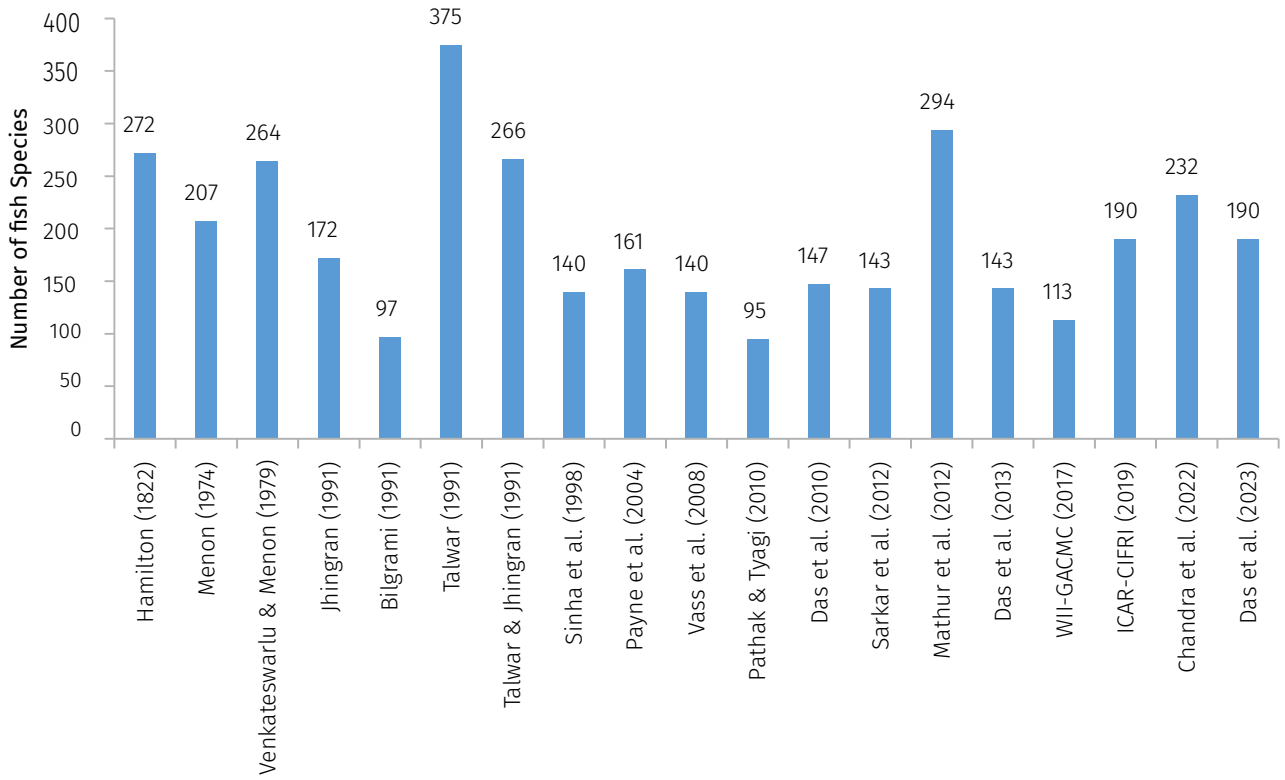


Figure 5.1 Fish abundance documented by previous studies in the Ganga River (1822-2023)

Furthermore, Das et al. (2013) recorded a total of 143 species from 40 families and 92 genera across the entire stretch of the Ganga River (Table 5.1). WII-GACMC (2017) reported 113 fish species from the Ganga River, including 56 species from Devprayag to Rishikesh, 80 species from Makdumpur to Narora, 50 species from Bhitaura to Ghazipur, 61 fish species from Chhapra to Kahalgaon, 89 fish species from Sahibganj to Rajmahal, and 25 fish species from Baharampur to Barrackpore. A recent study by Das et al. (2023) reported a total of 190 fish species (182 indigenous and 8 exotics) belonging to 133 genera, 62 families, and 23 orders from Harsil in upper Ganga stretch to the river mouth of the Hooghly estuary at Fraserganj.



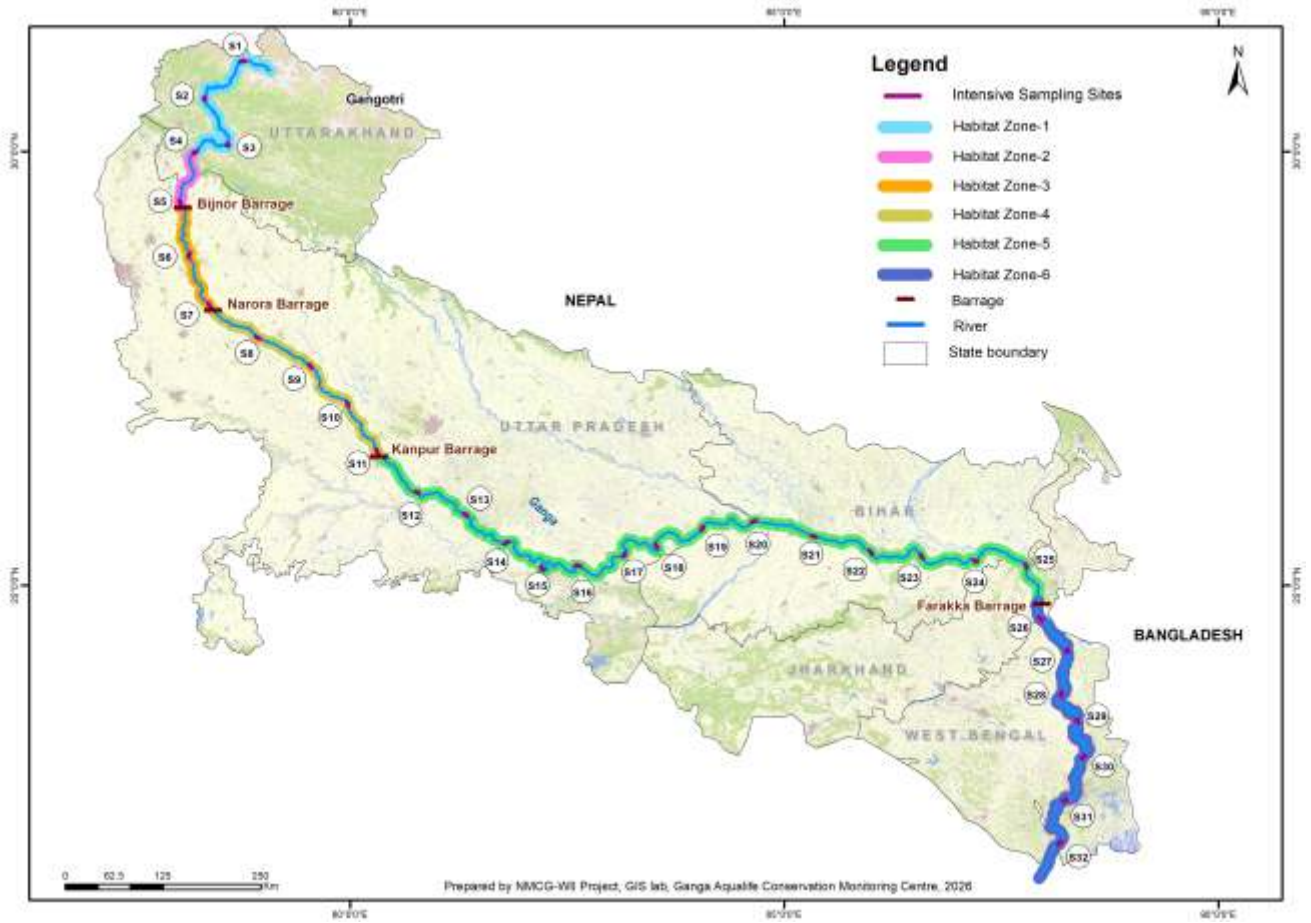


Figure 5.2 Sampling locations in different zones along the main course of the Ganga River



5.2 METHODS

Based on different topographical, geographical and ecological features, Ganga River was categorised into six zones i.e., i) Zone 1 (Mukhba, UK to Haridwar, UK), ii) Zone 2 (Bijnor, UP to Narora, UP), iii) Zone 3 (Kasganj, UP to Kanpur, UP), iv) Zone 4 (Fatehpur, UP to Varanasi, UP), v) Zone 5 (Ghazipur, UP to Sahibganj, JH) and vi) Zone 6 (Balliaghati, WB to Falta Haldia, WB) for fish diversity assessment (Figure 5.2). Altogether, 32 sampling sites were selected throughout the course of the river. Sampling sites were selected at every 75 km, representing all six zones. Surveys were carried out in 2019, 2023 and 2024 along the Ganga River. Intensive fish sampling was conducted in each sites using the mono-filamentous gill net of varying mesh sizes measuring from 1–6 inches (50m long and 3m wide), which were operated depending on the river depth and width conditions. Cast nets and drag nets were also used, depending on the condition of the habitat. An average of 4 hours of net effort was applied at all the intensive sampling sites. Samples were collected at all sites during morning time (06:00–9:00) and evening time (16:00–18:00). Fish samples were also collected from fish markets established at the bank of the river. Photographs were taken before preservation for identification. Fish specimens were preserved in 7–10% formalin for further study in the laboratory. Fish were correctly tagged and morphological details such as

length, weight, and body depth were noted before preservation. Fish abundance was estimated using the standard Catch Per Unit Effort (CPUE) method, expressed as individuals per panel hour (Musick & Bonfil, 2005). Habitat parameters such as river width were measured with a range finder, depth was recorded using a Hondex depth sounder Model-PS-7, and flow was measured with the Geopack Advanced River Pack digital flow meter. Physicochemical parameters were recorded using a YSI Ecosense digital handheld multiparameter. The conservation status is followed by IUCN (2025). Diversity indices were calculated by PAST software (Past version 5.2.2) and other data analysis in Microsoft Excel.

Fish were identified up to species level based on their morphometric and meristic characteristics in the field, and those that could not be identified in the field were identified in the laboratory. Preserved fish samples were determined using the following taxonomical keys of Day (1878), Jayaram (1981, 1999, 2010), and Talwar & Jhingran (1991); and electronic versions of Fishbase (Froese & Pauly, 2025) and Eschmeyer's Catalog of Fishes (Fricke et al., 2026).

5.3 RESULTS

5.3.1 Richness and Diversity

A total of 2138 individuals of 125 species belonging to 85 genera, 41 families and 15 orders were recorded across all 32 sites of the Ganga River in 2019 (Figure 5.2; Annexure II). Of the 125 species, 117 were native 8 were invasive, 4 species were unidentified and 4 species were synonymized, as per Eschmeyer's Catalog of Fishes. In 2023, a total of 56 fish species belonging to 11 orders, 22 families and 43 genera were recorded. Among these 56 species, 54 species were native, and two species *Cyprinus carpio* and *Hypophthalmichthys molitrix* were invasive, while in 2024, a total of 114 species belonging to 15 orders, 37 families and 81 genera were recorded across all 32 sites. Among the total fish species, 107 species were native to the Ganga River, and seven were invasive fish species, including *Cyprinus carpio, Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Hypophthalmichthys nobilis*, *Oreochromis niloticus*, *Pterygoplichthys disjunctivus*, and *Salmo trutta.* In the 2024 assessment of the Ganga River, the occurrence of the vulnerable species, Bull shark (*Carcharhinus leucas*), in the Hooghly estuary highlighted the significance of the threatened species in the Ganga River. In 2019, *L. cutcutia* was recorded from upstream of the Bijnor barrage, representing a new distribution range for this species in the Ganga River.

In 2019, most diverse order was Cypriniformes (50), followed by Siluriformes (32), Anabantiformes (8), Mugiliformes (7), Clupeiformes (5), Synbranchiformes (4), Acanthuriformes (3), Gobiiformes (3), Carangiformes (2), and Osteoglossiformes (2). The least diverse orders were Anguilliformes, Beloniformes, Cichliformes, Salmoniformes and Tetraodontiformes with each order accounting for one species (Figure 5.3). The species diversity among the families, Cyprinidae (28), being the most abundant family, followed by Danionidae (13), Sisoridae (9), Bagridae (6), Ailiidae (5), and Ambassidae (4). Dorsomatidae, Channidae, Mastacembelidae, Siluridae, Ambassidae, Dorosomatidae, Mastacembelidae and Xenocyprididae each family accounting for three species, whereas Botiidae, Cobitidae, Engraulidae, Nemacheilidae, Notopteridae, Osphronemidae and Sciaenidae each accounting for two species (Figure 5.3). Low diversity, i.e. only one species, was recorded for Amblycipitidae, Anabantidae, Ariidae, Belonidae, Badidae, Cichlidae, Chacidae, Cynoglossidae, Eleotridae, Gobiidae, Horabagridae, Loricariidae, Nandidae, Oxudercidae, Polynemidae, Ritidae, Salmonidae, Synbranchidae, Scatophagidae, and Tetraodontidae.

In 2023, most diverse order was Cypriniformes (25), followed by Siluriformes (14), Anabantiformes (4), Mugiliformes (4), Clupeiformes (3). The least diverse orders were Acanthuriformes, Beloniformes, Carangiformes, Gobiiformes, Osteoglossiformes, Synbranchiformes with each order accounting for one species (Figure 5.3). Whereas the most abundant family was Cyprinidae (18), followed by Danionidae (5), Bagridae (4), Ailiidae (4), Channidae (3) and Ambassidae, Dorosomatidae, Clariidae, Mugilidae and Siluridae, each family accounting for three species (Figure 5.4). Low diversity, i.e. only one percent, was recorded among the following families: Botiidae, Belonidae, Cynoglossidae, Engraulidae, Gobiidae, Mastacembelidae, Notopteridae, Nandidae, Sisoridae, Sciaenidae, Ritidae and Xenocyprididae.

In 2024, the most diverse order was Cypriniformes (49), followed by Siluriformes (27), Anabantiformes (8), Clupeiformes (5), Mugiliformes (5), Acanthuriformes (4), Gobiiformes (4), Synbranchiformes (3), Carangiformes (2), and Osteoglossiformes (2). The least diverse orders were Anguilliformes, Beloniformes, Cichliformes, and Salmoniformes, with each order accounting for one species (Figure 5.3). Whereas the most abundant family was Cyprinidae (25), followed by Danionidae (12), Ailiidae (7), Bagridae (6), Sisoridae (5), Nemacheilidae (5), Channidae (4), Siluridae (4) and Ambassidae, Dorosomatidae, Mastacembelidae, Oxudercidae, Sciaenidae, Xenocyprididae each family accounting for three species, Botiidae, Engraulidae, Mugilidae, Notopteridae and Osphronemidae each accounting for two species (Figure 5.4). Low diversity, i.e. only one species, was recorded for Anabantidae, Ariidae, Belonidae, Carcharhinidae, Cichlidae, Cobitidae, Clariidae, Horabagridae, Latidae, Loricariidae, Nandidae, Ophichthidae, Polynemidae, Psilorhynchidae, Ritidae, Salmonidae, and Sillaginidae. The pattern of species richness, abundance was similar across the three sampling years.

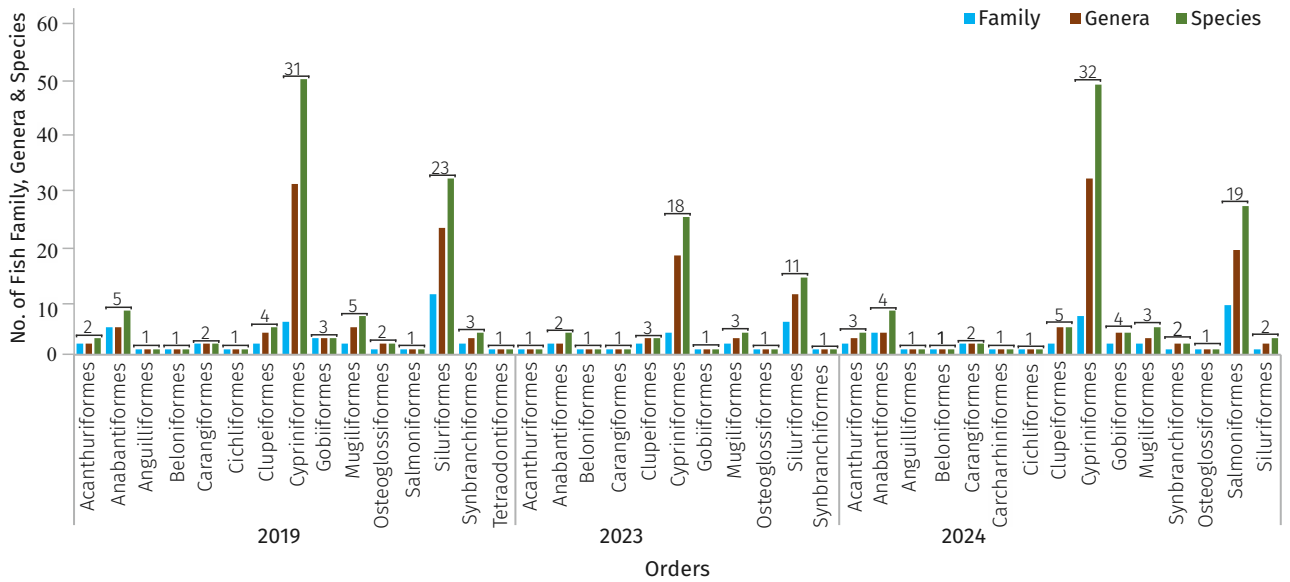


Figure 5.3 Species richness, families, and genera were recorded among the orders during the survey of Ganga River in 2019, 2023 and 2024

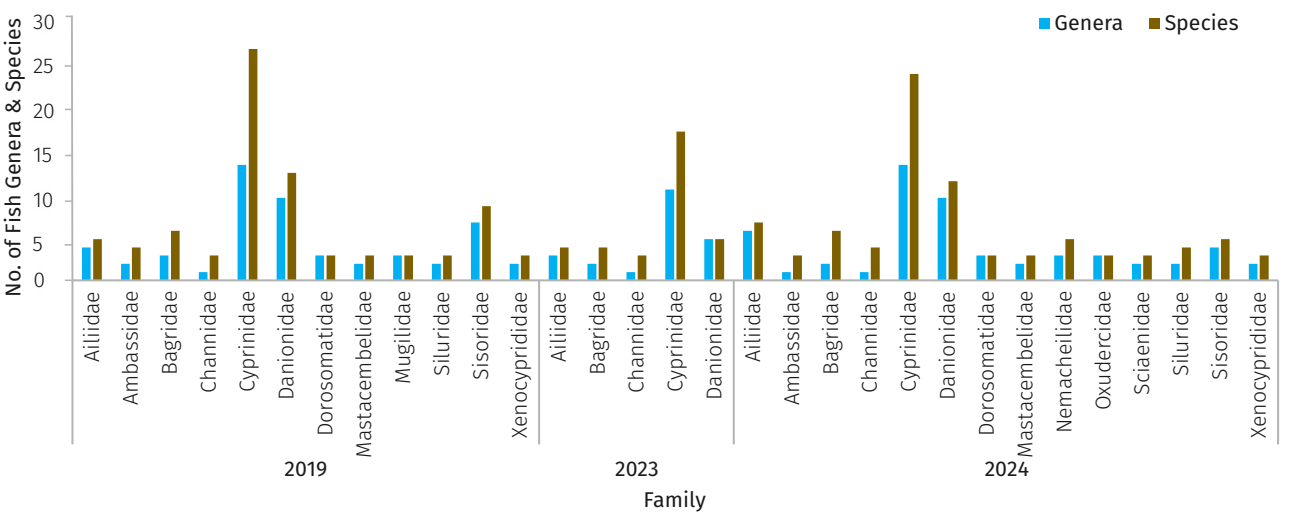


Figure 5.4 Taxonomic richness of dominant families across the sampling years (2019, 2023, and 2024) in the Ganga River

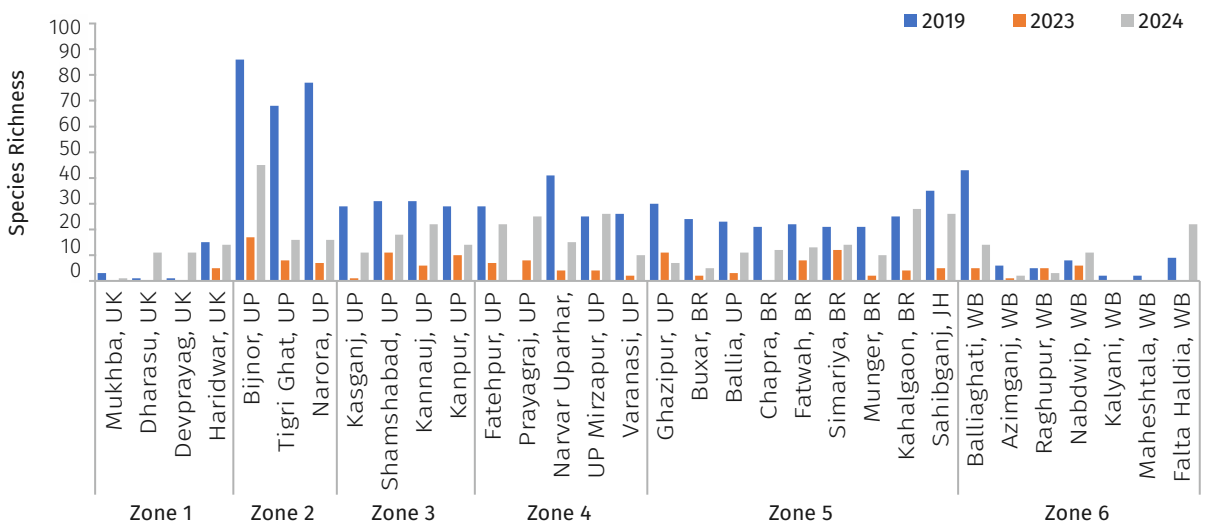


Figure 5.5 Variation in species richness across all sampling years (2019, 2023, 2024) in the Ganga River

Overall, 2019 diversity values were found higher than 2023 and 2024 (Figure 5.6). The highest Shannon-Weiner index (H') values were recorded in Site 4 (Haridwar) during 2019 (H'= 2.16) and 2023 (1.48) in Zone 1, while in 2024, Dharasu (2.09) (Figure 5.6). In Zone 2, the highest diversity value was recorded in Site 5 (Bijnor; H'=4.35) and Site 6 (Tigri Ghat=4.35) in 2019, while in 2023 and 2024, in Bijnor (H'=2.32 in 2023, 3.38 in 2024, respectively). In Zone 3, the highest diversity values were recorded in the same site, Shamshabad (Site 9) during 2019 (3.56) and 2024 (2.68), and site 11, Kanpur (1.91) in 2023, while in Zone 4 highest diversity value was reported in Narvar Uparhar (3.62) in 2019, Prayagraj (2.06) in 2023 and Fatehpur (2.8) in 2024. In Zone 5, the highest diversity value was observed in Kahalgaon, Bihar (3.62) in 2019, Ghazipur, Uttar Pradesh (2.64) in 2023 and Sahibganj, Jharkhand (2.79) in 2024. In Zone 6, the highest value was recorded in Balliaghati, West Bengal (3.89 in 2019, 2.01 in 2023), and in Falta Haldia (2.98) in 2024 (Figure 5.6).

The zone-wise analysis of Dominance (D), Simpson's diversity index (1-D), and Evenness (J) reveals distinct spatial patterns in ecological conditions along the river (Table 5.1). The 2019 data show that in Zone 1, at site 1 Mukhba, exhibited zero dominance and maximum diversity (1-D=1.00) with high evenness, indicating an undisturbed habitat, whereas Haridwar showed higher dominance (0.18) and lower diversity (0.82) with reduced evenness, suggesting moderate anthropogenic stress. Dharasu and Devprayag indicate even distribution, indicating uniform species distribution. In Zone 2, all sites (Bijnor, Tigri Ghat, and Narora) recorded very low dominance (0.01) and very high diversity (0.99) with good evenness, exhibiting healthy and stable ecological conditions. In Zone 3, all sites showed low dominance (0.03-0.05) and high diversity (0.95-0.97) with moderate to high evenness, indicating maintained ecological communities. In Zone 4, most sites (Fatehpur, Narvar Uparhar, Mirzapur, and Varanasi) documented low dominance and high diversity, showing stable conditions, while Prayagraj recorded no species. In Zone 5, the majority of sites show low dominance (0.03-0.05), high diversity (0.95-1.00), and high evenness (>1.0), reflecting good ecological health. Munger and Kahalgaon show high diversity and evenness, indicative of less disturbed environments. In Zone 6, most sites show zero dominance and the highest diversity, indicating good ecological conditions, while Azimganj shows the highest dominance (0.16) and lowest diversity (0.84), indicating localised stress. The 2019 analysis suggests the majority of ecosystems were stable with high biodiversity, except for some disturbances in Haridwar and Azimganj.

In 2023, zone-wise analysis indicates a general decline in ecological health and increased variability across the river system compared to 2019. In Zone 1, Mukhba, Dharasu, and Devprayag lack data, while Haridwar showed moderate dominance (0.24) and reduced diversity (0.76), suggesting ongoing anthropogenic stress. In Zone 2, sites such as Bijnor, Tigri Ghat, and Narora exhibited moderate dominance (0.17-0.23) and relatively lower diversity (0.77-0.83), with reduced evenness, indicating declining ecological stability. In Zone 3, a highly disturbed condition is evident, particularly at Kasganj (D=1.00, 1-D=0.00), indicating complete dominance by a single species and total loss of diversity. Other sites also show increased dominance and reduced diversity and evenness, reflecting ecological stress. Similarly, in Zone 4, Fatehpur and Mirzapur exhibit high dominance (0.53-0.54) and low diversity, indicating disturbed habitats, while Prayagraj shows comparatively high diversity (0.86) and evenness (0.98), suggesting some ecological recovery. Varanasi exhibited moderate conditions, with balanced diversity and evenness. In Zone 5, conditions vary; Ghazipur shows good ecological health (high diversity and evenness), while Buxar, Ballia, and Munger indicate disturbed environments. Other sites, such as Fatwah, Simariya, and Sahibganj, maintain moderate to good conditions. In Zone 6, Balliaghati shows excellent diversity (1.00) and high evenness, while Raghupur and Nabdwip display moderate ecological conditions. Kalyani, Maheshtala, and Haldia recorded no species. Overall, the 2023 survey indicates increased ecological stress and reduced diversity, reflecting deterioration in riverine ecosystem health.

In 2024, in Zone 1, Mukhba shows complete dominance (D=1, 1-D=0), indicating extreme ecological imbalance or the presence of a single species *(Naziritor chelynoides)*. Dharasu exhibits moderate diversity (0.85) and evenness, showing some recovery. However, Devprayag and Haridwar reflect relatively higher dominance (0.43-0.46) and low evenness, indicating ongoing environmental stress in this region. In Zone 2, Bijnor maintains low dominance (0.05) and high diversity (0.95), indicating healthy conditions, while Tigri Ghat and Narora show moderate dominance and reduced evenness, suggesting slight ecological disturbances. In Zone 3, most sites show low to moderate dominance (0.08-0.16) and relatively high diversity (0.84-0.92), with improved evenness, indicating recovery and stabilisation of fish communities compared to 2023. In Zone 4, ecological conditions are improving, with Prayagraj showing moderate diversity and evenness, indicating recovery from the degraded state seen in 2023. In Zone 5, most sites display moderate dominance (0.11-0.30) and high diversity (0.70-0.89) with moderate to high evenness, suggesting a stable community but slightly stressed ecosystems. Sites like Fatwah and Simariya show lower evenness, indicating uneven species distribution. In Zone 6, Balliaghati and Azimganj exhibit high dominance (0.52-0.72) and low diversity, reflecting significant ecological stress, while Raghupur and Nabdwip demonstrate moderate to good diversity and evenness. Kalyani and Maheshtala recorded no species. Haldia shows low dominance and high diversity (0.94) with good evenness, indicating healthy conditions in the estuarine region. Overall, the temporal trend suggests that the river ecosystem was relatively healthy in 2019, experienced significant degradation in 2023, and showed signs of gradual recovery in 2024. Anthropogenic disturbance and uneven ecological conditions persist across different zones.

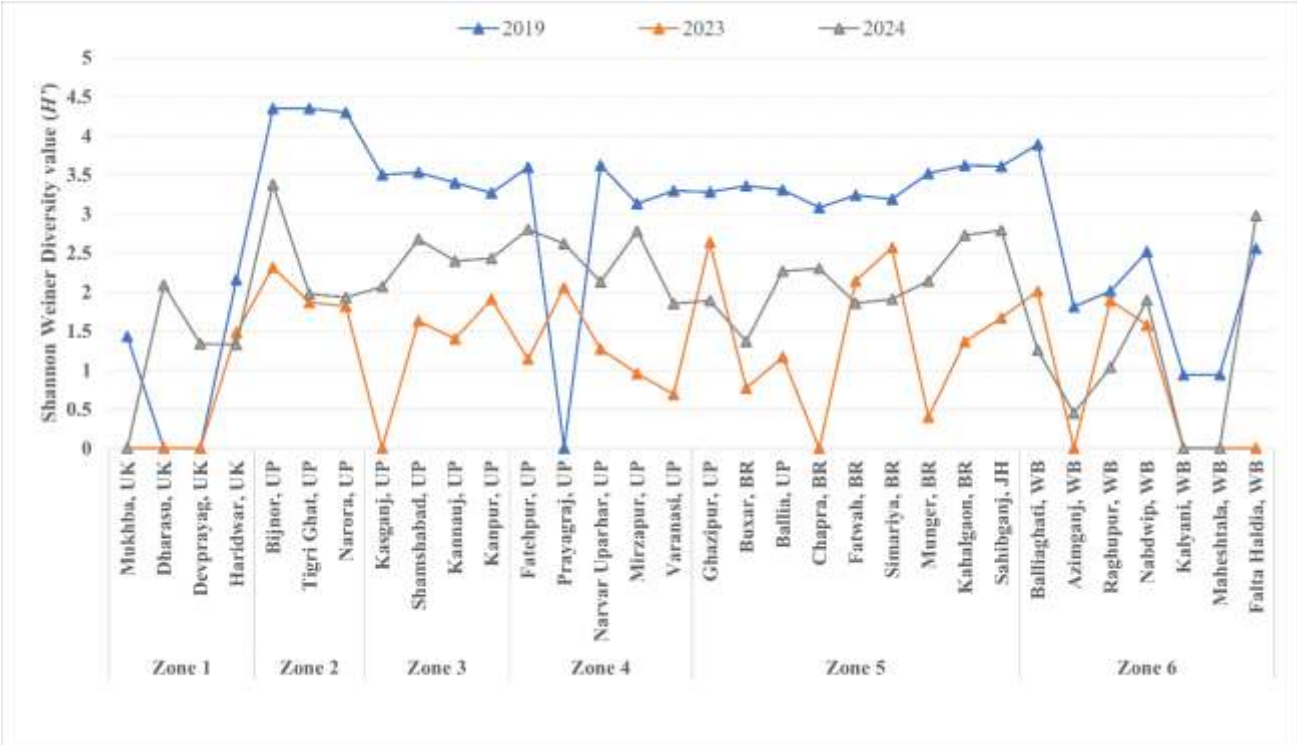


Figure 5.6 Temporal variation Shannon diversity values (H') across all sampling sites of the Ganga River during the 2019, 2023 and 2024 survey





Table 5.1 Zone-wise and Site-wise species richness and diversity indices, in the Ganga River during the surveys of 2019, 2023 and 2024

Zones	Sites	Species Richness			No. of Individuals			Dominance (D)			Simpson (1-D)		
		2019	2023	2024	2019	2023	2024	2019	2023	2024	2019	2023	2024
Zone 1	Mukhba, UK	3	0	1	3	0	5	0.00	0	1	1.00	0	0
	Dharasu, UK	1	0	11	1	0	58	NAN	0	0.15	NAN	0	0.85
	Devprayag, UK	1	0	11	1	0	90	NAN	0	0.46	NAN	0	0.54
	Haridwar, UK	15	5	14	78	31	182	0.18	0.24	0.43	0.82	0.76	0.57
Zone 2	Bijnor, UP	86	17	45	407	92	127	0.01	0.17	0.05	0.99	0.83	0.95
	Tigri Ghat, UP	68	8	16	114	17	115	0.01	0.23	0.22	0.99	0.77	0.78
	Narora, UP	77	7	16	280	15	233	0.01	0.20	0.21	0.99	0.80	0.79
Zone 3	Kasganj, UP	29	1	11	48	14	32	0.03	1.00	0.16	0.97	0.00	0.84
	Shamshabad, UP	31	11	18	61	81	55	0.03	0.30	0.08	0.97	0.70	0.92
	Kannauj, UP	31	6	22	108	71	114	0.04	0.32	0.15	0.96	0.68	0.85
	Kanpur, UP	29	10	14	121	84	46	0.05	0.19	0.10	0.95	0.81	0.90
Zone 4	Fatehpur, UP	29	7	22	40	27	65	0.02	0.54	0.08	0.98	0.46	0.92
	Prayagraj, UP	0	8	25	0	22	116	0	0.14	0.12	0	0.86	0.88
	Narvar Uparhar, UP	41	4	15	146	13	61	0.03	0.32	0.18	0.97	0.68	0.82
	Mirzapur, UP	25	4	26	61	15	151	0.05	0.53	0.08	0.95	0.47	0.92
	Varanasi, UP	26	2	10	92	4	41	0.04	0.50	0.22	0.96	0.50	0.78
Zone 5	Ghazipur, UP	30	11	7	123	15	9	0.05	0.05	0.16	0.95	0.95	0.84
	Buxar, BR	24	2	5	43	5	31	0.03	0.40	0.30	0.97	0.60	0.70
	Ballia, UP	23	3	11	39	8	16	0.03	0.29	0.12	0.97	0.71	0.88
	Chapra, BR	21	0	12	54	0	32	0.04	0	0.12	0.96	0	0.88
	Fatwah, BR	22	8	13	41	20	51	0.03	0.11	0.27	0.97	0.89	0.73
	Simariya, BR	21	12	14	39	25	47	0.03	0.07	0.26	0.97	0.93	0.74
	Munger, BR	21	2	10	21	9	13	0.00	0.78	0.15	1.00	0.22	0.85
	Kahalgaon, BR	25	4	28	27	17	91	0.01	0.26	0.12	0.99	0.74	0.88
	Sahibganj, JH	35	5	26	76	16	67	0.03	0.18	0.11	0.97	0.83	0.89
Zone 6	Balliaghati, WB	43	5	14	73	5	168	0.02	0.00	0.52	0.98	1.00	0.48
	Azimganj, WB	6	1	2	14	1	6	0.16	NAN	0.72	0.84	NAN	0.28
	Raghupur, WB	5	5	3	5	6	4	0.00	0.07	0.38	1.00	0.93	0.63
	Nabdwip, WB	8	6	11	8	43	44	0.00	0.25	0.19	1.00	0.75	0.81
	Kalyani, WB	2	0	0	2	0	0	0.00	0	0.00	1.00	0	0.00
	Maheshtala, WB	2	0	0	2	0	0	0.00	0	0	1.00	0	0
	Falta Haldia, WB	9	0	22	10	0	59	0.02	0	0.06	0.98	0	0.94



5.3.2 Relative Abundance

The ichthyofaunal surveys conducted in 2019, 2023, and 2024 reveal significant shifts in species composition, diversity indices, and catch effort across the six ecological zones (Figure 5.7 and Tables 5.2a, 5.2b and 5.2c). In 2019, the upper stretch (Zone 1) was dominated by *Tor putitora* (31.33%), whereas the 2023 survey showed *Labeo dero* (35.48%) as the most abundant species, and the 2024 survey indicated a transition to *Pethia ticto* (34.03%) as the most prevalent species (Figure 5.7). In the middle stretch (Zone 2), the highest relative abundance was observed for *S. bacaila* (4%) in 2019, while *Puntius sophore* (28.23%, 26.95%) was dominant in 2023 and 2024, respectively. In Zone 3 (Kasganj, UP to Kanpur, UP), the greatest relative abundance was recorded for *Macrognathus pancalus* (8.88%) in 2019, *Salmostoma bacaila* (44.40%) in 2023, and *Ailia coila* (12.15%) along with *Clupisoma garua* (12.15%) in 2024 (Figure 5.7). While certain species, such as *Cabdio morar,* remained consistently dominant in Zone 4 (Kanpur, UP to Varanasi, UP) across both periods (9.36% in 2019 and 16.36% in 2024), in 2023, the small indigenous fish *Puntius sophore* (24.69%) exhibited the highest dominance. In Zone 5 (Ghazipur, UP to Sahibganj, JH), the highest relative abundance was also observed for *Puntius sophore* (7.99%) in 2019, and for *Salmostoma bacaila* in 2023 (17.39%) and 2024 (16.81%). In the lower stretch (Zone 6, Balliaghati, WB to Falta Haldia, WB), the dominance shifted from a shared relative abundance of *Rhinomugil corsula* and *Setipinna phasa* (8.77%) in 2019 to a higher abundance of *Puntius sophore* (34.55%) in 2023 and *Pisodonophis boro* (42.70%) in 2024. The lowest species diversity was recorded in 2023 compared to 2019 and 2024 (Figure 5.7).

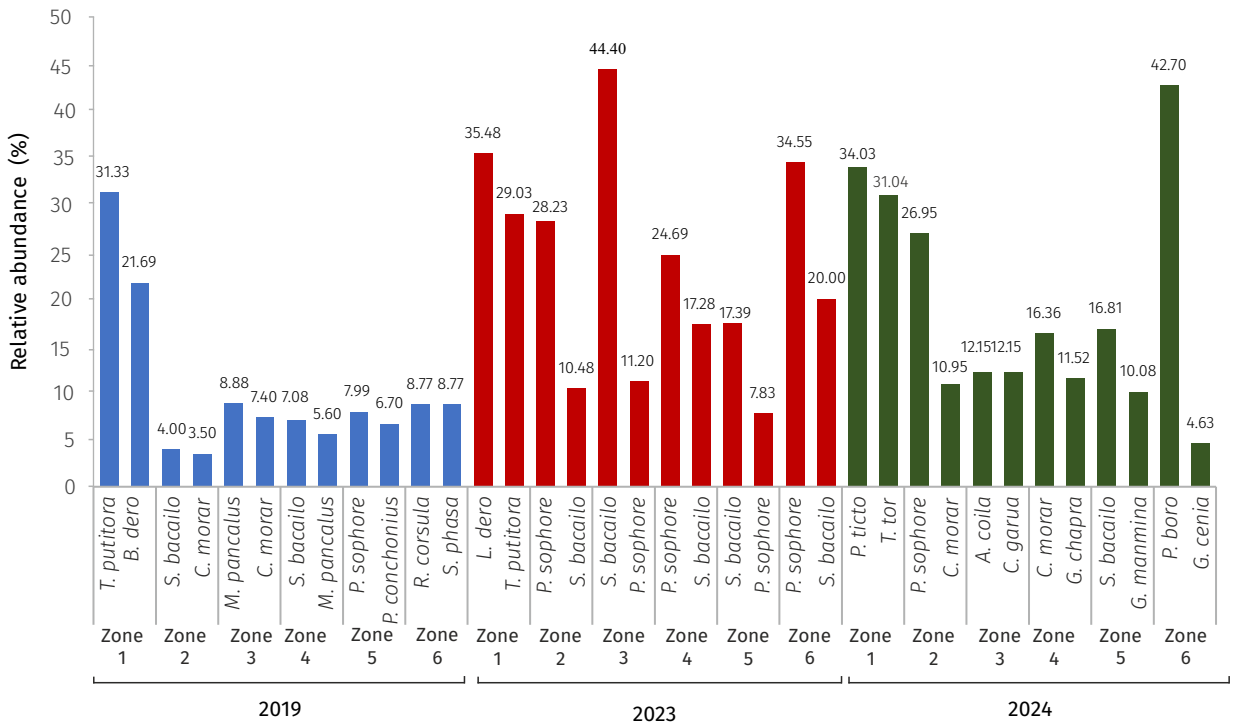


Figure 5.7 Zone-wise relative abundance of dominant species recorded in the Ganga River during the 2019, 2023 and 2024 surveys



Table 5.2 Zone wise Relative Abundance recorded in Ganga River during the survey of 2019-2024

Scientific Name	Zone 1			Zone 2			Zone 3		
	2019	2023	2024	2019	2023	2024	2019	2023	2024
Ailia coila	0	0	0	2	0.81	0.63	3.25	0	12.15
Ailiichthys punctata	0	0	0	0	0	0	0	0	0
Amblyceps mangois	0	0	0	0.75	0	0	0	0	0
Amblypharyngodon mola	0	0	0	1	4.84	0.42	1.78	1.6	2.83
Anabas testudineus	0	0	0	0.62	0	0.42	0	0	0
Anguilla bengalensis	0	0	0	0	0	0	0	0	0
Apocryptes bato	0	0	0	0	0	0	0	0	0
Arius gagora	0	0	0	0	0	0	0	0	0
Badis badis	0	0	0	0.25	0	0	0	0	0
Bagarius bagarius	0	0	0	0.99	0	0.42	0.59	0	0.4
Bangana dero	21.69	35.48	1.49	1.5	0	0	0	0	0
Barilius barila	0	0	0	0.25	0	0	1.18	0	0
Barilius sp.	0	0	0	0.12	0	0	0	0	0
Barilius vagra	1.2	3.23	2.09	0	0	0	0	0	0
Batasio batasio	0	0	0	1.37	0	0	0	0	0
Botia dario	0	0	0	0	0	0	0	0	0
Botia lohachata	0	0	0	0.75	0.81	0	0	0	0
Botia rostrata	0	0	0	0	0	0	0	0	0
Cabdio jaya	0	0	0	1.25	0	0	2.37	0	0
Cabdio morar	0	0	0	3.5	4.03	10.95	7.4	8	2.83
Chaca chaca	0	0	0	0.12	0	0	0	0	0
Chagunius chagunio	0	0	1.19	1	0	0.21	0	0	0
Chanda baculis	0	0	0	1.25	0	0.63	0	0	1.21
Chanda nama	0	0	0	1.5	0.81	0.63	0	0	0.81
Chanda ranga	0	0	0	1.75	4.03	0	0	0	0.4
Channa gachua	0	0	0	0	0.81	0.42	0	0.4	0
Channa marulius	0	0	0	0.75	0	0.42	0	0	0
Channa punctata	0	0	0	1.5	0	1.89	2.07	0	0
Channa striata	0	0	0	0.5	0	0.21	0	0	0
Chela cachius	0	0	0	0	0	0.21	0	0	0
Chelon persicus	0	0	0	0	0	0	0	0	0
Chitala chitala	0	0	0	0.75	0	0.21	0	0	1.62
Cirrhinus mrigala	0	0	0	1	0	1.47	1.18	0	6.88
Cirrhinus reba	0	0	0	1.87	4.84	4	2.66	0	1.21
Clarias magur	0	0	0	0	0	0	0	0	0
Clupisoma garua	0	0	0	1.37	0	0	2.96	0	12.15
Clupisoma montanum	0	0	0	0	0	0.42	0	0	1.21
Coilia ramcarati	0	0	0	0	0	0	0	0	0
Ctenopharyngodon idella	0	0	0.3	0	0	0	0	0	0
Cynoglossus cynoglossus	0	0	0	0	0	0	0	0	0
Cyprinus carpio	0	0	0.6	0.12	1.61	1.47	2.96	0	1.62
Devario devario	0	0	0	0	0	0.84	0	0	0

Zone 4			Zone 5			Zone 6		
2019	2023	2024	2019	2023	2024	2019	2023	2024
2.06	0	2.07	1.3	0	1.4	2.63	0	1.07
0	0	0	0	0	0.56	0	0	0
0	0	0	0	0	0	0	0	0
1.47	0	0.69	1.73	2.61	0.28	1.75	0	1.42
0	0	0	0.43	0	0.28	0.88	0	0
0	0	0	0.22	0	0	0	0	0
0	0	0	0	0	0	0.88	0	1.07
0	0	0	0.22	0	0	0	0	0.71
0	0	0	0	0	0	0	0	0
0	0	0.69	0	0	0	0.88	0	0
0	0	0	0	0	1.96	0	1.82	0.36
0	0	0	0	0	0.56	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.56	0	0	0
0.59	0	0	0	0	1.68	0	0	0
0	0	0	0.43	0	0	0.88	0	0
1.18	0	0	0	0	0	0	0	0
5.31	0	16.36	4.97	6.96	1.12	2.63	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0.36
0	0	0	0	0	1.12	0	0	0
0	0	0	1.3	0	2.24	0.88	0	3.2
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1.82	0
2.06	0	2.07	3.02	0	0.84	0.88	0	1.42
0	0	0.23	0	0	0	0	1.82	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0.88	0	0
0	0	0	0	0.87	0	0	0	0
0.88	0	1.84	0	1.74	0	0	0	0
2.65	0	1.61	4.75	0	0.84	2.63	0	1.42
0	0	0	0	0.87	0	0	0	0
0.88	0	0.46	0.22	3.48	0.84	0.88	5.45	0
0	0	3.46	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1.42
0.29	0	0	0	0	0.56	0	0	0
0	0	0	0	0	0	0.88	3.64	0
5.31	3.7	3.69	1.73	0.87	3.08	0.88	0	1.42
0	0	0	1.08	0	0	1.75	0	0

Scientific Name	Zone 1			Zone 2			Zone 3		
	2019	2023	2024	2019	2023	2024	2019	2023	2024
Eleotris fusca	0	0	0	0	0	0	0	0	0
Erethistes pusillus	0	0	0	0.12	0	0	0	0	0
Eutropiichthys murius	0	0	0	0.5	0	0	0	2.4	0
Eutropiichthys vacha	0	0	0	1.5	0	0.63	2.07	5.6	0.81
Gagata cenia	0	0	0	1.5	0	0	0	0	0
Gagata sexualis	0	0	0	1.25	0	0	0	0	0
Garra gotyla	1.2	19.35	0.6	0	0	0	0	0	0
Glossogobius giuris	0	0	0	1.12	0.81	0.42	0	0.4	0
Glyptothorax cavia	7.23	0	0.3	0.37	0	0	0	0	0
Glyptothorax gracilis	4.82	0	0	0	0	0	0	0	0
Glyptothorax sp1	0	0	0	0.5	0	0	0	0	0
Glyptothorax sp2	0	0	0	0.12	0	0	0	0	0
Glyptothorax telchitta	0	0	0.6	0	0	0	0	0	0
Gogangra viridescens	0	0	0	0.12	0	0	0	0	0
Gonialosa manmina	0	0	0	0	0	0	0	3.2	3.24
Gudusia chapra	0	0	0	1.87	0	0	2.66	2.8	4.05
Heteropneustes fossilis	0	0	0	1	0.81	0.63	0	0	0
Hypophthalmichthys molitrix	0	0	0	0	0.81	0.42	0	0	0
Hypophthalmichthys nobilis	0	0	0	0	0	0	0	0	0
Johnius coitor	0	0	0	0	0	0	0	0	0
Johnius gangeticus	0	0	0	0	0	0	0	0	0
Labeo bata	0	0	0	1.12	0	6.95	2.37	1.2	0.81
Labeo boga	0	0	0	0.37	0	0.84	0	0	0.4
Labeo calbasu	0	0	0	3	0	0.42	4.14	0	1.62
Labeo catla	0	0	0	0.5	0	0	1.18	0.4	0
Labeo dyocheilus	1.2	0	0.6	0	0	0	0	0	0
Labeo fimbriatus	3.61	0	0	0	0	0	0	0	0
Labeo gonius	0	0	0.9	1.25	8.87	4.42	0	0	1.21
Labeo pangusia	4.82	0	0	0.12	0	0	0	0	0
Labeo rohita	0	0	0	0.75	4.03	0.21	0	0	2.83
Lates calcarifer	0	0	0	0	0	0	0	0	0
Laubuka laubuca	0	0	0	0.62	4.03	0	0	0	0
Leiodon cutcutia	0	0	0	0.5	0	0	0	0	0
Lepidocephalichthys guntea	0	0	1.19	1.12	0	0	0	0	0
Leptomelanosoma indicum	0	0	0	0	0	0	0	0	0
Macrognathus aculeatus	0	0	0	0	0	0.21	0	0	0
Macrognathus aral	0	0	0	1	0	0	2.37	0	0
Macrognathus pancalus	0	0	0	2.12	0	0	8.88	0	0.81
Mastacembelus armatus	0	0	0.3	1.75	0	0.21	3.85	0	0
Mystus bleekeri	0	0	0	0	0	0	0	0	0
Mystus cavasius	0	0	0	1.62	0	1.26	3.55	0	2.02
Mystus tengara	0	0	0	1.25	4.03	0.84	0.3	0	1.21
Mystus vittatus	0	0	0	0.75	0	0.42	0	0.8	2.02
Nandus nandus	0	0	0	0.75	0.81	0.42	0	0	0

Zone 4			Zone 5			Zone 6		
2019	2023	2024	2019	2023	2024	2019	2023	2024
0	0	0	0	0	0	0.88	0	0
0	0	0	0	0	0	0	0	0
0	1.23	0.92	0	0	0.84	0	0	0
1.18	2.47	1.84	0.22	6.96	1.96	0.88	0	1.42
0	1.23	1.15	0.65	0	1.96	0.88	1.82	4.63
0	0	0	0.22	0	0	0.88	0	0
0	0	0	0	0	0	0	0	0
0.29	1.23	0.46	3.46	0	1.4	7.02	5.45	3.56
0	0	0	0	0	0.28	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.56	0	0	0
0	0	0.23	0	0	0	0	0	0
0.88	4.94	0.23	1.73	3.48	10.08	0	1.82	1.07
5.31	4.94	11.52	4.1	0	1.4	4.39	1.82	0.71
0	0	0.23	0	0	0.28	0	0	0
0.29	0	0	0	0	0.56	0	0	0.36
0.29	0	0	0	0	0.28	0	0	0.36
0	0	5.76	0.43	0	2.24	0	5.45	2.49
1.77	0	0.69	0	0	0	0	0	0
0.88	0	0	0	0	0	1.75	0	1.42
0	0	0	0	0	0	0	0	0
1.77	4.94	0.23	0.86	4.35	0.56	0	0	0.36
0.59	0	0.23	0	0.87	0.28	0	0	0.36
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.59	0	0.46	0.43	0	0	0.88	0	0
0	0	0	0	0	0	0	0	0
0.29	0	1.38	0	0.87	0.28	0	0	0.71
0	0	0	0	0	0	0	0	0.36
0	0	0	0	0	0	0	1.82	0
0	0	0	0	0	0	0.88	0	0
0	0	0	0.22	0	0.28	0.88	0	0
0	0	0	0	0	0	1.75	0	0
0	0	0	0	0	0	0	0	0
1.47	0	0	3.24	0	0	0.88	0	0
5.6	0	0.23	5.62	0	1.4	0.88	0	0
3.54	1.23	0.92	3.24	3.48	1.12	0.88	0	0
0	0	0	0	0	0.56	0	0	0
2.95	0	1.84	3.46	0	0	0.88	0	0
0	0	0	0	0	1.4	0	0	0
0	0	0	0.86	5.22	2.8	0	1.82	1.78
0	0	0	0	0	0.28	0	0	0.36

Scientific Name	Zone 1			Zone 2			Zone 3		
	2019	2023	2024	2019	2023	2024	2019	2023	2024
Naziritor chelynoides	2.41	0	1.49	0	0	0	0	0	0
Nemacheilus corica	0	0	0.6	0	0	0	0	0	0
Notopterus synurus	0	0	0	1.25	0	1.05	0	0	0
Odontamblyopus rubicundus	0	0	0	0	0	0	0	0	0
Ompok bimaculatus	0	0	0	0.5	0	0.84	0	0	2.43
Ompok pabda	0	0	0	0.62	0.81	0.84	0	0	0
Ompok pabo	0	0	0	0	0	0	0	0	0.81
Ophichthys cuchia	0	0	0	0	0	0	0	0	0
Opsarius barna	1.2	0	1.19	0.12	0	0	0	0	0
Opsarius bendelisis	4.82	0	11.64	0.25	0	0	0	0	0
Oreochromis niloticus	0	0	0	0	0	0	0.89	0	2.02
Osteobrama cotio	0	0	0	3.37	0	0	5.03	8	3.24
Pachypterus atherinoides	0	0	0	1.25	0	0.42	0	0	0.4
Pangio pangia	0	0	0	1.37	0	0	0	0	0
Panna microdon	0	0	0	0	0	0	0	0	0
Paracanthocobitis botia	0	0	1.19	1.12	0	0.42	0	0	0
Paracanthocobitis mooreh	0	0	0	0	0	0	0	0	0
Periophthalmus weberi	0	0	0	0	0	0	0	0	0
Pethia conchonius	0	0	0	2.12	5.65	10.53	5.03	0.8	0
Pethia sp	0	0	0	0.12	0	0	0	0	0
Pethia ticto	0	0	34.03	1.5	0	1.68	2.66	0.8	0
Pisodonophis boro	0	0	0	0	0	0	0	0	0
Polynemus paradiseus	0	0	0	0	0	0	0	0	0
Pseudambassis lala	0	0	0	1.37	0	0	1.18	0	0
Pseudecheneis sulcata	1.2	0	0.9	0	0	0	0	0	0
Psilorhynchus balitora	0	0	0	0	0	0	0	0	0
Pterygoplichthys disjunctivus	0	0	0	0.25	0	0.21	0	0	0
Puntius chola	0	0	0.6	2.5	0	2.95	3.25	0	0.81
Puntius sophore	0	0	0	3.12	28.23	26.95	4.44	11.2	4.86
Raiamas bola	0	0	0	0.75	0	0.21	0	0	0.81
Rasbora daniconius	0	0	0	1.5	0	0	0	0	0
Rhinomugil corsula	0	0	0	0	0	0	0	0	0
Rita rita	0	0	0	1	0	0	0	0	0.4
Salmo trutta	1.2	0	0.3	0	0	0	0	0	0
Salmostoma bacaila	0	0	0	4	10.48	5.47	6.21	44.4	8.1
Scatophagus argus	0	0	0	0	0	0	0	0	0
Schistura gangetica	1.2	0	0	0	0	0	0	0	0
Schistura rupecula	0	0	0.9	0	0	0	0	0	0
Schistura scaturigina	0	0	0	0	0	0	0	0	0
Schizothorax plagiostomus	1.2	0	0	0	0	0	0	0	0
Schizothorax progastus	0	0	0.6	0	0	0	0	0	0
Schizothorax richardsonii	2.41	0	2.69	0	0	0	0	0	0
Securicula gora	0	0	0	0.75	0	0	0	0	0

Zone 4			Zone 5			Zone 6		
2019	2023	2024	2019	2023	2024	2019	2023	2024
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.29	0	0	0	0	0.56	1.75	0	0.71
0	0	0	0	0	0	0	0	1.07
0	0	1.15	0.22	0	0.28	0.88	0	0
0	0	0	0	0	0.56	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0.88	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.77	0	2.76	1.51	0	2.8	0	0	0
5.01	2.47	0.46	4.54	4.35	0	0.88	0	0
0	0	0.23	0	0	1.12	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1.78
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.28	0	0	0
0	0	0	0	0	0	0	0	0.71
3.24	0	1.15	6.7	0	7	3.51	1.82	3.56
0	0	0	0	0	0	0	0	0
2.65	0	0	1.51	3.48	1.12	0	0	0
0	0	0	0	0	0	0	0	42.7
0	0	0	0	0	0	0	0	0.71
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.28	0	0	0
0	0	0	0	0	0	0	0	0
2.36	0	0	3.67	1.74	0	1.75	9.09	0
3.24	24.69	4.61	7.99	7.83	10.08	2.63	34.55	4.63
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.56	0.88	0	0
0.88	1.23	4.61	3.67	3.48	1.68	8.77	0	1.42
1.47	7.41	1.84	1.08	0.87	0	0.88	0	1.78
0	0	0	0	0	0	0	0	0
7.08	17.28	6.91	5.4	17.39	16.81	2.63	20	2.85
0	0	0	0	0	0	0.88	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	1.4	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.56	0	0	0

Scientific Name	Zone 1			Zone 2			Zone 3		
	2019	2023	2024	2019	2023	2024	2019	2023	2024
Setipinna brevifilis	0	0	0	0	0	0	0	0	0
Setipinna phasa	0	0	0	0.12	0	0	0	0	0
Sicamugil cascasia	0	0	0	2.25	2.42	0	0.3	0	0
Sillaginopsis domina	0	0	0	0	0	0	0	0	0
Silonia silondia	0	0	0	0	0	0	0	0	0
Sisor rabdophorus	0	0	0	0	0	0	0	0	0
Sperata aor	0	0	0	1	0.81	0	2.07	0	1.21
Sperata lamarrii	0	0	0	0.87	0	0.63	2.07	0.4	4.05
Systomus sarana	0	0	0	1.87	0.81	0.21	2.37	0	0.4
Tariqilabeo latius	0	0	0.9	1.62	0	0	0	0	0
Tariquilabeo latius	0	12.9	0	0	1.61	0	0	7.6	0
Tenualosa ilisha	0	0	0	0	0	0	0	0	0
Tor putitora	31.33	29.03	1.79	0	0	0	0	0	0
Tor tor	7.23	0	31.04	0	0	0.21	0	0	0
Trichogaster chuna	0	0	0	0.99	0	0.63	0	0	0
Trichogaster fasciata	0	0	0	3.25	0	1.47	0	0	2.83
Wallago attu	0	0	0	0.87	0	0.42	2.07	0	1.21
Xenentodon cancila	0	0	0	1.87	2.42	0.63	2.66	0	0

5.3.3 Trends in Catch per Unit Effort

Overall, higher CPUE (Catch per Unit Effort) were recorded in 2024 than in 2019 and 2023 (Figure 5.8). CPUE data further illustrate a change in fish abundance and habitat productivity. The highest CPUE (per panel hour) recorded in 2019 in zone 1 at site 4 (Haridwar) (19.50), 7.75 in 2023, and 45.50 in 2024 at the same site, shows substantial productivity increases. In 2019 and 2023, Zone 2, Bijnor (101.75 in 2019, 23 in 2023), recorded a peak CPUE, while in 2024, Narora (58.25) shows the highest CPUE in that zone. In Zone 3, maximum CPUE was observed in Kanpur (30.25 in 2019, 21 in 2023) and Kannauj (28.50 in 2024) (Figure 5.8). In Zone 4, Prayagraj (43.50) in 2019, Fatehpur (6.75) in 2023 and Mirzapur (37.75) in 2024, while in Zone 5, Ghazipur, UP (30.75) in 2019, Simariya (6.25) in 2023, and Kahalgaon (22.75) in 2024, recorded the highest CPUE. In Zone 6, the highest CPUE for both years was recorded in Balliaghati (18.25 in 2019, 42 in 2024), indicating higher productivity in 2024 than in 2019, while in 2023, the highest CPUE was recorded in Nabdwip, WB (10.75). However, the most concerning trend is the CPUE values observed in 2019 and 2024 (Figure 5.8) Dharasu recorded 0.50 and Mukhba 2.50 in zone 1, respectively. In 2023, both Mukhba, Dharasu, and Devprayag experienced a complete absence of catch due to environmental stressors (adverse weather conditions and low water temperature). In zone 2, the lowest CPUE were noted at Tigri Ghat (28.50 in 2019, 28.75 in 2024), while in 2023, Narora recorded 3.75. In zone 3, Kasganj had the lowest CPUE, with values of 12.00 in 2019, 3.50 in 2023, and 8.00 in 2024. In zone 4, Fatehpur recorded 10.00 in 2019, and Varanasi showed 1.00 in 2023 and 10.25 in 2024. In zone 5, Munger had 5.25 in 2019, Chapra showed a total absence of catch (0.00) in 2023, and Ghazipur had 2.25 in 2024. In zone 6, CPUE declined from a minimum of 0.50 at Kalyani and Maheshtala in 2019 to a complete absence of catch (0.00) in 2023 at Kalyani, Maheshtala, and Falta Haldia, and only at Kalyani and Maheshtala in 2024, suggesting potential stock depletion or environmental stressors.



Glyptothorax sp.

Zone 4			Zone 5			Zone 6		
2019	2023	2024	2019	2023	2024	2019	2023	2024
5.31	0	0	0.86	0	0	0	0	0
3.54	0	0.46	1.73	2.61	1.12	8.77	0	0.71
3.54	3.7	0.46	4.54	0	0	6.14	0	0
0	0	0	0	0	0	0	0	0.71
0	0	0	0	0	0.84	0.88	0	0
0	0	0	0	0	0	1.75	0	0
2.06	0	5.07	1.3	0	0	0.88	0	0
2.36	16.05	1.84	1.08	6.09	0	0.88	0	0
0.88	1.23	0	0	0	1.4	0	0	0
0.59	0	1.61	0	0	1.68	0	0	1.42
0	0	0	0	6.96	0	0	0	0
0	0	0	0	0	0.28	7.02	0	0.71
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0.23	0	0	0	0	0	0
0	0	1.38	0	0	0	0	0	0.36
0.88	0	3.69	0.22	0.87	0.56	0.88	0	0
2.36	0	0	3.89	1.74	0.28	1.75	0	0.36

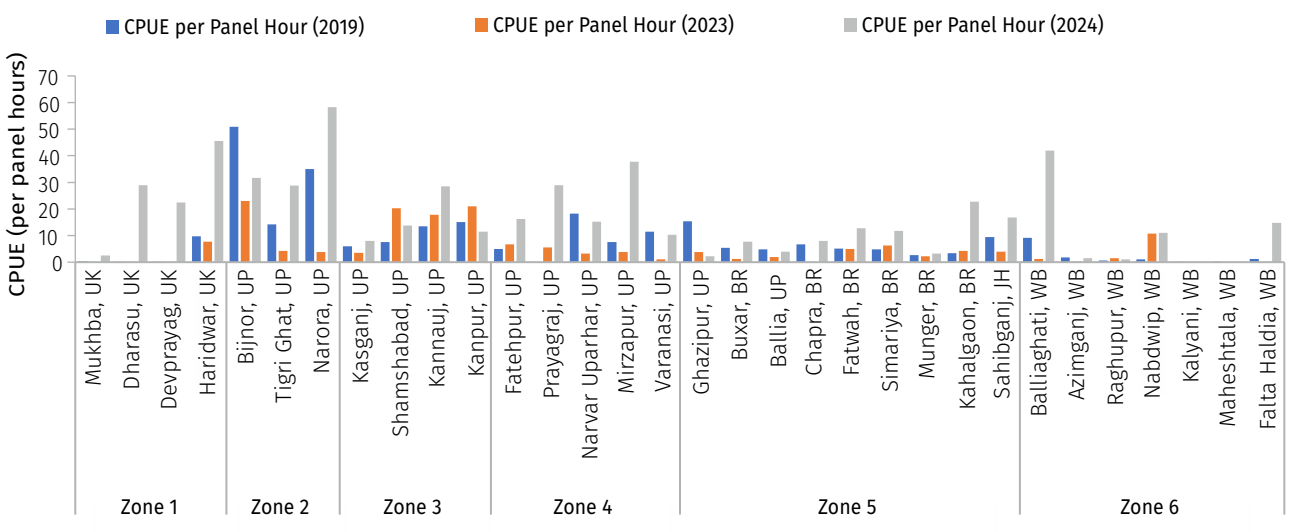


Figure 5.8 Variation in CPUE across sampling sites of the Ganga River (2019, 2023 and 2024)

5.3.4 Environmental Variables Influencing Fish Abundance

For 2019 survey, water temperature was the only variable found significantly (Coefficient = 0.241, R^2=0.21, p=0.030) infleuncing the Shannon diversity index, indicating that higher temperature is associated with an increase in the diversity index (Table 5.3). Other selected water variables (pH, TDS, DO, Conductivity, NO_3, NH_4, and Salinity) were non-significant coefficients (p>0.05) and had very low partial R^2 values (mostly <0.06), indicating that, when considered together, they contribute little additional explanatory power beyond temperature. Thus, among the tested variables, water temperature emerges as the primary driver of variation in the response, while the remaining physico-chemical parameters do not show statistically significant individual effects in this dataset. In 2023, none of the variables shows statistical significance (p<0.05) in 2023, suggesting that the relationship between Shannon diversity and environmental variables may be attributed to chance (Table 5.4). Average width showed the highest R^2 (0.131) despite its small negative coefficient (-0.00076) and non-significant P-value (0.488), implying it captures some variability but lacks reliable predictive strength. Average flow (p=0.273, R^2=0.064) and Salinity (p=0.315, R^2=0.063) showed moderate effect sizes relative to the other variables, with flow positively associated and salinity negatively associated with the Shannon diversity. Conductivity demonstrated a positive trend (Coefficient= 0.022, p= 0.138), while TDS showed a weak negative association (p=0.176). Environmental variables such as pH, Temperature, Elevation, and Depth contributed very little explanatory power, with R^2 values below 0.05 and p-values well above 0.5.

Overall, the absence of statistically significant predictors and low R^2 values indicate substantial unexplained variability in the data. This may reflect high natural ecological variability or insufficient sample size. In 2024, flow and depth showed positive influences on species diversity, as flow and depth increase, species diversity increases (Table 5.5). Water Temperature and pH have exhibited nonlinear relationship with species diversity. Total dissolved solids (TDS) showed a negative correlation, indicating that higher TDS levels reduced species diversity but non-significantly (p=0.588). The Elevation had a significant negative effect on species diversity (p < 0.05), confirming that species diversity declines with increasing elevation. Other variables, such as water temperature, flow, depth, conductivity, TDS, salinity, and pH, did not exhibit statistically significant relationships with species diversity (p-values > 0.05), implying that their influence on species diversity might not be strong or may be confounded by other variables. Overall, elevation, width, water temperature, and TDS demonstrated negative association with Shannon Diversity Index.

Table 5.3 Regression analysis between diversity and physico-chemical water parameters for all studied sites in 2019

Environmental Variables	Coefficient	Standard error	*t Stat*	*P-value*	R^2
Intercept	12.69	14.25	0.89	0.38	
Water Temperature (°C)	**0.24**	**0.10**	**2.32**	**0.03**	**0.21**
pH	-2.28	1.76	-1.29	0.21	0.00
DO (mg/l)	0.35	0.33	1.06	0.30	0.06
TDS (mg/l)	0.00	0.02	-0.14	0.89	0.00
Conductivity (µs/cm)	0.01	0.01	1.07	0.29	0.00
NO_3 (mg/l)	0.00	0.10	0.04	0.97	0.00
Nh_4 (mg/l)	0.20	1.29	0.15	0.88	0.00
Salinity (mg l^{-1})	-14.16	19.07	-0.74	0.47	0.00



Tor putitora (Hamilton 1822)

Table 5.4 Regression analysis of species diversity against environmental variables in the 2023 survey.

Environmental Variables	Coefficient	Standard error	*t Stat*	*P-value*	R^2
Intercept	-0.947	6.682	-0.142	0.889	
Elevation (m)	-0.001	0.004	-0.151	0.882	0.043
Average Width (m)	-0.001	0.001	-0.709	0.488	0.131
Average Flow (m/s)	0.553	0.488	1.132	0.273	0.064
Average Depth (m)	-0.032	0.045	-0.721	0.480	0.045
Water Temperature (°C)	-0.031	0.093	-0.336	0.741	0.027
Conductivity (µs/cm)	0.022	0.014	1.557	0.138	0.006
Salinity (mg l^{-1})	-6.910	6.680	-1.034	0.315	0.063
TDS (mg/l)	-0.029	0.020	-1.413	0.176	0.019
pH	0.372	0.695	0.536	0.599	0.005

Table 5.5 Regression analysis of species diversity against environmental variables in the 2024 survey.

Environmental Variables	Coefficients	Standard Error	*t Stat*	*P-value*	R^2
Intercept	2.45	2.35	1.04	0.31	
Elevation (m)	**-0.0011**	**0.0004**	**-2.91**	**0.009**	**0.236**
Average Width (m)	-0.0001	0.0006	-0.19	0.849	0.040
Average Flow (m/s)	0.373	0.297	1.255	0.224	0.005
Average Depth (m)	0.033	0.041	0.800	0.433	0.153
Water Temperature (°C)	-0.065	0.064	-1.017	0.321	0.010
Conductivity (µs/cm)	0.004	0.006	0.651	0.522	0.153
TDS (mg/l)	-0.007	0.012	-0.550	0.588	0.151
Salinity (mg l^{-1})	3.368	6.428	0.524	0.606	0.006
pH	0.095	0.437	0.219	0.829	0.009

5.3.5 Status of Species of Conservation Significance

The conservation assessment of the fish of the Ganga River from the Mukhba, Uttarakhand, to Lower Ganga at Haldia, West Bengal is given in Figure 5.9. Among species found in 2019, *Botia rostrata*, *Naziritor chelynoides*, *Schizothorax plagiostomus*, *Schizothorax richardsonii* and *Bagarius bagarius*, *Wallago attu* were Vulnerable species, while *Chitala chitala*, *Anguilla bengalensis*, *Labeo pangusia, Ailia coila, Ompok bimaculatus, Ompok pabda, Arius gagora, Pseudambassis lala* were Near Threatened, as per IUCN Red List. One Endangered species *Tor putitora* was collected from Upper stretch. Among species recoreded in 2023, only one vulnerable species *Wallago attu*, three Near threatened species *Chitala chitala, Ailia coila* and *Ompok pabda* and two endangered species *Clarias magur* and *Tor putitora* were recorded. During 2024 survey, out of the 114 fish species, approximately 10% were assessed to be threatened based on IUCN Red List Criteria, which included *Tor putitora*, an Endangered species, four species, viz., *Naziritor chelynoides*, *Schizothorax richardsonii*, *Bagarius bagarius*, and *Wallago attu*, were categorised as Vulnerable, six species, including *Ailia coila*, *Arius gagora*, *Chitala chitala*, *Ompok bimaculatus*, and *Ompok pabda*, were classified as Near Threatened. *Tor putitora, Naziritor chelynoides* and *Schizothorax richardsonii* were only observed in the upper stretches of the Ganga River. Vulnerable species *Bagarius bagarius* and near-threatened species *Chitala chitala* were typically found in the middle stretch. Near Threatened species, including *Ailia coila*, *Chitala chitala*, *Ompok bimaculatus*, *Ompok pabda*, and *Ompok pabo*, were mainly present in the middle and lower stretches. Near Threatened *Arius gagora* is usually located in the lower areas. Our recent study on the occurrence of the vulnerable species, Bull shark *(Carcharhinus leucas)*, in the Hooghly estuary, emphasised the importance of threatened species in the Ganga River (Das et al., 2025).



Ompok bimaculatus (Hamilton 1822)

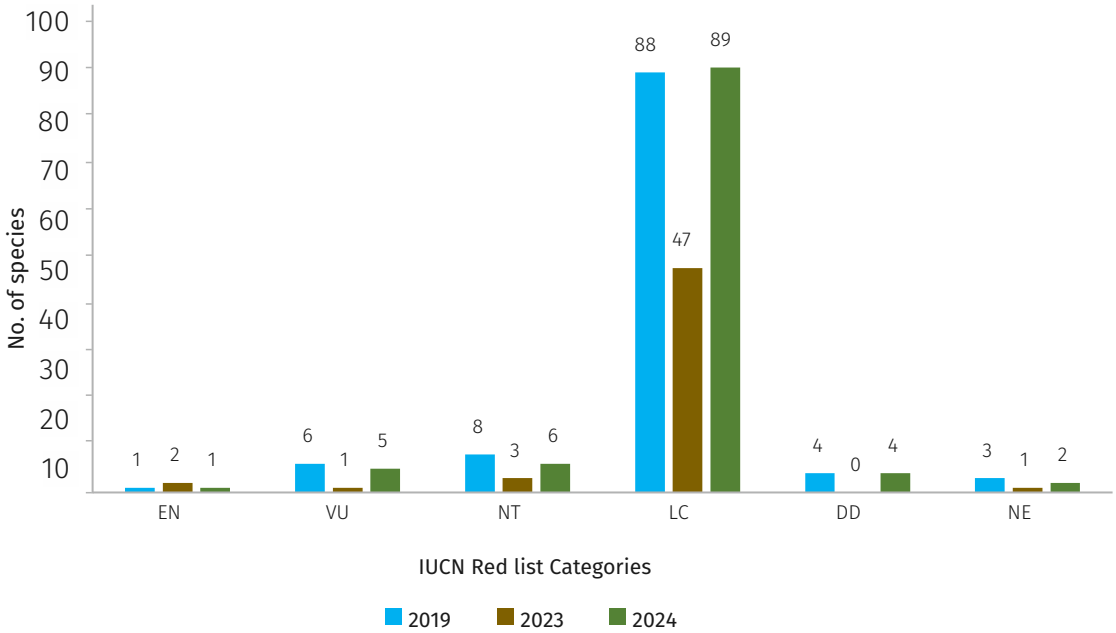


Figure 5.9 IUCN redlist status of threatened fish species recorded during the survey of the Ganga River during 2019, 2023

5.3.6 Status of invasive species

A total of seven invasive/exotic species, including *Cyprinus carpio*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Hypophthalmichthys nobilis*, *Oreochromis niloticus*, *Pterygoplichthys disjunctivus*, and *Salmo trutta*, were recorded from the Ganga River during 2019 and 2024 (Figure 5.10). In 2019, 2023 and 2024, of the total invasive species *Cyprinus carpio* (38 individuals in 2019, 6 individuals in 2023 and 44 individuals in 2024) was found to be the most abundant species across the Ganga River, followed by *Oreochromis niloticus* (16 individuals in 2019 and 27 individuals in 2024). *Cyprinus carpio* was recorded from all zones except Zone 1 in 2019, while in 2023 it was recorded from zones 2 4, and 5, while it was recorded from all six zones in 2024. In 2019 and 2024, *Oreochromis niloticus* was recorded from Zones 3, 4 and 5. *Hypophthalmichthys molitrix* was recorded from Zone 4 in 2019, Zone 2 in 2023 and Zone 2, 5 and 6 in 2024. *Ctenopharyngodon idella* was documented from Zone 4 in 2019 and Zones 1 and 5 in 2024. *Hypophthalmichthys* nobilis was recorded from Zone 4 in 2019 and Zones 5 and 6 in 2024. *Pterygoplichthys disjunctivus* was recorded from Zone 2 in 2019 and 2024. *Salmo trutta* was documented from Zone 1 in 2019 and also in 2024. *Salmo trutta* was not found in the middle and lower stretches of the Ganga River. *C. carpio* was the most commonly found species in all the upper, middle and lower stretches of the Ganga River, followed by *O. niloticus*. Additional invasive species, including *H. molitrix, C. idella, H. nobilis, P. disjunctivus,* and *S. trutta,* were only observed in specific stretches. Sighting of *Pterygoplichthys disjunctivus* at the Bijnor, Uttar Pradesh raises concerns about the ability to control these invasive species in the Ganga River.

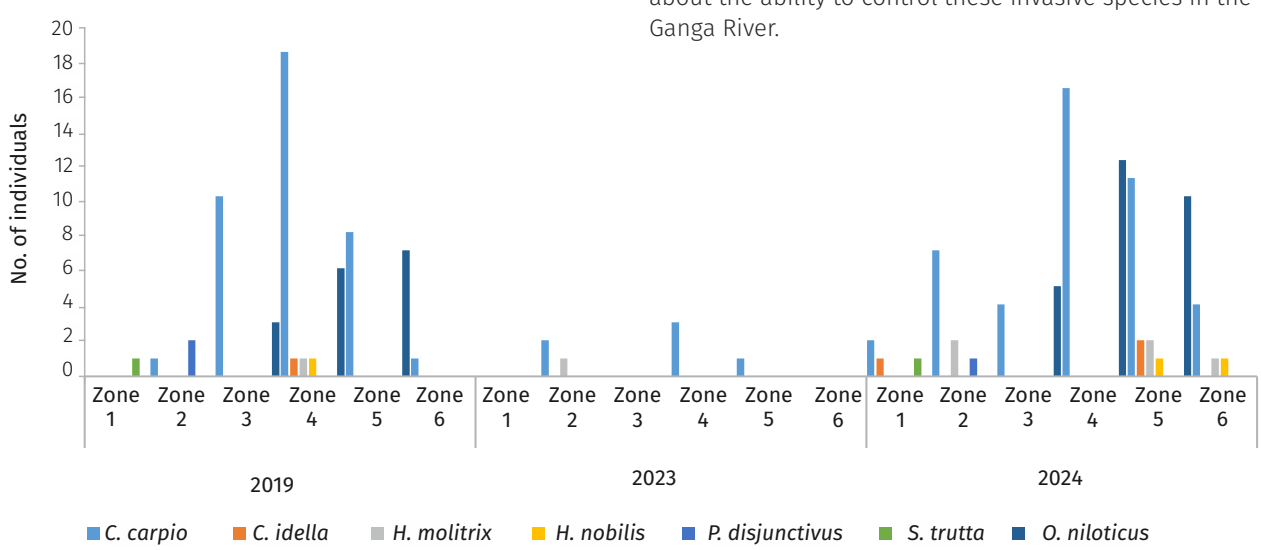


Figure 5.10 Occurrences of the invasive fish species across all Zones of the Ganga River during 2019, 2023 and 2024.

The Distribution Index (%) of the invasive fish species showed that exotic fish *C. carpio* has high distribution index values during 2019 and 2024, followed by *O. niloticus*, *C. idella*, *H. molitrix*, *H. nobilis*, *P. disjunctivus*, and *S. trutta* (Figure 5.11). Subsequently, the Distribution Index for all invasive species also increased periodically, except for *P. disjunctivus* and *S. trutta*. This highlights that *C. carpio* and *O. niloticus*, are rapidly increasing, and others are slowly increasing in the Ganga River. The stable distribution indices for *P. disjunctivus* and *S. trutta* indicate that these exotic species might have established and could invade other sites in the future. No invasive species were recorded from 19 sites during 2019 survey, while, only 8 sites had no invasive species in 2024. In 2019, the highest invasion coefficient index was recorded at Mukhba (S01; Ixi = 0.33), followed by Site 14 (Narvar Uparhar, Ixi = 0.12), Site 18 (Buxar, Ixi = 0.09), Site19 (Ballia, Ixi = 0.08), Site 17 (Ghazipur, Ixi = 0.07), Site 10 (Kannauj, Ixi = 0.05), Site 11, 12, & 15 (Kanpur, Fatehpur, & Mirzapur, each Ixi = 0.05), Site 16 (Varanasi, Ixi = 0.04), Site 13 (Prayagraj, Ixi = 0.02), and Site 5 & 26 (Bijnor & Balliaghati, each Ixi = 0.01). Whereas in 2024, highest invasion coefficient index was recorded at site 17 (Ghazipur; Ixi = 0.22), followed by site 19 (Ballia; Ixi = 0.19), Site 12, and 23 (Fatehpur, and Munger; each Ixi = 0.15), Site18 (Buxar; Ixi = 0.13), Site 11 and 20 (Chapra and Kanpur; each Ixi = 0.09), Site 16 (Varanasi; Ixi = 0.07), Site 5, 22, and 25 (Bijnor, Simariya,

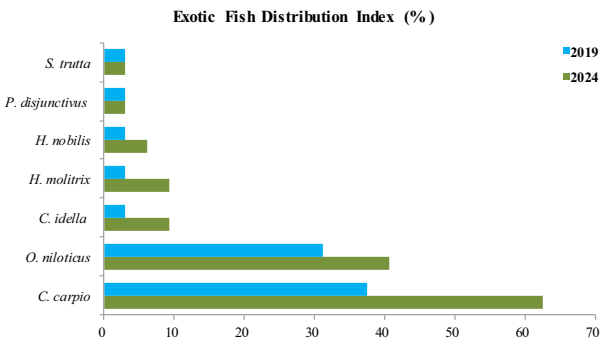


Figure 5.11 Species-wise distribution index of invasive fish in the Ganga River

and Sahibganj; each Ixi= 0.06), Site 14 & 15 (Narvar Uparhar and Mirzapur; each Ixi = 0.05), Site 10, 13, 21, 24, and 26 (Kannauj, Prayagraj, Fatwah, Kahalgaon, and Balliaghati; each Ixi= 0.06), Site 6 (Tigri Ghat; Ixi = 0.03), site 2, 3 and 29 (Dharasu, Devprayag, and Nabadwip; each Ixi = 0.02), and the Sites 12, and 23 (Haridwar and Narora; each Ixi= 0.01). Native fish in zones 3, 4, and 5 were highly vulnerable to invasive species in 2019; however, in 2024, native fish vulnerability increased in all zones of the river (Figure 5.12). These results are alarming and emphasise the importance of controlling these invasive species in the Ganga River

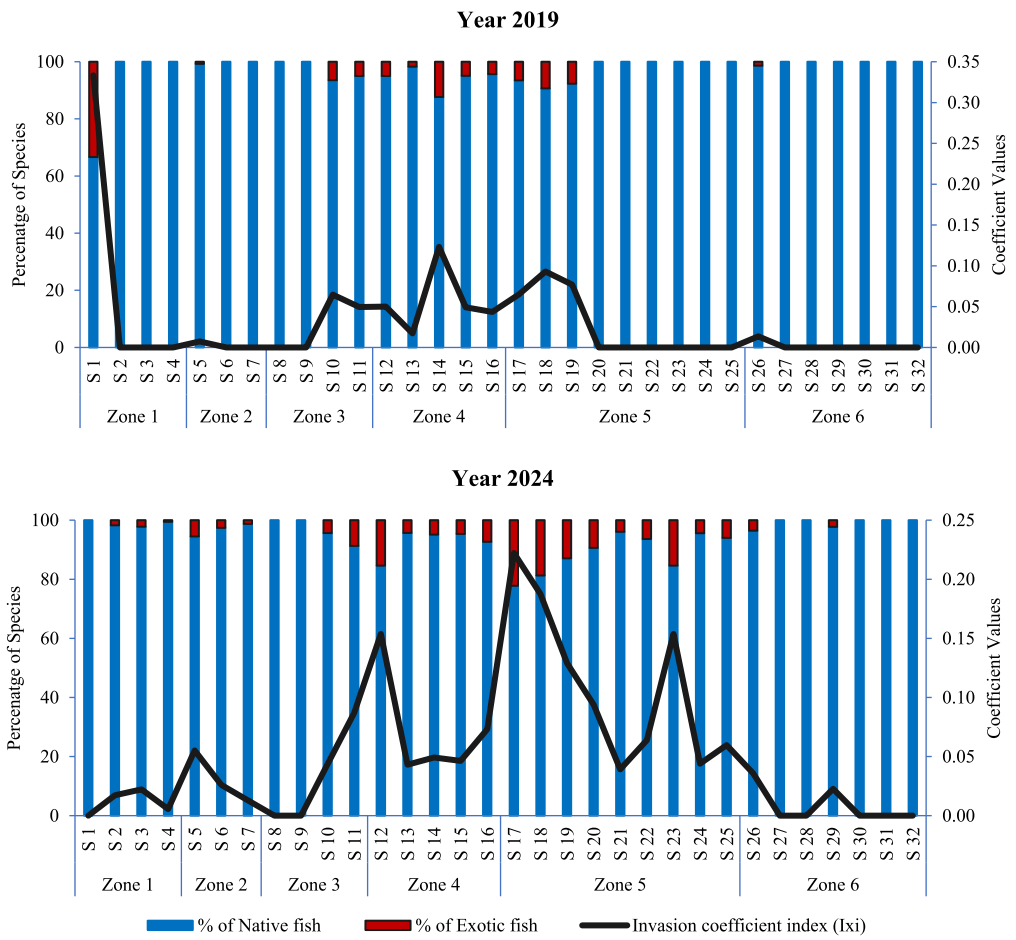


Figure 5.12 Percentage of native and exotic fish and the invasion coefficient index value across the Ganga River.

5.4 DISCUSSION

The present study provides a comprehensive temporal comparison of ichthyofaunal diversity in the Ganga River, showing substantial fluctuations in species composition, diversity indices, and fish abundance across 2019, 2023, and 2024. The notable decline in species richness from 2019 (125 species) and 2024 (114 species) to 2023 (56 species) suggests a period of ecological stress, likely linked to increased anthropogenic pressures, including pollution, habitat fragmentation, and altered hydrological regimes. Similar declining trends in the Ganga River have been previously documented, highlighting shifts in community structure and a reduction in commercially important species (Vass et al., 2010; Sarkar et al., 2012). The dominance of small, opportunistic species such as *Puntius sophore* and *Salmostoma bacaila* in 2023 reflects ecological simplification, a common response of fish assemblages to disturbed environmental conditions (Kang et al., 2009). In contrast, 2019 and 2024 showed relatively higher diversity indices and more balanced assemblages, indicating comparatively stable ecological conditions. The improvements observed in 2024, including increased CPUE and the reappearance of sensitive and threatened taxa such as *Carcharhinus leucas,* suggest partial ecosystem recovery and resilience.

In the 2019, 2023, and 2024 surveys, the highest species richness was observed in Zone 2, at site 5, Bijnor (86 in 2019, 92 in 2023, 45 in 2024), indicating a rich biodiversity hotspot for fish. The 2019 survey recorded the highest species richness, indicating a healthy river ecosystem, and few anthropogenic activities, whereas the 2023 survey exhibited the lowest species richness, reflecting degraded water quality, increased anthropogenic pollution and inadequate management practices. However, an increase in species richness observed in 2024 suggests a reduction in environmental stressors. Whereas upstream (Zone 1, Mukhba to Devprayag) in 2023 and lower stretches, Zone 6 (Kalyani to Falta Haldia) in 2023 and 2024 (Kalyani and Maheshtala) exhibited episodic zero CPUE values, indicating localised habitat degradation and possible stock depletion (Nath & Patra, 2015; Das et al. 2019). This study suggests dynamic changes in ecological health and species distribution patterns along the Ganga's longitudinal profile over the past five years.

Overall, the study highlights the sensitivity of ichthyofaunal assemblages as bioindicators of river health and underscores the urgent need for integrated river basin management strategies that focus on pollution control, maintenance of environmental flows, and habitat restoration to ensure the long-term sustainability of the Ganga River ecosystem.

CONCLUSION

The present study provides a robust temporal and spatial assessment of ichthyofaunal diversity across the main stretch of the Ganga River, revealing significant fluctuations in species richness, community composition, and fish abundance across the years 2019, 2023, and 2024. The findings clearly demonstrate that the river's ecological health is dynamic and strongly influenced by anthropogenic pressures and environmental variability. The sharp decline in species richness observed in 2023, followed by a notable recovery in 2024, highlights both the vulnerability and resilience of the Ganga River ecosystem.

Among the six zones studied, Zone 2 (Bijnor-Narora stretch) consistently emerged as a vital biodiversity hotspot, showing the highest species richness, diversity indices, and CPUE values across all survey years. This stretches likely benefits from favourable hydrological



conditions, habitat heterogeneity, and relatively lower human disturbance compared to downstream sections. Likewise, parts of Zones 3 and 5 also supported moderate diversity, highlighting their ecological importance in maintaining fish populations. In contrast, upstream (Zone 1) and lower estuarine stretches (Zone 6) showed reduced diversity and frequent low or zero CPUE, particularly in 2023, indicating habitat degradation, altered flow regimes, and pollution stress.

The study also identified several ecologically important and high-biodiversity species contributing to the river's functional integrity. Species such as *Tor putitora, Labeo rohita, Cirrhinus mrigala, Clupisoma garua,* and *Ailia coila* were observed across multiple zones, indicating their ecological significance and adaptability. The detection of the vulnerable *Carcharhinus leucas* (Bull shark) in the lower stretch further emphasises the importance of the Ganga River as a critical habitat for threatened and migratory species. However, the increasing dominance of small-bodied, opportunistic species such as *Puntius sophore* and *Salmostoma bacaila,* particularly during 2023, signals ecological simplification and stress within the system.

A major concern highlighted by the study is the presence and growing spread of invasive and exotic species, including *Cyprinus carpio, Oreochromis niloticus, Ctenopharyngodon idella, Hypophthalmichthys molitrix, Hypophthalmichthys nobilis, Pterygoplichthys disjunctivus,* and *Salmo trutta.* These species pose significant threats to native biodiversity through mechanisms such as competition for food and habitat, predation on native species, alteration of trophic structures, and the potential introduction of diseases. Their increasing occurrence and wider distribution, especially in 2024, indicates an expanding ecological footprint that could further destabilise native fish communities if left unmanaged.

From a conservation perspective, the study highlights the urgent need for zone-specific management strategies. Biodiversity-rich areas like Bijnor-Narora should be prioritised for conservation and possibly designated as fish conservation zones or aquatic biodiversity reserves. Efforts should centre on maintaining environmental flows, protecting spawning and breeding habitats, and regulating fishing pressure. In degraded stretches, especially in Zones 1 and 6, restoration measures such as pollution control, habitat rehabilitation, and flow regulation are vital to improve ecological conditions and support fish recovery. The study also emphasises the importance of long-term monitoring and adaptive management. Regular biodiversity assessments using standardised methodologies, coupled with the integration of advanced tools such as environmental DNA (eDNA) and species distribution modelling, can improve the detection of rare and invasive species and provide early warning signals of ecological changes. Additionally, strengthening community participation, promoting sustainable fisheries practices, and enhancing policy implementation under programmes like *Namami Gange* will be vital for long-term conservation success.

In conclusion, the Ganga River continues to support significant ichthyofaunal diversity, but its ecological integrity remains questionable due to potential stressors in the form of anthropogenic disturbances. The observed recovery in 2024 offers a positive remark that timely and targeted interventions can produce measurable improvements. Nevertheless, sustained and integrated river basin management, with a strong emphasis on biodiversity conservation, invasive species control, and habitat restoration, is vital to secure the long-term sustainability and resilience of the Ganga River ecosystem.



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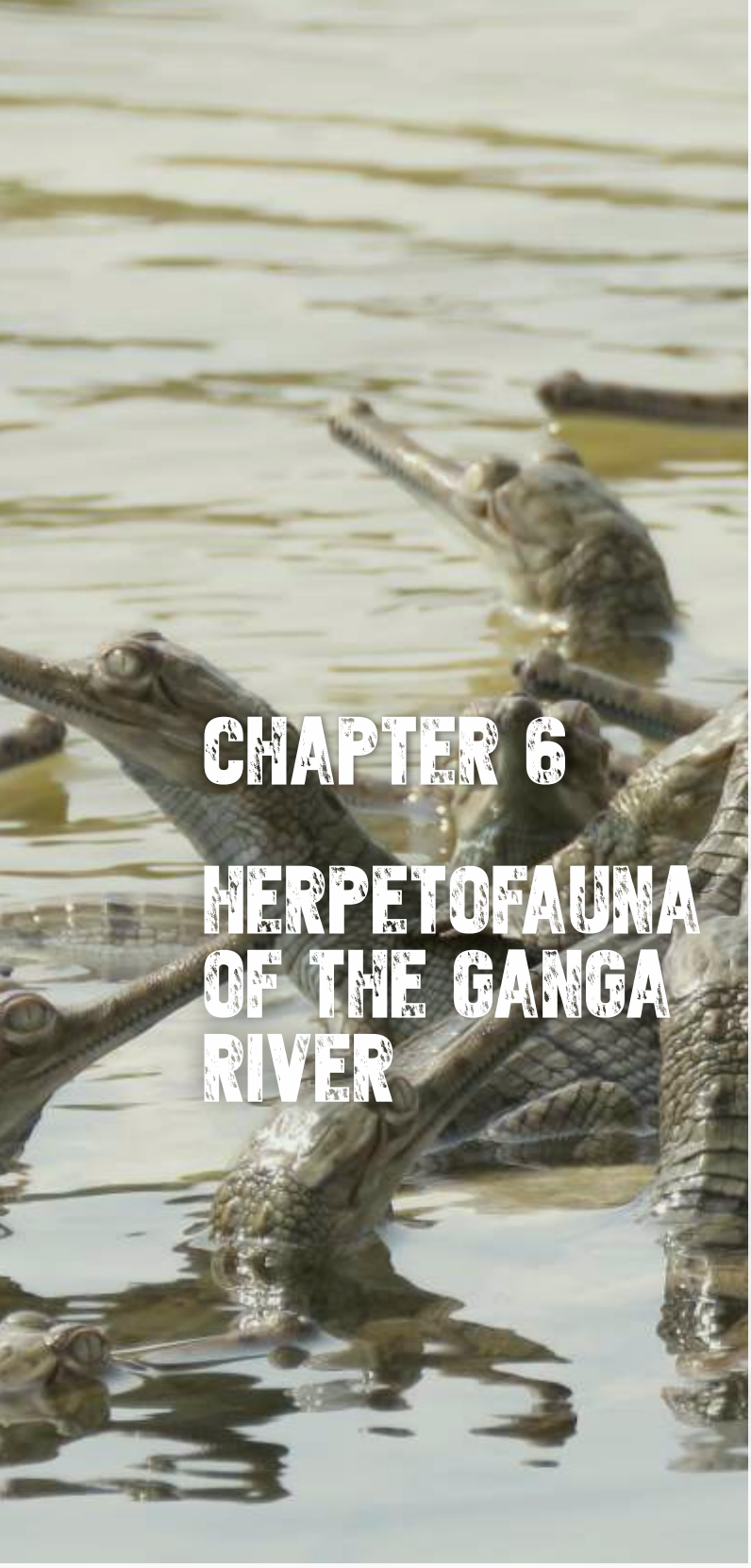
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CHAPTER 6

HERPETOFAUNA OF THE GANGA RIVER

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SUMMARY

Herpetofauna is a collective term to address the amphibians and reptiles. This group of animals are highly sensitive and thus serve as bioindicators of environmental change due to their close connectivity to the microhabitat. Herpetofauna occupy multiple trophic positions, as both prey and consumer, and connect aquatic and terrestrial food webs. Thus, their presence and abundance influence ecosystem processes. Among the herpetofauna of the Ganga River, the crocodilians are the most well studied group, followed by the turtles. This chapter provides insights into the distribution of herpetofauna (amphibians, crocodiles and turtles) along the Ganga River across multiple sampling locations. Taxa specific methodology was employed to evaluate the status of amphibians, crocodilians and turtles. Amphibians were surveyed in 2024, whereas turtles and crocodilians were surveyed in 2018, 2019 and 2020.

A total of 27 amphibian taxa belonging to 11 genera and five families were documented during 2024. The family Dicroglossidae was the most dominant, contributing 48% of the recorded species, followed by Microhylidae (22%), while Rhacophoridae, Bufonidae, and Ranidae were less represented. Species richness varied considerably across 31 sampling sites, with the highest richness observed at Bijnor (15 species) and the lowest at Dharasu (4 species). Shannon diversity indices indicated moderate to high diversity at several locations, particularly Ballia, Bijnor, and Nabadwip, whereas Byas Ghat exhibited the lowest diversity. Spatial patterns across river stretches revealed moderate diversity with noticeable variation in species composition and richness. Relative abundance analysis showed that *Microhyla nilphamariensis* was the most dominant species, followed by *Euphlyctis cyanophlyctis* and *Minervarya syhadrensis*, while several species contributed minimally to overall abundance, indicating uneven assemblage structure.

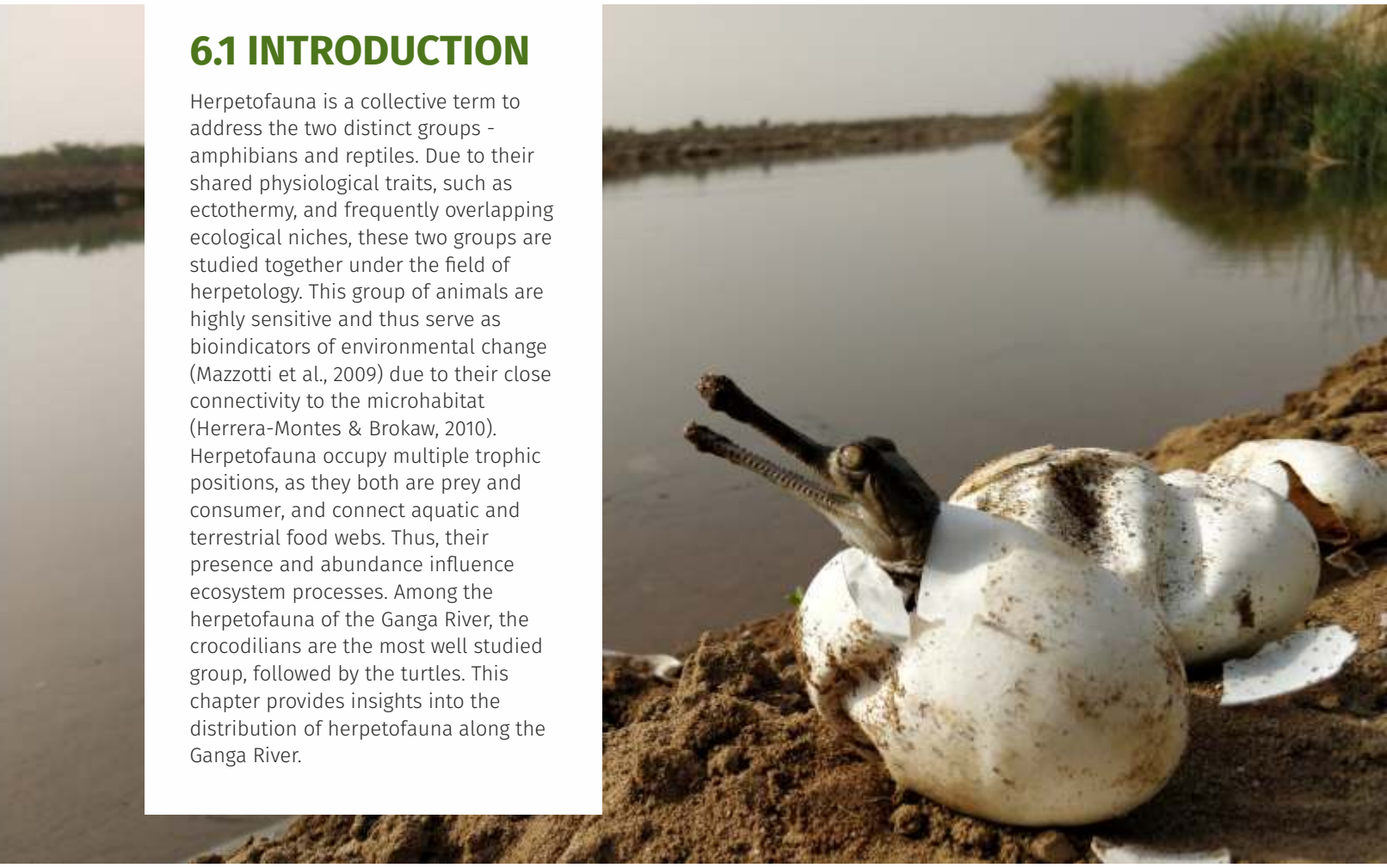
During three years of turtle monitoring between Haridwar and Ghaghra confluence of the Ganga River, an increasing trend in population was observed. In 2019, abundance and encounter rates of turtles were found highest, while lowest during 2018 dominated by the genus *Pangshura* (>96%). In addition, Critically Endangered species such as *Batagur dhongoka* and *B. kachuga* were confirmed during the present study from different sites. Turtle distribution was found to be highly clustered; the middle Ganga (HZ-3 and HZ-4) consistently supported the highest abundance, while the upper and lower extremes recorded negligible sightings.

Statistical analyses (ANOVA and GLM) confirmed that water depth and habitat zone are primary predictors of the turtle distribution. Species distribution models (AUC 0.76-0.99) revealed varying ecological niches in the Ganga Riverscape, *Batagur* spp. and *Chitra indica* were restricted by climatic variables and require stable upstream/middle stretches with sandbars and deep pools. *Nilssonia gangetica* exhibited higher ecological tolerance, primarily influenced by terrain ruggedness. *Melanochelys trijuga* demonstrated minimal suitability within the riverscape, suggesting a reliance on off-channel lentic habitats. Over 90% of the riverscape was found unsuitable for specialized species.

Gharial was the only member of the three crocodilian species that was frequently encountered along the Ganga River mainstem. The salt-water crocodile (*Crocodylus porosus*) was not assessed during this study. Mugger sightings were rare during the surveys. Only two individuals were recorded during the PoM 2019 survey, while a single individual was observed during the PoM 2020 survey. The ecological assessments conducted during post-monsoon surveys from 2018 to 2020 indicated that gharial was primarily confined to the Hastinapur Wildlife Sanctuary, with sporadic occurrences upstream and downstream along the Ganga River. The minimum population size increased from 27 individuals in 2018 to 43 in 2020, accompanied by a corresponding rise in encounter rates. However, population structure exhibited temporal variability, with no hatchlings recorded across surveys and fluctuations observed among juvenile, sub-adult, and adult classes. Long-term trends (2018-2024) suggested a gradual increase in gharial encounter rates; however, this trend was not statistically significant. Moreover, the majority of surveyed units recorded no sightings, underscoring the species' restricted distribution and fragmented population.

Overall, observed patterns highlight that amphibian diversity has increased since 2017-18, and gharial population also exhibited an increase over the years. Recent records of *Amolops jaunsari* reiterate the importance of manistem Ganga River for amphibians in the Himalayan region. Turtle conservation must prioritize protecting sandbar complexes, regulating sand mining, and maintaining natural flow regimes in core habitat patches within Uttar Pradesh and Bihar. Overall, the findings emphasize the need for sustained monitoring and targeted conservation interventions to ensure the persistence of these ecologically important taxa in the Ganga River.





6.1 INTRODUCTION

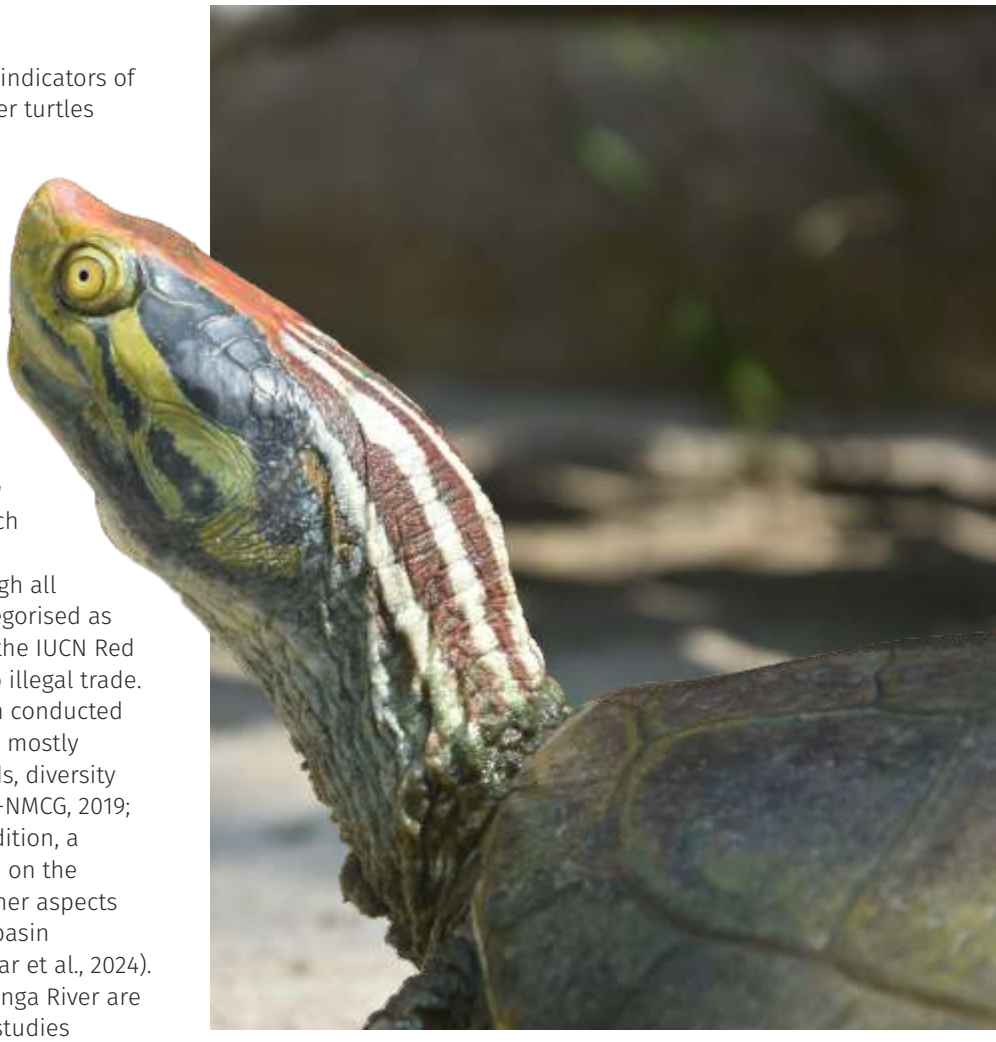
Herpetofauna is a collective term to address the two distinct groups - amphibians and reptiles. Due to their shared physiological traits, such as ectothermy, and frequently overlapping ecological niches, these two groups are studied together under the field of herpetology. This group of animals are highly sensitive and thus serve as bioindicators of environmental change (Mazzotti et al., 2009) due to their close connectivity to the microhabitat (Herrera-Montes & Brokaw, 2010). Herpetofauna occupy multiple trophic positions, as they both are prey and consumer, and connect aquatic and terrestrial food webs. Thus, their presence and abundance influence ecosystem processes. Among the herpetofauna of the Ganga River, the crocodilians are the most well studied group, followed by the turtles. This chapter provides insights into the distribution of herpetofauna along the Ganga River.

6.1.1 Amphibians

Amphibians play a crucial role in ecosystem services and are highly sensitive to environmental changes (Liu et al., 2021). Their supporting services include structural components like ecosystem functions and processes (Hocking & Babbitt, 2014). This allows them to be used as an indicator species of pollution, climate change, and environmental toxicity (Olson & Saenz, 2013), aiding ecologists in understanding ecosystem functioning. Moreover, amphibians are essential in regulating insect populations through predation (Bowatte et al., 2013; Khatiwada et al., 2016). As prey, amphibians also sustain the higher trophic levels within an ecosystem (Poulin et al., 2001). Amphibians are identified as one of the most threatened vertebrate groups in the world (Stuart et al., 2004; Sodhi et al., 2008; Borzée et al., 2025). Their decline may signal freshwater ecosystem service loss (Collins et al., 2009) and aid in predicting biotic and abiotic changes as well as species extinction (Sekercioglu et al., 2004). A total of 454 species of amphibians have been recorded from India, of which 411 species belong to order Anura, 2 species belong to order Caudata and 41 species belong to order Gymnophiona (Dinesh et al., 2023). Sporadic and regional studies on Amphibians conducted in the Ganga River, identified 17 species of amphibians (Chandra, 1991; Sharma, 1991; Kanaujia et al., 2017; Boruah et al., 2020). A systematic and comprehensive study on the amphibians from the Ganga River is lacking and thus this study was undertaken to address this gap.



6.1.2 Turtles



Akin to amphibians, reptiles can also act as indicators of environmental changes, especially freshwater turtles (Adams et al. 2016; Otten et al. 2023). They are considered as one of the most threatened taxa due to illegal trade in India and elsewhere (Badola et al., 2019; Stanford et al., 2020). In India, turtles and tortoises are distributed throughout different biogeographic zones, reflecting one of the turtle priority areas globally (Buhlmann et al., 2010; Mittermeier et al., 2015). There are 14 turtle species found in the Ganga River Basin (Talukdar et al., 2019). *Batagur baska*, *B. dhongoka* and *B. kachuga* are three critically endangered species, which thrive in the Ganga River system (Moll, 1987; Kumar et al., 2024; Balan et al., 2025). Although all 14 species found in the Ganga River are categorised as Threatened or Near Threatened species on the IUCN Red List, they remain understudied and prone to illegal trade. To date, only a handful of studies have been conducted on the freshwater turtles in the Ganga River, mostly focused on the individual occurrence records, diversity and breeding biology (Singh et al., 2006; WII-NMCG, 2019; Singh et al., 2025; Tripathi et al., 2025). In addition, a couple of studies have also been conducted on the genetic identity, population genetics and other aspects of turtle species in the Ganga River and its basin (Yadav et. al., 2021; Talukdar et al., 2021; Kumar et al., 2024). Nevertheless, turtles and tortoises in the Ganga River are understudied and warrant more ecological studies (Singh et al., 2009).



6.1.3. Crocodilians

Three species of crocodiles viz. the gharial (*Gavialis gangeticus*), the mugger or marsh crocodile (*Crocodylus palustris*), and the saltwater crocodile (*Crocodylus porosus*) are found along the Ganga River (Bustard, 1975; Hussain, 1999; Grigg & Kirshner, 2015). The gharial (*Gavialis gangeticus* Gmelin, 1789) is a Critically Endangered freshwater crocodilian species endemic to the northern part of the Indian subcontinent (Hussain, 1999; Lang et al., 2019). The gharial has the narrowest distribution range and is the most threatened species among all other crocodilians occurring in the Indian subcontinent. Until the early 20th century, the gharial was widely distributed in the Ganga, Indus, Mahanadi, Brahmaputra, Kaladan and Irrawaddy River systems spanning across Pakistan, India, Nepal, Bangladesh, Bhutan, and Myanmar (Singh, 1978; Whitaker & Basu, 1982; Hussain, 1999). Over the years, the gharial has suffered a population decline of over 80% and substantial range contraction due to habitat loss, poaching, and mortalities in passive fishing (Bustard, 1975; Hussain, 1999; 2009). Conservation interventions, including captive rearing and release programs and the protection of suitable habitats through the establishment of protected areas, have helped reverse the decline of gharial populations. In the Ganga River, the highest

number of gharials has been reported from Hastinapur Wildlife Sanctuary (HWLS) in Uttar Pradesh, while sporadic sightings of isolated individuals have also been documented from several other locations, particularly after monsoon floods (Sarkar et al., 2018). Nevertheless, tributaries such as the Chambal, Ghaghra, and Gandak rivers have continued to function as major refugia for the species (Panda et al., 2023; Sharma et al., 2025). Conservation interventions initiated during the 1970s under the Crocodile Conservation Project including captive rearing and release (grow-and-release) programs, the establishment of protected areas such as the National Chambal Sanctuary, Son Gharial Sanctuary played a critical role in stabilizing and partially recovering gharial populations in the Ganga River Basin (Sharma et al., 2021).

The mugger (*Crocodylus palustris* Lesson, 1831) is a medium-sized freshwater crocodile, a member of the family Crocodylidae. It is principally restricted to the Indian subcontinent, extending up to eastern Iran. The mugger occurs in inland freshwater habitat types, including lakes, marshes and rivers, or any other slow moving and shallow rivers (Jacobson, 1999). The muggers are adapted well to natural as well as man-made habitats. The species occurs in sympatric relation with gharial in the north Indian rivers such as the Chambal, Girwa and Ramganga, and the Mahanadi in eastern India (Choudhary et al., 2017). The third crocodilian species, the salt water crocodile (*C. porosus*), found in the Sunderban delta of the Ganga River basin, was not surveyed for this study.



6.2. METHODS

6.2.1 Amphibians

The study was conducted at 32 sites in six habitat zones between July and October 2024 (Figure 6.1). A time-constrained Visual Encounter Survey (VES) method was employed to evaluate the status of amphibians in the Ganga River (Crump and Scott, 1994; Khatiwada et al., 2016). At each site, VES was performed at dusk from 1900 to 2100 h, supplemented by opportunistic surveys to record amphibians. The observers walked approximately 1 km on a 5 km wide transect searching along banks of the river recording all amphibian species encountered. Surveys covered all potential habitats within a 500 m buffer area along the Ganga River, including river mouths, wetlands, pools, crop fields, and other temporary water bodies. Species identification was done using field guides by Smith (1935, 1943), Das (1996), Dutta (1997), Chanda (2002), Schleich and Kastle (2002), and Das and Das (2017). The nomenclature and taxonomic classification adhere to the standards set by Frost (2018) and Dinesh et al. (2023). The threat status of the documented species has been determined using the IUCN Red List criteria (http://www.iucnredlist.org). The present amphibian richness was also compared with monitoring data from 2017-18 to assess and infer potential temporal trends.





6.2.2 Turtles

Continuous boat-based surveys were conducted across each BEU employing the VES method along the Ganga River mainstem between Haridwar and Ghaghra confluence. Turtles observed basking or resting along riverbanks, snags, or surfacing in the water column were recorded using binoculars during daylight hours (0700-1700 h). Species identification was carried out following the field guide (Talkukdar et al., 2019). To detect elusive or rare species, net sampling was also employed. Nylon gill nets with mesh size of 4" & 8" were deployed at selected sampling sites only during the 2018 assessment (WII-NMCG, 2019), with an effort duration of 3-4 hours. Nets were monitored at two-hour intervals to minimize stress, and all captured individuals were promptly released after recording basic morphometric and ecological data. Relative abundance was calculated as the proportion of total sightings contributed by each habitat zone and substrate category. Encounter rates were inferred based on the frequency of observations within the habitat zones. For trend analysis of turtles, the natural log transformed encounter rates of three temporal scale data (2018, 2019 & 2020) were used for linear regression. The influence of habitat variables on turtle distribution was assessed using rigorous statistical analyses. A one-way Analysis of Variance (ANOVA) was performed to test for significant differences in water depth across habitat zones, treating habitat zone as a categorical predictor and depth as the response variable (Congdon et al., 1992). A Generalized Linear Model (GLM) with a Poisson error distribution was applied to examine the relationship between turtle abundance and habitat zones (Stratmann et al., 2019; Araya-Donoso et al., 2022).

The habitat suitability models for turtles prepared using the MaxEnt algorithm incorporated climatic, topographic, and anthropogenic variables that are ecologically relevant for determining the distribution of freshwater turtles within the 10 km buffer of the Ganga River, referred as Ganga Riverscape (Kumar et al., 2024; Panda et al., 2024). A total of bioclimatic variables derived from the WorldClim dataset, along with human disturbance and terrain-related variables, were considered in the modeling framework. The bioclimatic variables included Annual Mean Temperature (bio1), Mean Diurnal Range (bio2), Isothermality (bio3), Temperature Seasonality (bio4), Maximum Temperature of the Warmest Month (bio5), Minimum Temperature of the Coldest Month (bio6), Temperature Annual Range (bio7), Mean Temperature of the Wettest Quarter (bio8), Mean Temperature of the Driest Quarter (bio9), Mean Temperature of the Warmest Quarter (bio10), Mean Temperature of the Coldest Quarter (bio11), Annual Precipitation (bio12), Precipitation of the Wettest Month (bio13), Precipitation of the Driest Month (bio14), Precipitation Seasonality (bio15), Precipitation of the Wettest Quarter (bio16), Precipitation of the Driest Quarter (bio17), Precipitation of the Warmest Quarter (bio18), and Precipitation of the Coldest Quarter (bio19) (Lê et al., 2024; Rai et al., 2023). In addition to these climatic predictors, two landscape variables representing environmental heterogeneity and anthropogenic pressure were included in the model: Human Footprint Index, Terrain Ruggedness Index, and Slope (elevation) (Duan et al., 2014). These 22 variables collectively represent climatic conditions, habitat structure, and human disturbance gradients that potentially influence the distribution and habitat suitability of freshwater turtles in the Ganga Riverscape. The model was developed using presence-only occurrence records from the river channel, along with selected bioclimatic, topographic, and anthropogenic variables. Model performance was evaluated using receiver operating characteristic (ROC) analysis.

6.2.3 Crocodilians

Boat-based visual encounter surveys were conducted in each BEU to document the occurrence and number of crocodilian species along the banks of the Ganga River during different sampling years. The survey was conducted during daylight between 1000 and 1600 h. A motorboat fitted with a 25HP outboard engine was used to survey the river, and the speed of the boat was maintained between 8 and 10 km/ hr. Two observers equipped with 8 × 40 mm binoculars were positioned to spot the basking gharial. The gharial was identified based on their morphology using established description keys following the identification guide. When spotted, the number of gharial individuals, visually estimated size and associated habitat variables were recorded for each sighting. The observed individuals were categorized into the following size classes: Hatchlings (< 0.6 m), Yearlings (0.6-0.9 cm), Juveniles (0.9-1.8 cm), Sub-adults (1.8-3.0 m), and Adults (> 3.0 cm) (Hussain, 1999). The total number of gharials observed during the surveys was referred to as Minimum Population Size (MPS). MPS is the minimum number of individuals to be present within the surveyed area (Barao-Nobrega et al., 2022). The MPS provides a conservative baseline estimate of population size (Sánchez-Herrera et al., 2011). We used the MPS to estimate gharial encounter rate, i.e., individuals sighted per km of the river stretch. For each river surveyed, the encounter rate was also calculated, referred to as the relative density index, which is defined as the number of gharials observed per kilometre of river surveyed (Bayliss, 1987). This index serves as a useful comparative metric for evaluating population density across spatial units and temporal periods and helps inform conservation prioritization and management interventions. In addition, trends were also determined based on available information for four temporal periods (2018, 2019, 2020 & 2024) using natural log transformed encounter rates.



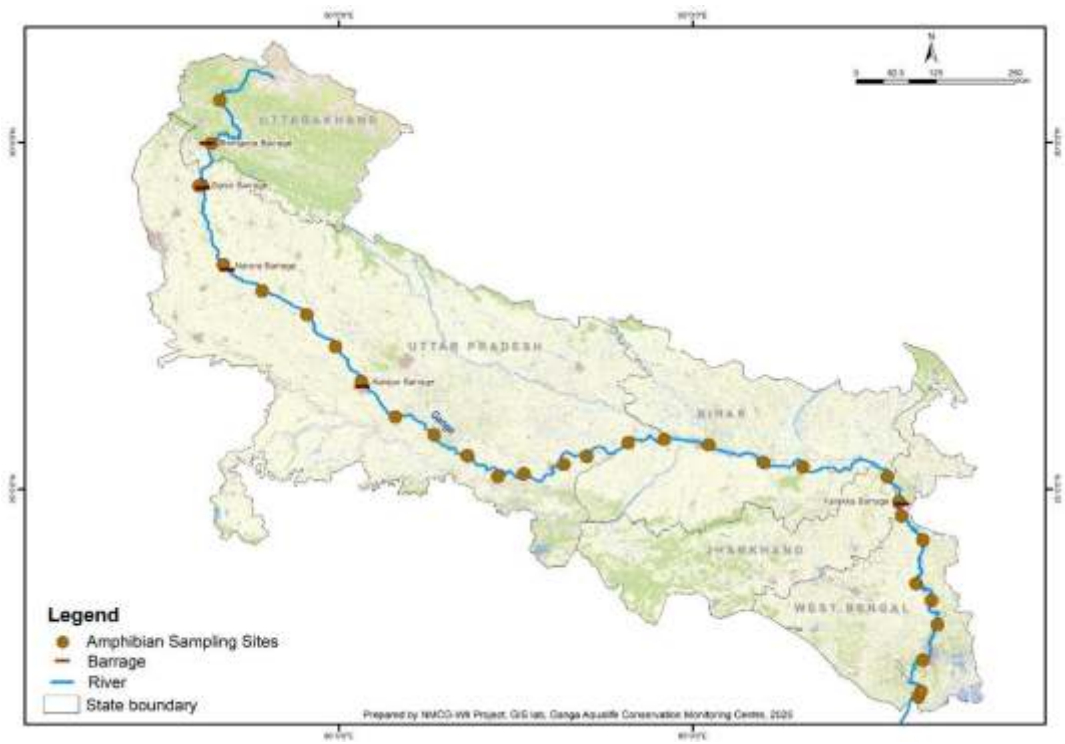


Figure 6.1 Intensive Monitoring sites for amphibians in the Ganga River

6.3 RESULTS

6.3.1 Amphibians of Ganga River

During the survey, 27 amphibian taxa were recorded from 13 genera and five families (Annexure IV). Among, 26 of these were identified to the species level, whereas one taxon (*Minervarya* spp.) could only be identified to the genus level and was thus not included in estimates of species-level richness. Among these, the family Dicroglossidae was the most dominant, contributing 11 species (48%) of the total assemblage. This was followed by Microhylidae, which accounted for five species (22%). The family Rhacophoridae was represented by four species (17%), while Bufonidae comprised three species (13%). In contrast, Ranidae was least represented, with only one species (4%) recorded during the survey (Figure 6.2). Altogether, 25 species are classified as Least Concern (LC) and one as Data Deficient (DD) on the IUCN Red List.



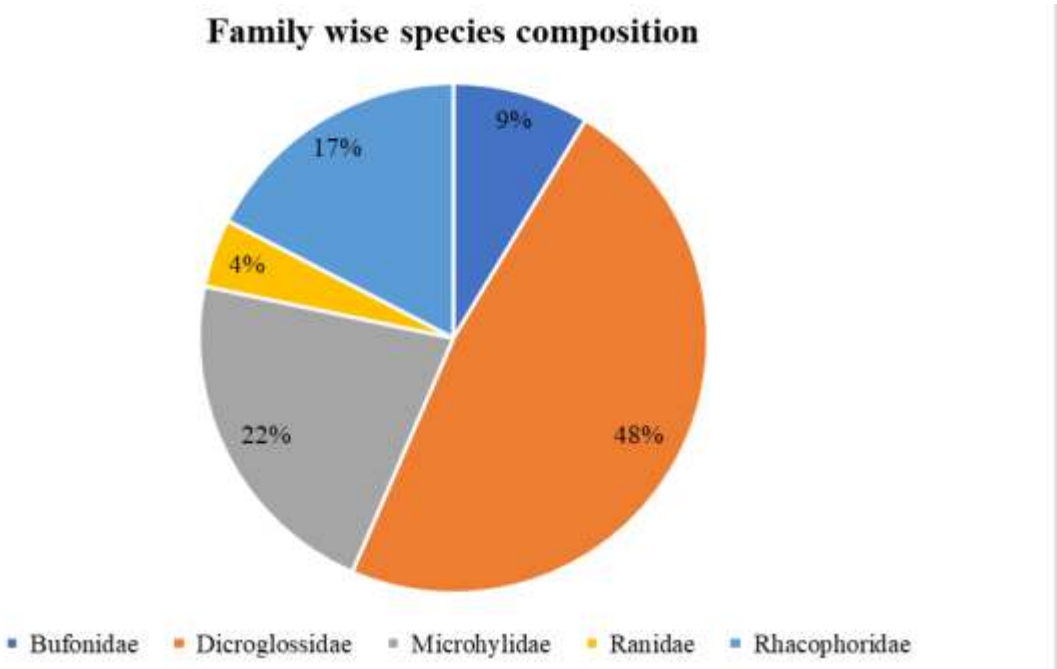


Figure 6.2 Amphibian families documented during 2024 along the Ganga River

A total of 12 species were recorded from the upper stretch, and 19 species each from the middle and lower stretches of the Ganga River. Among the sampled sites of the Ganga River, Bijnor had the highest species richness with 15 species with a Shannon diversity index value of *H'*= 2.20. Kalyani and Katwa followed closely, each with 14 species. Species richness was lowest in Dharasu with only four species, while Mirzapur, Tigri Ghat, and Byas Ghat each reported five species. Ballia (*H'*= 2.35), Bijnor (2.20), and Nabadwip (2.18) had the highest diversity values, while Byas Ghat had the lowest at 1.05. Sites with high species richness and diversity values between 2.1 and 2.3, reflected relatively stable diversity (Figure 6.3).

In the upper stretch of the river, Haridwar recorded the highest diversity value (1.85) with eight species, while Dharasu with lowest diversity value (1.30) with four species. In the middle stretch, Ballia had the highest diversity value (2.35), with 12 species, whereas Tigri Ghat recorded the lowest diversity (1.23) with five species. In the lower stretch, Nabadwip exhibited the highest diversity (2.18) with 13 species, while Maheshtala recorded the lowest diversity value (1.75) with 8 species (Figure 6.3).

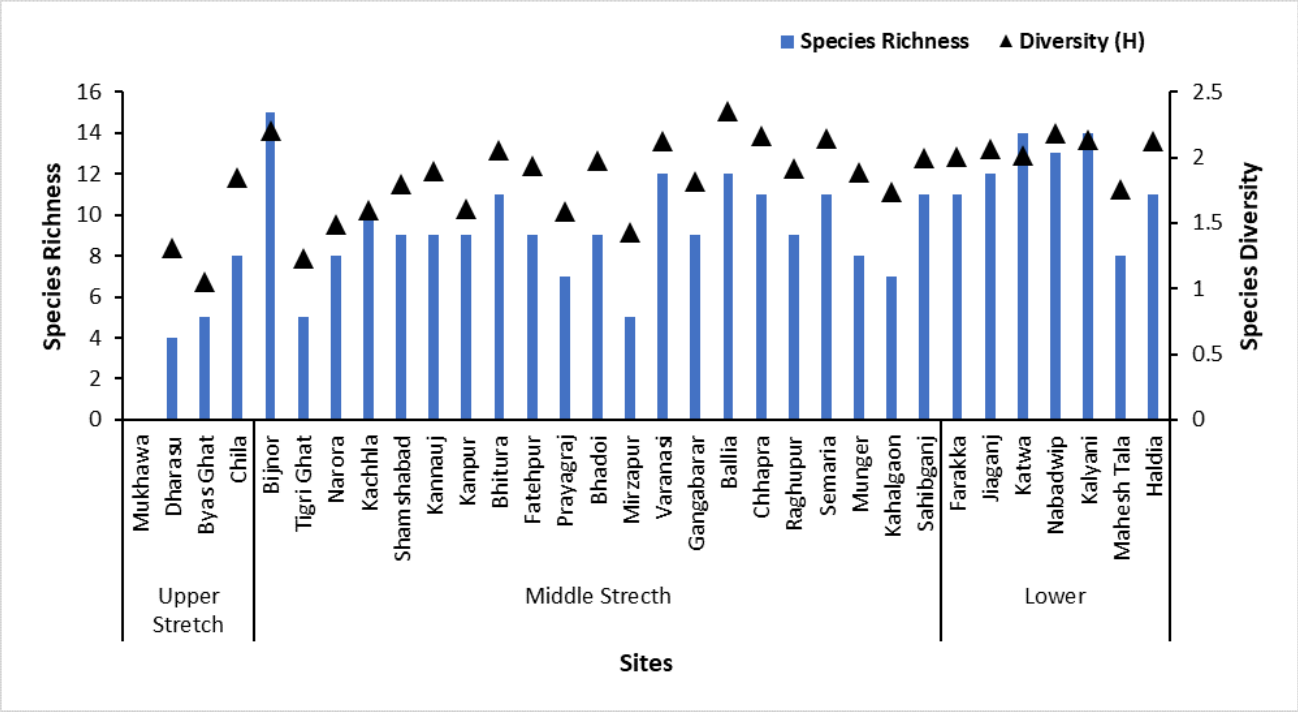


Figure 6.3 Amphibian richness and diversity in 31 sampling sites along the Ganga River

I. Relative abundance of the Amphibians

Among the 27 species, *Microhyla nilphamariensis* was the most abundant (18.33%), followed by *Euphlyctis cyanophlyctis* (12.67%) and *Minervarya syhadrensis* (11.18%). While *Duttaphrynus himalyensis*, *Uperodon variegatus* and *Fejervarya cf. moodiei* accounted for < 0.10% of the total relative abundance (Figure 6.4). Of recorded species, *D. himalyansus* (0.06%) was found to be restricted to the Himalayan ranges. Besides, occurrence of *Amolophs jaunsari* (0.60%) in Devprayag stretch of the mainstem Ganga River is a rare record.

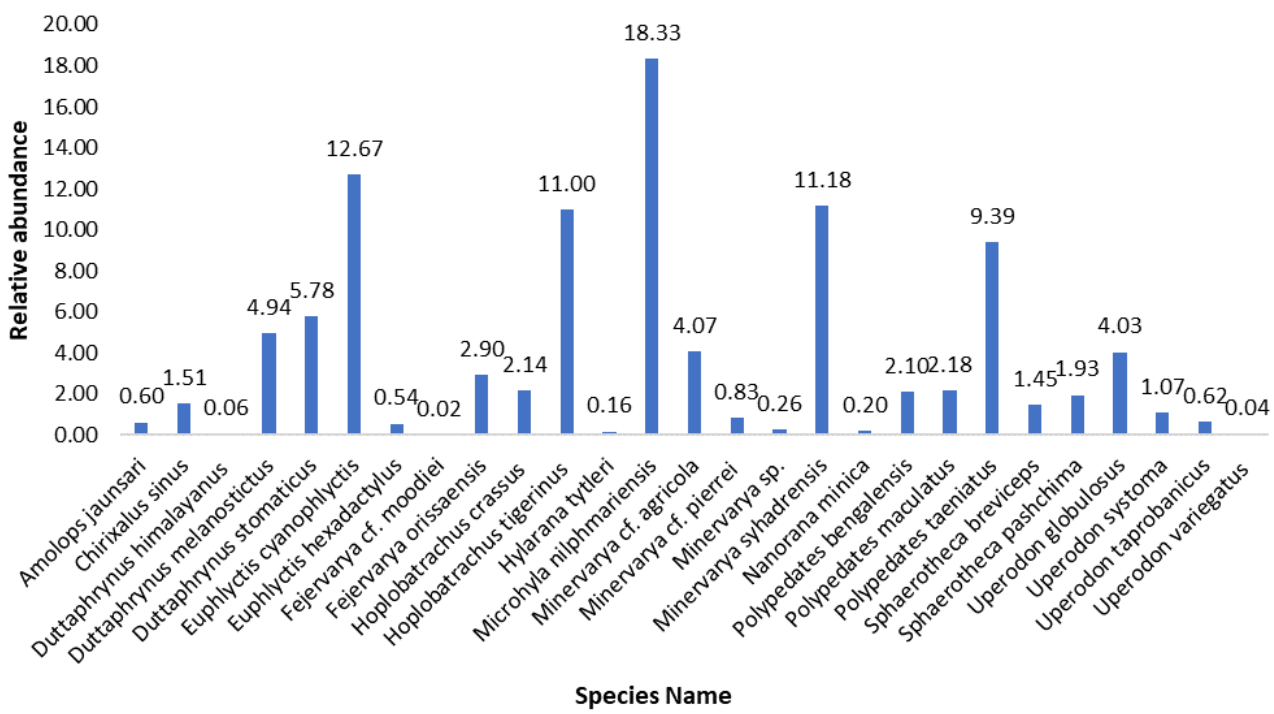


Figure 6.4 Relative abundance of amphibians in the Ganga River

II. Trends in Amphibian richness

Present findings of 2024 were compared with a previous assessment undertaken in 2017-18 (WII-NMCG, 2019). A total of 25 sites were sampled during 2017-18, while all 32 sites were sampled during 2024 (Table 6.1). Overall, richness patterns during two temporal periods (2017-18 and 2024) exhibited trends for 25 overlapping sites studied between Byas Ghat (Uttarakhand) and Haldia (West Bengal). An increasing trend was found in the sitewise amphibian richness over the years, with comparatively higher richness during 2024 than 2017-18 assessment (Table 6.1). In 2017-18, species richness varied between 2 and 8 per site. During 2024, the highest 15 species were recorded from Bijnor (S5), whereas no species was recorded from S1 (Mukhwa) (Table 6.1). Mukhwa and other six sites were not sampled during 2017-18.

Table 6.1 BEU and site wise variation in species richness and diversity during two assessments (2017-18 & 2024)

BEU No	Site Name	Longitude	Latitude	2017-18	2024
7	Mukhawa	78.78728	31.040785	-	0
25	Dharasu	78.32826	30.621249	-	4
43	Byas Ghat	78.59156	30.084577	4	5
55	Chila	78.23437	30.006587	-	8
70	Bijnor	78.03303	29.434392	8	15
86	Tigri Ghat	78.15298	28.825642	7	5
101	Narora	78.36568	28.245238	7	8
116	Kachhla	78.91359	27.866842	510	
131	Shamshabad	79.52496	27.543049	5	9
146	Kannauj	79.96274	27.109421	5	9
161	Kanpur	80.29786	26.569625	5	9
176	Bhitura	80.7477	26.076239	-	11
191	Fatehpur	81.30711	25.824989	4	9
206	Prayagraj	81.78004	25.481039	4	7
225	Bhadoi	82.19884	25.208651	2	9
236	Mirzapur	82.60052	25.230269	3	5
253	Varanasi	83.1382	25.336288	4	12
266	Gangabarar	83.53875	25.437415	3	9
281	Ballia	84.04185	25.636455	3	12
296	Chhapra	84.6264	25.727402	5	11
311	Raghupur	85.3131	25.573109	-	9
326	Semaria	85.98233	25.398234	4	11
341	Munger	86.56944	25.353448	3	8
366	Kahalgaon	87.17932	25.291065	-	7
371	Sahibganj	87.77432	25.244103	2	11
383	Farakka	87.93215	24.63059	5	11
401	Jiaganj	88.25379	24.266115	4	12
416	Katwa	88.19602	23.765048	414	
430	Nabadwip	88.36627	23.462553	5	13
446	Kalyani	88.45382	23.044451	414	
461	Mahesh Tala	88.24024	22.537027	-	8
476	Haldia	88.18405	22.051548	5	11

6.3.2 Turtles

I. Distribution, population count and encounter rate

Across the study period, a total of 32,309 turtle individuals representing seven genera were recorded along the mainstem of the Ganga River, indicating substantial temporal and spatial variation in turtle distribution. In 2018, 3,883 individuals belonging to six genera were documented, with a mean group size of 12.86 ± 1.10 SE (range = 1-127 individuals). A marked increase followed in 2019, where 15,132 individuals from five genera were recorded, exhibiting a significantly higher mean group size of 86.47 ± 3.25 SE (range = 1- 430 individuals). In 2020, 13,294 individuals representing seven genera were observed, with a mean group size of 47.82 ± 4.50 SE (range = 1-500 individuals). These results indicate strong inter-annual variability, with 2019 showing a peak, followed by a slight decline in 2020, while remaining substantially higher than 2018.

The encounter rate (ER), shown as the number of individuals per kilometer, varied considerably across years (Figure 6.5). The highest mean ER was recorded in 2019 (20.04 ± 2.82 SE individuals/km), followed by 2020 (11.17 ± 1.96 individuals/km), while the lowest was observed in 2018 (3.32 ± 0.66 individuals/km). Although there was an apparent increasing trend in ERs from 2018 to 2020, regression analysis indicated that this trend was not statistically significant ($R^2 = 0.43$, $p = 0.53$) (Figure 6.5). The elevated Ers in 2019 and 2020 likely reflect improved detection conditions, seasonal behavior, particularly in middle river stretches.



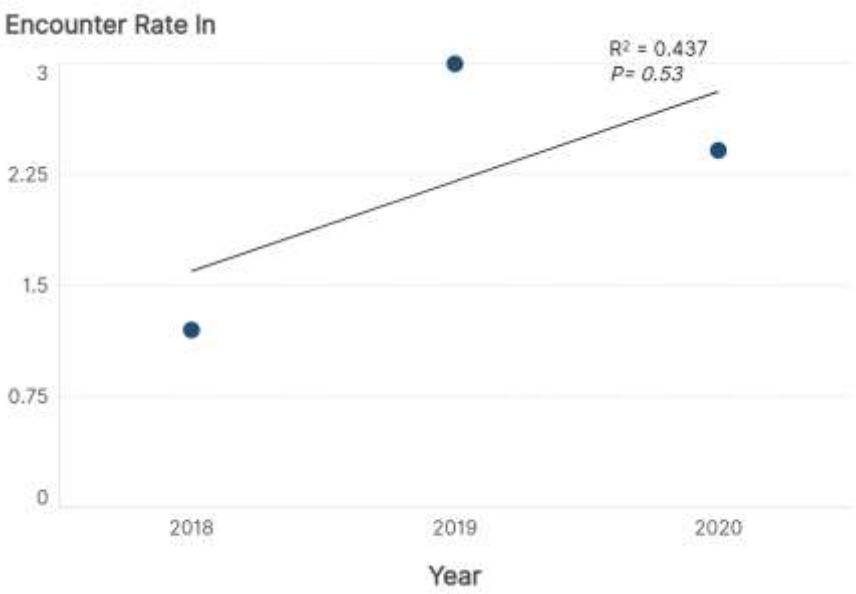


Figure 6.5 Temporal trends in encounter rate (ER) of Turtles between 2018 and 2020 monitoring

Turtle distribution exhibited strong spatial clustering across habitat zones (Figure 6.6). The majority of observations were concentrated in HZ-3 (Narora-Kanpur: Bithura, Manikpur, Tela, Kolhar, Mustafabad Ramchandrapur) and HZ-4 (Kanpur-Varanasi: Zamania Gangbarar, Pipora, Ravelganj, Raghupur, Maranichi, Tilakpur, Kahalgaon, Maharajpur). In 2018, these zones together accounted for approximately 94% of total sightings, with HZ-3 alone contributing 58.98% and HZ-4 contributing 35.02%. Similar spatial dominance of these zones was evident in 2019 and 2020, indicating that the middle Ganga stretch consistently supports the highest turtle abundance and encounter rates. In contrast, HZ-2 (Haridwar-Narora: Gangoli Khadar, Tigri, Narora, Sanwajpur, Azizabad, Mehendipur) and HZ-5 (Varanasi-Farakka: Chandpur, Jiaganj-Azimganj, Naliapur, Rudrapura Nabadwip, Raninagar Kalyani, Maheshtala, Haldia-Diamond Harbor) showed comparatively lower abundance, while negligible or no sightings were recorded in HZ-1 (Gangotri-Haridwar) and HZ-6 (Farakka-Ganga Sagar).

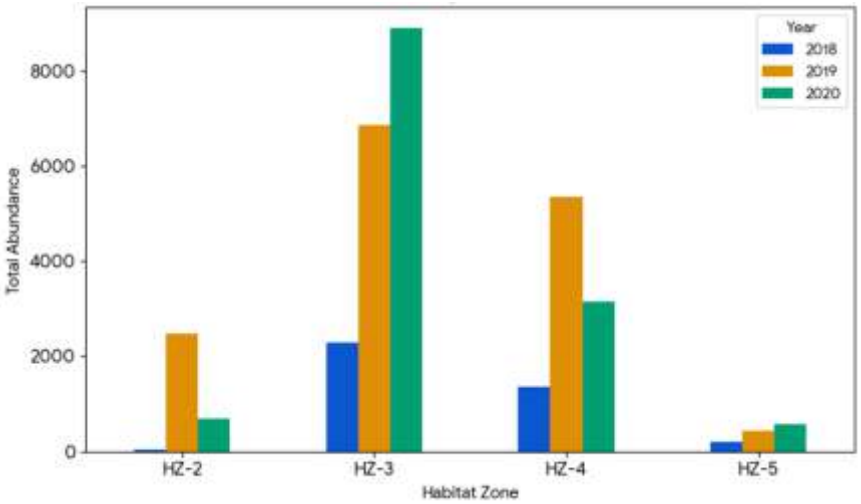


Figure 6.6 Habitat zone-wise variation in turtle abundance across three survey years (2018-2020) along the mainstem of the Ganga River

Across all surveys, genus *Pangshura* is the most dominant genus, contributing more than 96% of total observations, indicating its strong ecological adaptability and widespread distribution across habitat zones. This was followed by Genus *Nilssonia*, which showed moderate abundance and broad habitat tolerance, occurring across HZ-2 to HZ-5. Sporadic occurrences of critically endangered species *Batagur dhongoka* and *Batagur kachuga* were recorded, primarily within HZ-2 (Haridwar-Narora stretch), suggesting that this zone may serve as a species-specific refuge. *Chitra Indica* were extremely rare, with minimal detections in lower and transitional zones.

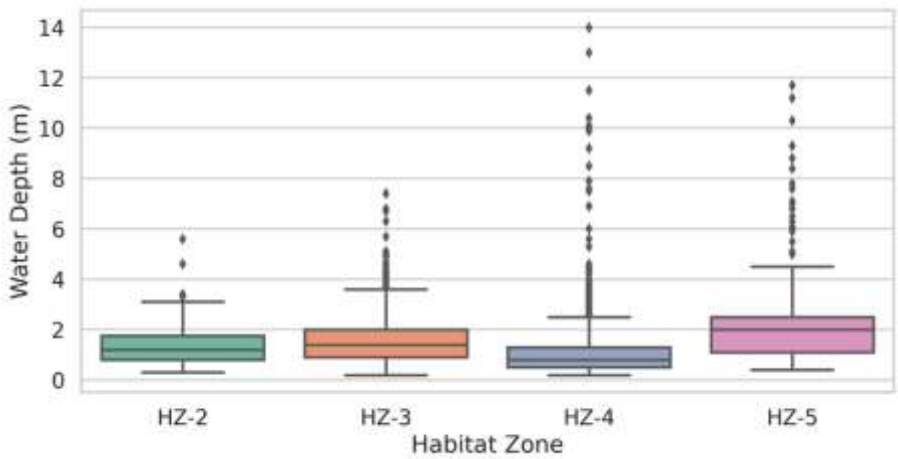


Figure 6.7 Variation in water depth (m) across habitat zones along the mainstem of the Ganga River. Boxplots represent the median, interquartile range, and outliers for each zone.

Statistical analyses confirmed that habitat variables significantly influenced turtle distribution. A one-way ANOVA revealed significant variation in water depth across habitat zones ($F_{3,3879} = 113.43$, $p < 0.001$), indicating that each zone represents a distinct hydrological environment (Figure 6.7). A Poisson GLM further demonstrated that habitat zone was a significant predictor of turtle abundance ($p < 0.001$), with HZ-3 and HZ-4 showing significantly higher expected counts compared to other zones.



II. Habitat Suitability of Turtles in the Ganga Riverscape

A. Genus *Batagur*

Species distribution modeling using the MaxEnt algorithm predicted the potential distribution of *Batagur* spp. in the Ganga Riverscape. The model demonstrated high predictive accuracy, with an average test AUC value of 0.949 ± 0.078, indicating strong discrimination between suitable and unsuitable habitats (Figure 6.8). The predicted habitat suitability map (Figure 6.9) shows that suitable habitats for *Batagur* are highly localized and discontinuous along the Ganga mainstem. The distribution is primarily concentrated in the upper and middle stretches of the river, with suitability declining sharply downstream (Figure 6.9).

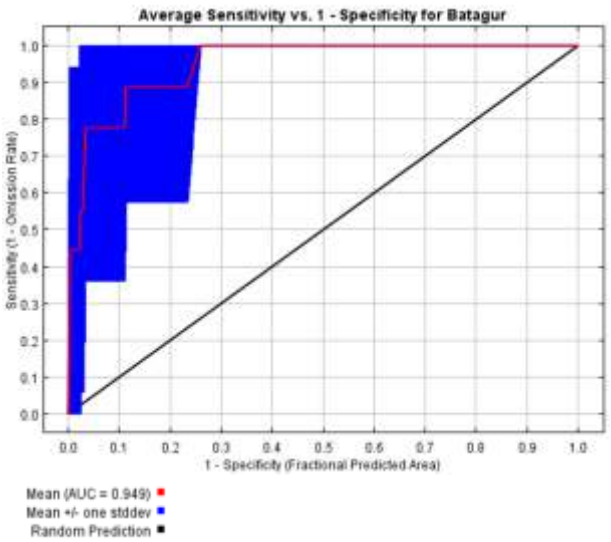


Figure 6.8 Receiver Operating Characteristic (ROC) curve showing model performance for the Genus *Batagur* (*Batagur kachuga* and *Batagur dhongaka*) habitat suitability model.

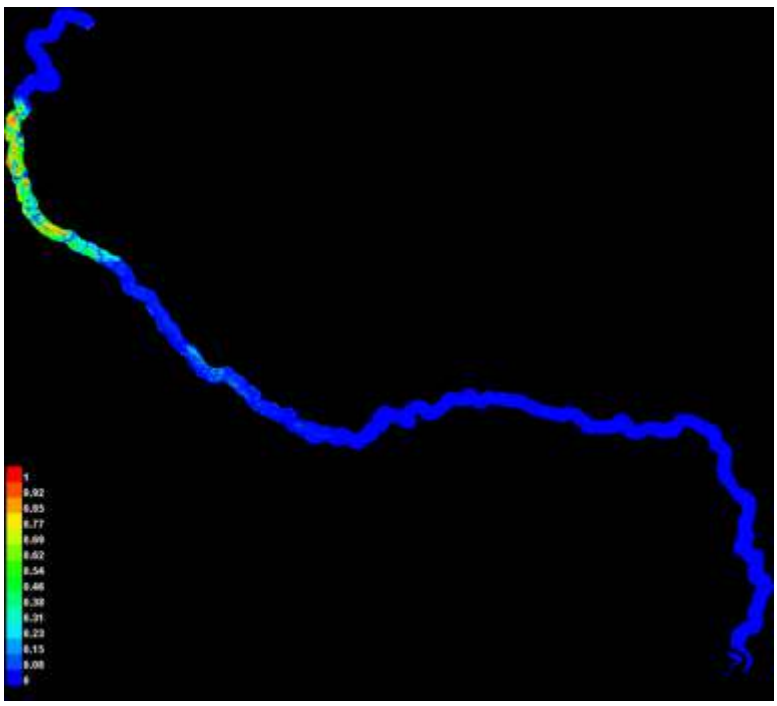


Figure 6.9 Predicted habitat suitability for the Genus *Batagur* (*Batagur kachuga* and *Batagur dhongaka*) in the Ganga Riverscape

The model identified key environmental drivers influencing habitat suitability (Table 6.2). Among these, mean diurnal temperature range (bio2) contributed the most (36.3%), followed by temperature seasonality (bio4) (22.6%) and human footprint index (13.3%). Additional contributing variables included the mean temperature of the driest quarter (bio9) (8.5%) and terrain ruggedness (7.4%), while other variables had comparatively minor influence.

Table 6.2 Relative contribution and permutation importance of environmental variables influencing the habitat suitability model for Genus *Batagur* (*Batagur kachuga* and *Batagur dhongaka*)

Variable	Percent contribution	Permutation importance
bio_2	36.3	4.6
bio_4	22.6	37.3
Human footprint	13.3	10.5
bio_9	8.5	12.6
Terrain ruggedness	7.4	6.4
bio_18	5.3	0
bio_5	4.6	24.4
bio_8	1.3	0.1
Slope	0.5	2.2
bio_13	0.2	0
DEM	0	0.9
LULC	0	0.4
bio_11	0	0.5
bio_1	0	0.1

Jackknife analysis further revealed that temperature seasonality (bio4) provided the highest gain when used in isolation, indicating strong independent explanatory power. In contrast, omission of the human footprint index resulted in the greatest reduction in model gain, highlighting the significant role of anthropogenic pressures in determining habitat suitability along the Ganga mainstem.

B. *Chitra indica* (Narrow-headed softshell turtle)

The model showed moderate predictive performance, with an average test AUC value of 0.764 ± 0.126, indicating a reasonable ability to distinguish between suitable and unsuitable habitats (Figure 6.10). The predicted habitat suitability map (Figure 6.11) indicates that suitable habitats for *Chitra indica* are strongly concentrated in the upper stretches of the Ganga mainstem, with a clear downstream decline in suitability. Highly suitable habitats are primarily located in upper Ganga regions, particularly in stretches characterized by deep channels, stable flow regimes, and relatively lower anthropogenic disturbance. Moderate suitability is observed in parts of the middle Ganga, particularly in sections where channel morphology supports moderate depth, reduced flow variability, and localized depositional features. However, these suitable patches are fragmented and discontinuous, indicating that habitat availability is not uniform along the river continuum. In contrast, the lower stretches of the Ganga mainstem show predominantly low to negligible suitability, as clearly visible in the suitability map (Figure 6.11), where downstream sections are dominated by low probability values (blue zones).



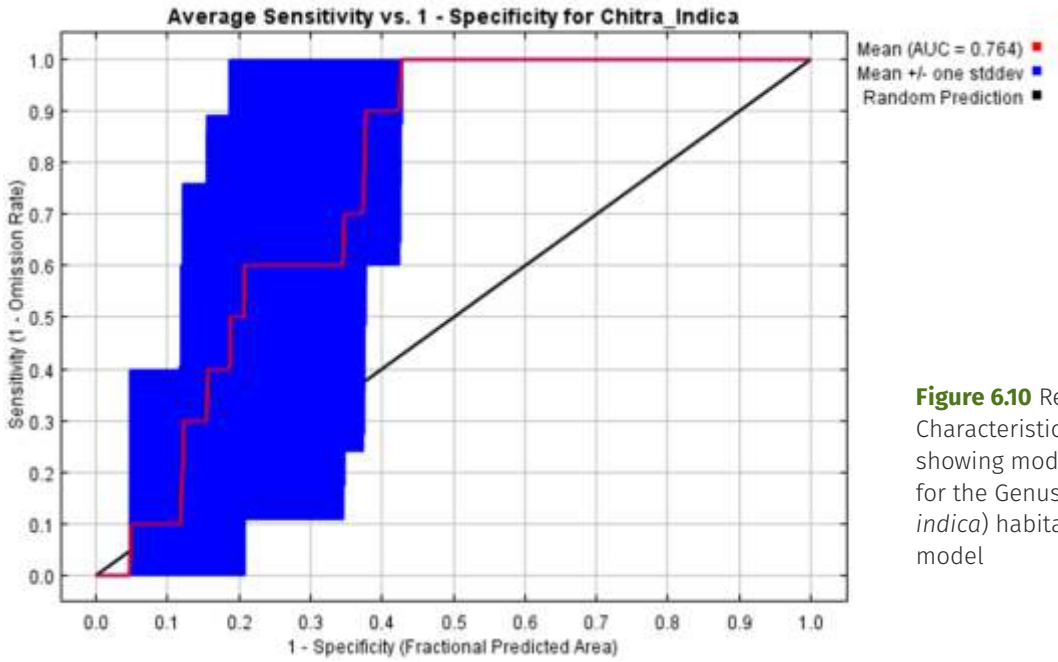


Figure 6.10 Receiver Operating Characteristic (ROC) curve showing model performance for the Genus *Chitra* (*Chitra indica*) habitat suitability model

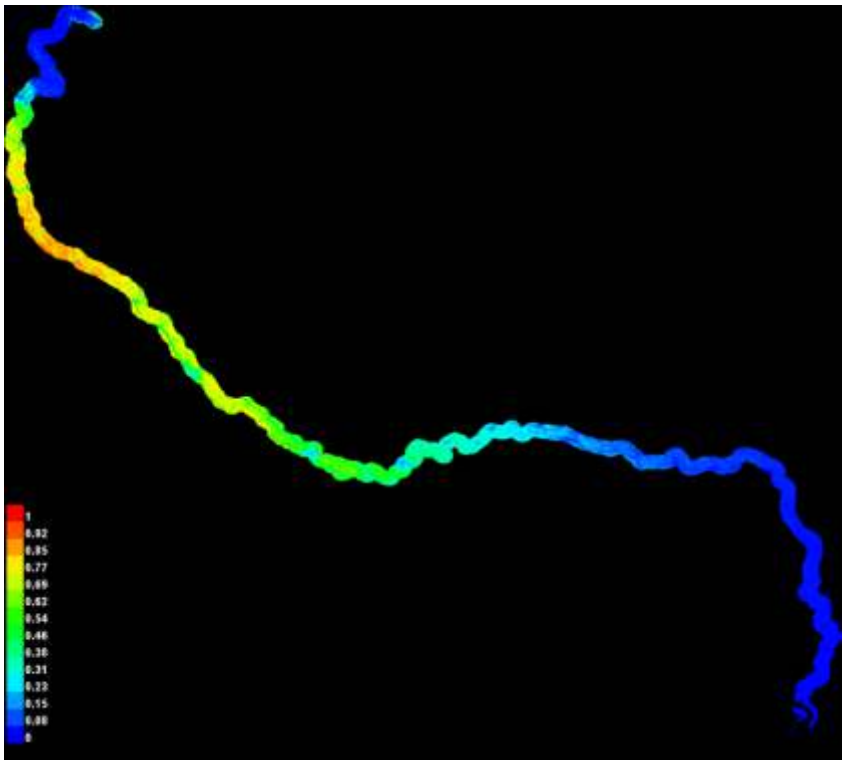


Figure 6.11 Predicted habitat suitability for the Genus *Chitra* (*Chitra indica*) in the Ganga Riverscape

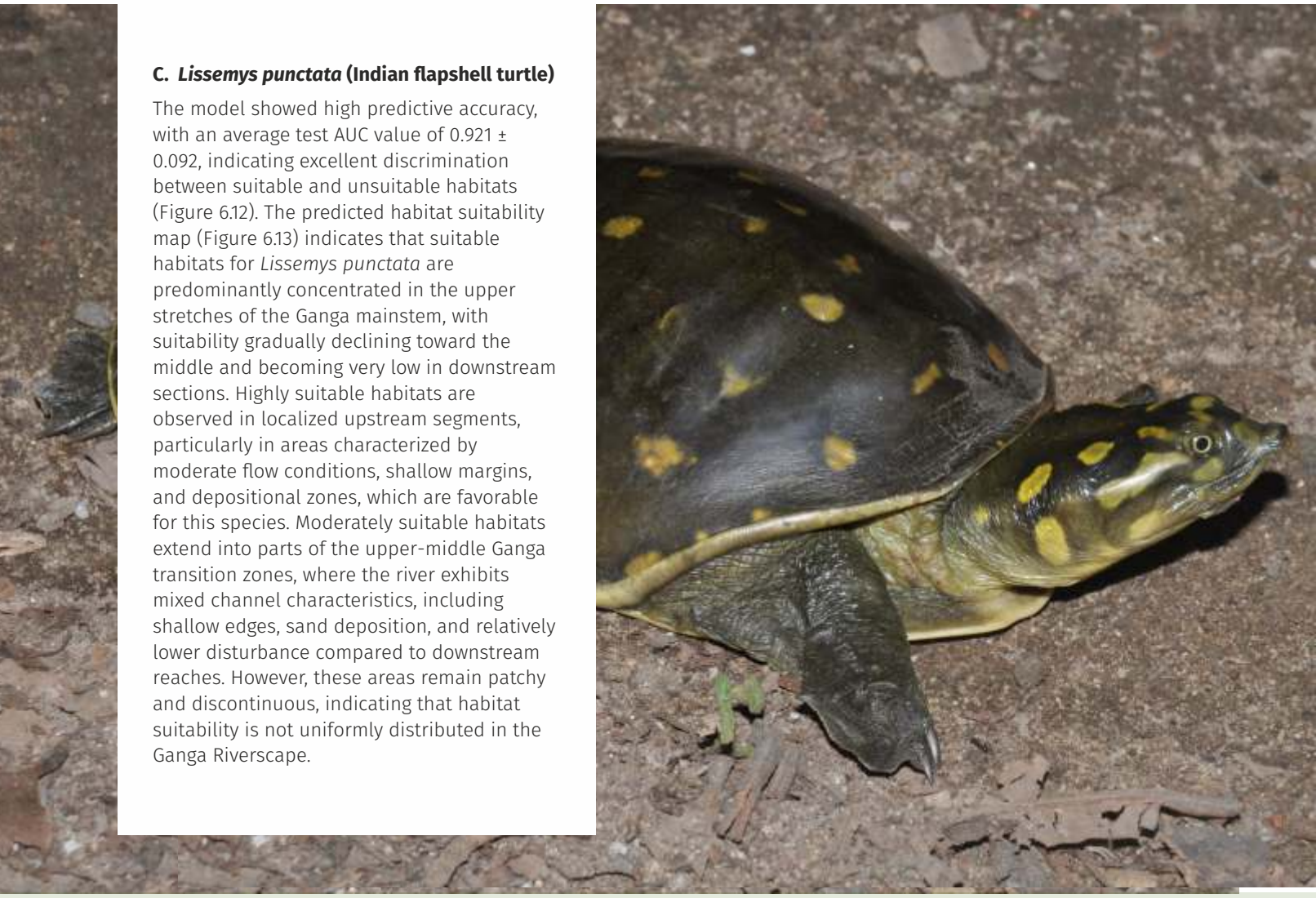
Among key environmental variables, the temperature annual range (bio7) contributed the highest proportion (71.6%), indicating that thermal variability plays a dominant role in determining species distribution (Table 6.3). This was followed by temperature seasonality (bio4) (14.0%) and river slope (4.3%). Other contributing variables included precipitation seasonality (bio15) (3.6%) and human footprint index (3.2%), while remaining variables had relatively minor contributions. The jackknife analysis further revealed that bio7 (temperature annual range) had the highest gain when used in isolation, indicating strong independent explanatory power. In contrast, bio4 (temperature seasonality) caused the greatest decrease in model gain when omitted, suggesting that it contains critical complementary information influencing the model predictions. These results highlight the importance of thermal regimes and seasonal variability in shaping habitat suitability for *Chitra indica*.

Table 6.3 Relative contribution and permutation importance of environmental variables influencing the habitat suitability model for *Chitra indica*

Variable	Percent contribution	Permutation importance
bio_7	71.6	0
bio_4	14	37.9
Slope	4.3	38.4
bio_15	3.6	4.1
Human footprint	3.2	6.1
bio_12	1.8	11.6
Terrain ruggedness	0.6	0.3
bio_9	0.6	0
bio_18	0.2	1.1
bio_10	0.1	0
bio_8	0.1	0
LULC	0	0.4

C. *Lissemys punctata* (Indian flapshell turtle)

The model showed high predictive accuracy, with an average test AUC value of 0.921 ± 0.092, indicating excellent discrimination between suitable and unsuitable habitats (Figure 6.12). The predicted habitat suitability map (Figure 6.13) indicates that suitable habitats for *Lissemys punctata* are predominantly concentrated in the upper stretches of the Ganga mainstem, with suitability gradually declining toward the middle and becoming very low in downstream sections. Highly suitable habitats are observed in localized upstream segments, particularly in areas characterized by moderate flow conditions, shallow margins, and depositional zones, which are favorable for this species. Moderately suitable habitats extend into parts of the upper-middle Ganga transition zones, where the river exhibits mixed channel characteristics, including shallow edges, sand deposition, and relatively lower disturbance compared to downstream reaches. However, these areas remain patchy and discontinuous, indicating that habitat suitability is not uniformly distributed in the Ganga Riverscape.



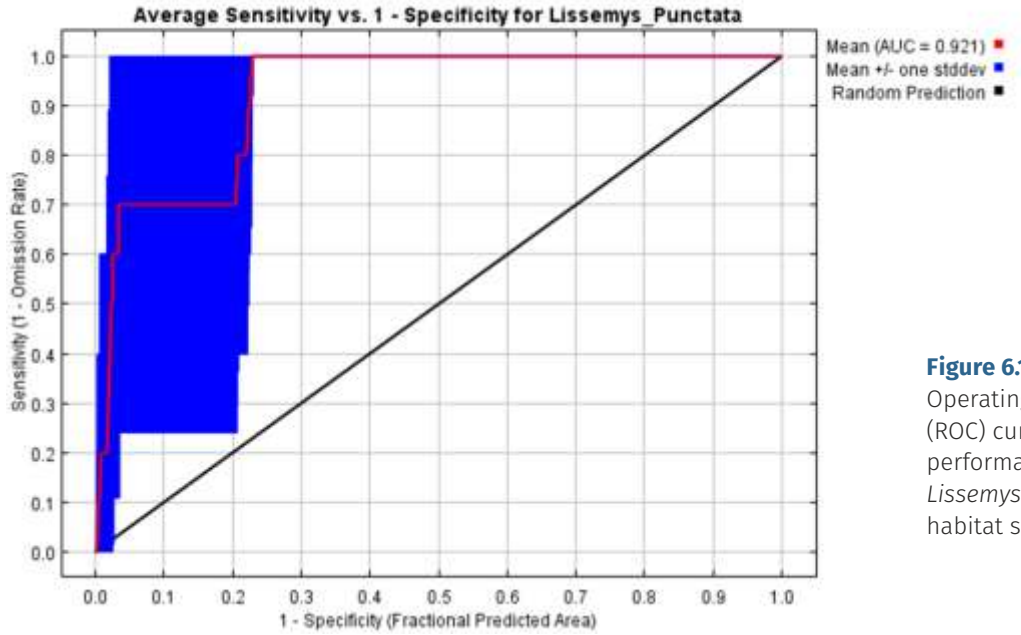


Figure 6.12. Receiver Operating Characteristic (ROC) curve showing model performance for the Genus *Lissemys* (*Lissemys punctata*) habitat suitability model.

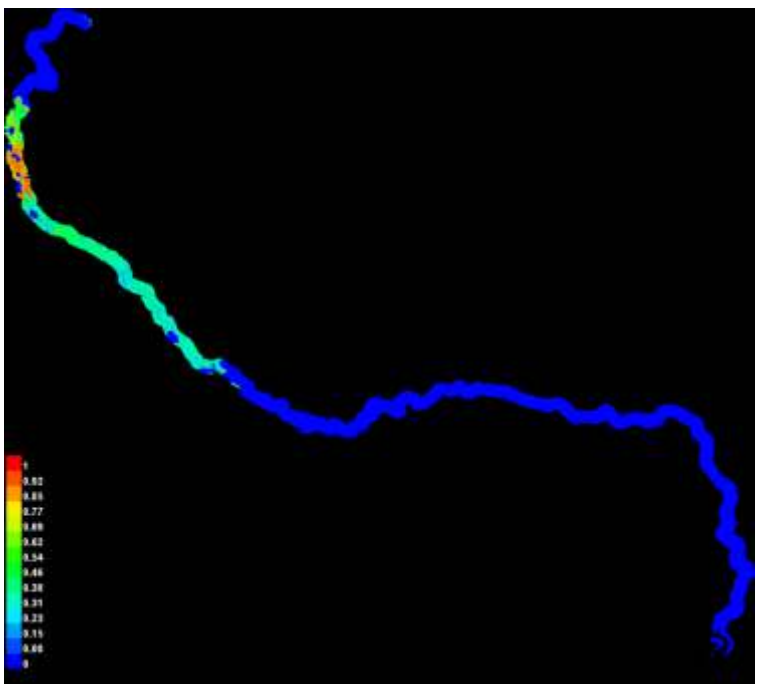


Figure 6.13. Predicted habitat suitability map for the *Genus Lissemys* (*Lissemys punctata*) in the Ganga Riverscape

In environmental variables, mean diurnal temperature range (bio2) contributed overwhelmingly to the model (83.8%), indicating that fine-scale thermal variability plays a dominant role in determining species distribution (Table 6.4). This was followed by the mean temperature of the warmest quarter (bio10) (6.3%) and river slope (4.0%). At the same time, anthropogenic influence (human footprint) showed a negligible contribution. The jackknife analysis further indicated that bio2 (mean diurnal temperature range) had the highest gain when used in isolation and also caused the greatest decrease in model gain when omitted, demonstrating that this variable contains the most critical and unique information influencing habitat suitability.



Table 6.4. Relative contribution and permutation importance of environmental variables influencing the habitat suitability model for *Lissemys punctata*

Variable	Percent contribution	Permutation importance
bio_2	83.8	64.7
bio_10	6.3	14.5
Slope	4	17.2
bio_5	2.4	0
bio_8	1.9	1.3
bio_13	1.2	1.2
Human footprint	0.2	0
bio_9	0.1	0.1
Terrain ruggedness	0.1	1

Based on habitat suitability classification, the majority of the Ganga Riverscape was predicted to be unsuitable or marginally suitable (>85-90%) for Lissemys punctata. Moderately suitable habitats account for approximately 6-10%, while highly suitable habitats are restricted to very small upstream patches (<3-5%).



D. *Melanochelys trijuga* (Indian black turtle)

The Maxent model showed exceptionally high predictive performance, with an average test AUC value of 0.998 ± 0.001, indicating near-perfect discrimination between suitable and unsuitable habitats (Figure 6.14). The predicted habitat suitability map (Figure 6.15) reveals that suitable habitats for *Melanochelys trijuga* are extremely restricted and highly localized along the Ganga mainstem. Unlike other species, the model indicates almost complete absence of suitability across the majority of the river, with only very small, isolated patches of moderate to high suitability observed in limited upstream sections. These suitable patches are confined to specific microhabitats, likely associated with low-flow zones, localized depositional areas, or marginal habitats with reduced disturbance (Figure 6.15). This pattern suggests that *Melanochelys trijuga* has very narrow habitat requirements within the Ganga Riverscape and is likely more associated with off-channel habitats such as ponds, wetlands, and slow-moving water bodies, rather than the main river channel itself.

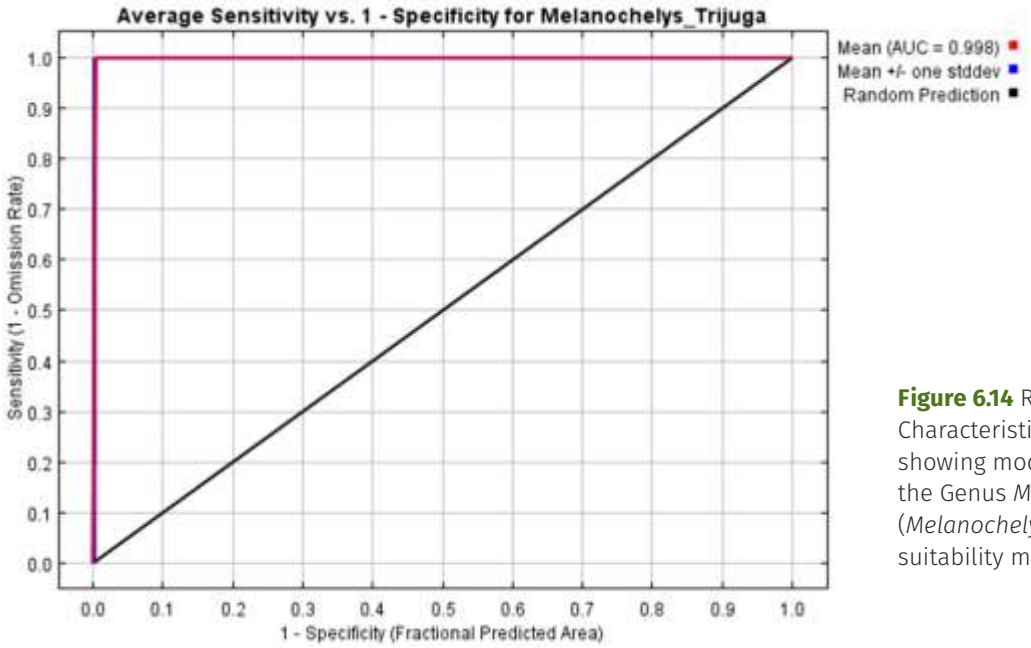


Figure 6.14 Receiver Operating Characteristic (ROC) curve showing model performance for the Genus *Melanochelys* (*Melanochelys trijuga*) habitat suitability model

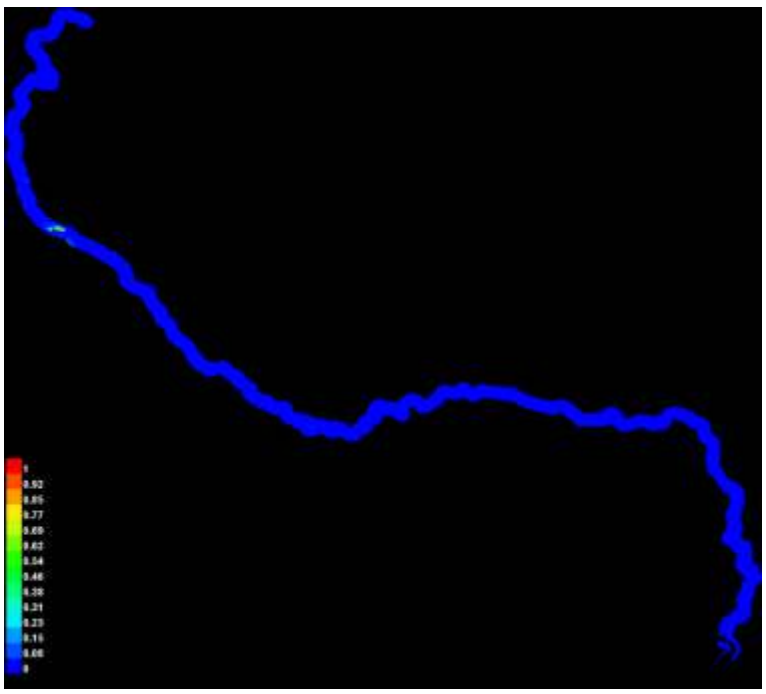


Figure 6.15 Predicted habitat suitability map for the Genus *Melanochelys* (*Melanochelys trijuga*) in the Ganga Riverscape

The model identified several environmental variables influencing habitat suitability. Among these, mean diurnal temperature range (bio2) contributed the highest proportion (33.0%), followed closely by precipitation of wettest month (bio13) (30.9%) and maximum temperature of warmest month (bio5) (11.1%). Additional contributions were observed from annual precipitation (bio12) (4.0%) and mean temperature of the wettest quarter (bio8) (3.7%), while other variables had a relatively minor influence. The jackknife analysis indicated that bio12 (annual precipitation) produced the highest gain when used in isolation, suggesting strong independent explanatory power. In contrast, omission of bio5 (maximum temperature of warmest month) resulted in the greatest decrease in model gain, indicating that this variable provides critical information not captured by other predictors. These results highlight the importance of precipitation regimes and temperature extremes in determining the distribution of *Melanochelys trijuga*.

Table 6.5 Relative contribution and permutation importance of environmental variables influencing the habitat suitability model for *Melanochelys trijuga*

Variable	Percent contribution	Permutation importance
bio_2	33	1.5
bio_13	30.9	10.5
bio_5	11.1	24.6
bio_12	4	24.4
bio_8	3.7	0.1
bio_1	3.2	0.4

Based on habitat suitability classification, almost the entire Ganga Riverscape (>95%) was predicted to be unsuitable for *Melanochelys trijuga*. Only a very small fraction of the river (<5%) showed moderate suitability, while highly suitable habitats were extremely rare and restricted to negligible patches (<1-2%). The few suitable habitats identified are highly fragmented and spatially isolated, suggesting that the Ganga Riverscape does not represent a primary habitat for this species. Instead, these results indicate that *Melanochelys trijuga* is likely ecologically constrained within the main river channel and may rely more on adjacent lentic or semi-lotic habitats for survival.

E. *Nilssonia gangetica* (Indian softshell turtle)

The model demonstrated high predictive accuracy, with an average test AUC value of 0.905 ± 0.054, indicating strong discrimination between suitable and unsuitable habitats (Figure 6.16). The suitable habitats for *Nilssonia gangetica* are extensively distributed along the upper and middle stretches of the Ganga mainstem, with a gradual downstream decline in suitability. Highly suitable habitats are primarily concentrated in upper Ganga stretches and extend into the middle Ganga, forming a relatively continuous belt of moderate to high suitability compared to other species (Figure 6.17). Unlike more specialized species, *Nilssonia gangetica* shows a broader distribution range along the mainstem, indicating higher ecological tolerance and adaptability to varying riverine conditions.



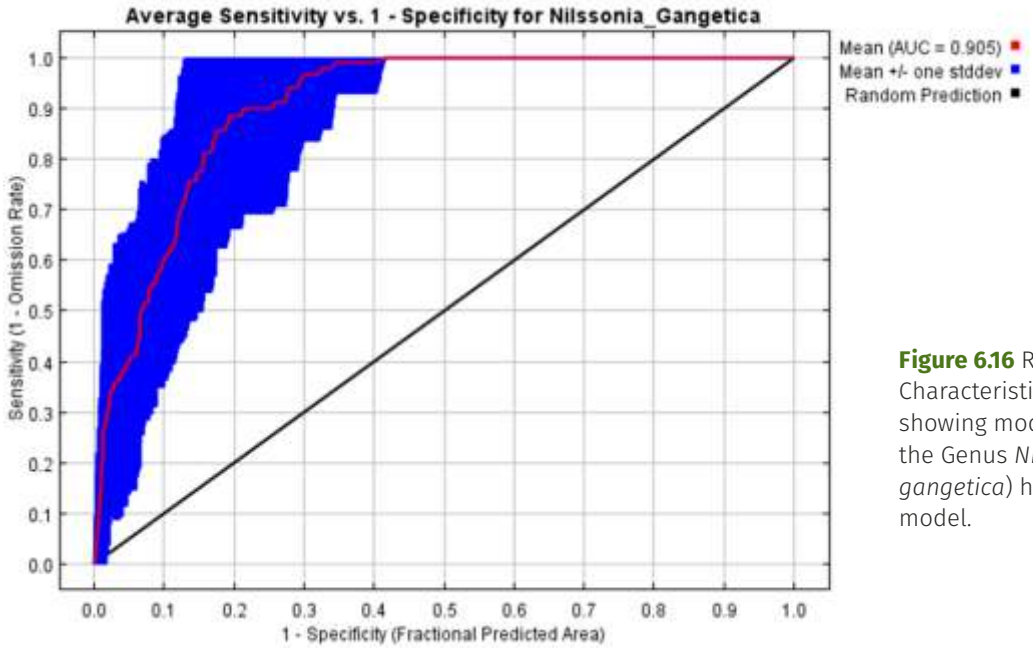


Figure 6.16 Receiver Operating Characteristic (ROC) curve showing model performance for the Genus *Nilssonia* (*Nilssonia gangetica*) habitat suitability model.

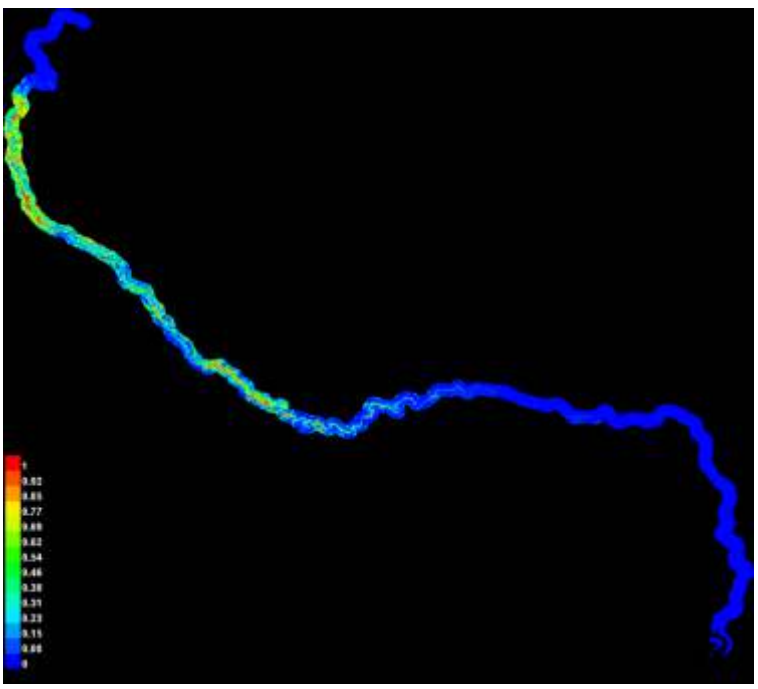


Figure 6.17 Predicted habitat suitability map for the Genus *Nilssonia* (*Nilssonia gangetica*) in the Ganga Riverscape

Among environmental variables, terrain ruggedness contributed the highest proportion (39.0%) influencing habitat suitability, followed by mean diurnal temperature range (bio2) (27.0%) and temperature annual range (bio7) (8.4%) (Table 6.6). Additional contributions were observed from the mean temperature of the driest quarter (bio9) (7.0%) and the human footprint index (4.1%), while other variables had comparatively smaller influence.

Table 6.6 Relative contribution and permutation importance of environmental variables influencing the habitat suitability model for *Nilssonia gangetica*.

Variable	Percent contribution	Permutation importance
Terrain ruggedness	39	13.9
bio_2	27	0
bio_7	8.4	39.9
bio_9	7	2.4

Variable	Percent contribution	Permutation importance
Human footprint	4.1	3.2
bio_18	3.6	9
bio_16	1.9	2.4
DEM	1.6	10.1
Slope	1.5	0.8
bio_8	1.2	0.3
bio_19	0.8	2.5
bio_17	0.8	0.5
bio_15	0.6	0.1
bio_10	0.4	2.5
bio_1	0.4	3.3
LULC	0.3	2
bio_13	0.3	3.9
bio_3	0.3	0.9
bio_5	0.3	0
bio_4	0.2	0.8
bio_19	0.2	0.4

The jackknife analysis indicated that terrain ruggedness provided the highest gain when used in isolation and also caused the greatest decrease in model gain when omitted, demonstrating its strong independent influence on habitat suitability. This highlights the importance of riverbed structure and geomorphological complexity in determining the distribution of *Nilssonia gangetica*. Based on habitat suitability classification, a substantial proportion of the Ganga Riverscape was predicted to be unsuitable or marginally suitable (~80-85%), while moderately suitable habitats accounted for approximately 10-15%, and highly suitable habitats were limited but more extensive than in other species (~3-6%).

F. *Pangshura* spp.

The model demonstrated high predictive accuracy, with an average test AUC value of 0.909 ± 0.017, indicating mainstrong discrimination between suitable and unsuitable habitats (Figure 6.18). The predicted habitat suitability map (Figure 6.19) shows suitable habitats for *Pangshura* spp. are widely distributed along the upper and middle stretches of the Ganga mainstem, forming a relatively continuous band of moderate to high suitability. Highly suitable habitats are primarily concentrated in upper Ganga stretches and extend well into the middle Ganga, particularly in river segments characterized by moderate flow, stable channel morphology, and the presence of basking sites such as sandbanks and exposed substrates.



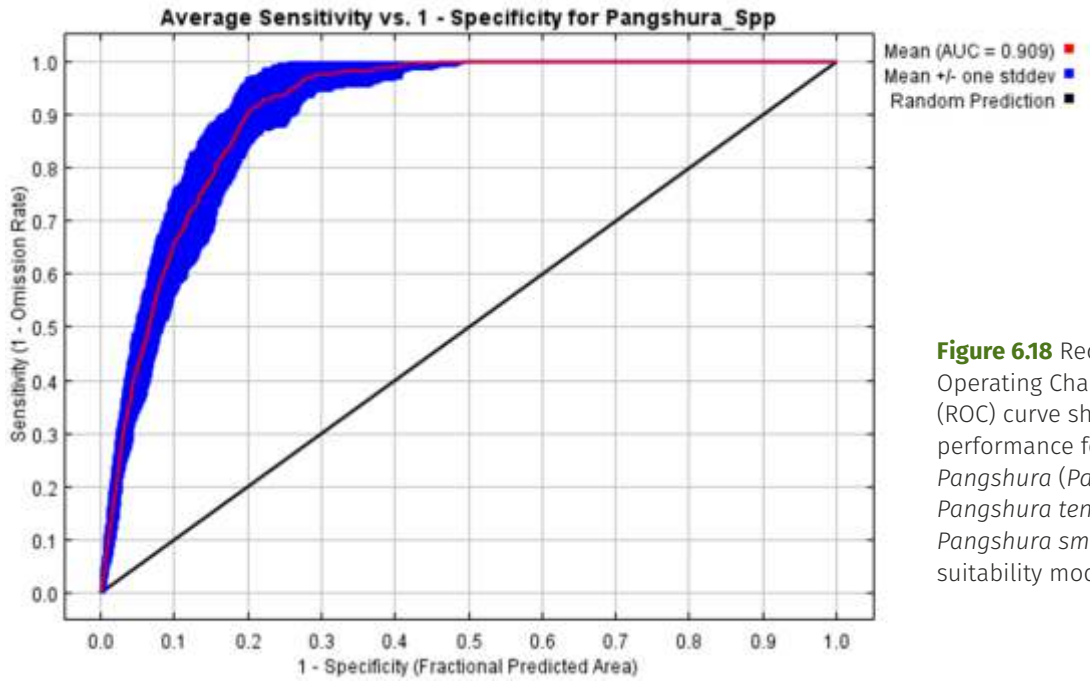


Figure 6.18 Receiver Operating Characteristic (ROC) curve showing model performance for the Genus *Pangshura* (*Pangshura tecta*, *Pangshura tentoria*, and *Pangshura smithii*) habitat suitability model.

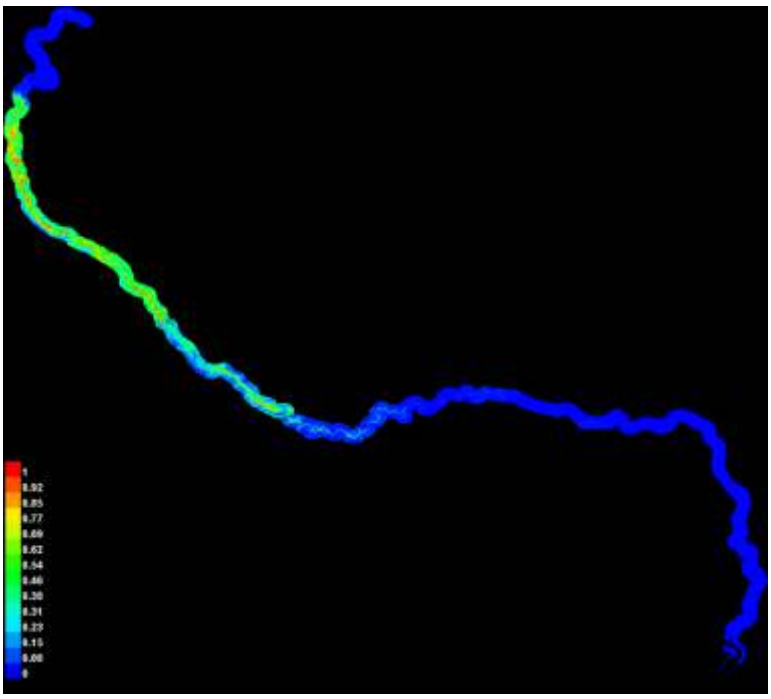


Figure 6.19 Predicted habitat suitability map for the Genus *Pangshura* (*Pangshura tecta*, *Pangshura tentoria*, and *Pangshura smithii*) in the Ganga Riverscape

Moderately suitable habitats are distributed across much of the middle Ganga, where the river exhibits heterogeneous channel features including braided sections, depositional zones, and marginal habitats. This pattern suggests that *Pangshura* spp. have broad ecological tolerance within the Ganga Riverscape, allowing them to utilize a range of riverine habitat conditions. In contrast, the lower Ganga stretches show predominantly low suitability, as evident from the suitability map (Figure 6.19), where low probability values largely dominate downstream regions. This downstream decline may be attributed to increased anthropogenic pressure, channel modification, reduced basking sites, and altered hydrological conditions.

The model identified key environmental variables influencing habitat suitability. Among these, mean diurnal temperature range (bio2) contributed the highest proportion (44.0%), followed by river elevation (DEM) (12.1%) and human footprint index (9.4%) (Table 6.7). Additional important variables included terrain ruggedness (7.3%) and precipitation-related variables (bio19_2: 6.3%, bio4: 5.5%), indicating the combined influence of thermal, geomorphological, and anthropogenic factors.

Table 6.7 Relative contribution and permutation importance of environmental variables influencing the habitat suitability model for Genus *Pangshura* (*Pangshura tecta*, *Pangshura tentoria*, and *Pangshura smithii*).

Variable	Percent contribution	Permutation importance
bio_2	44	0.5
DEM	12.1	14.3
Human footprint	9.4	3.7
Terrain ruggedness	7.3	2.1
bio_19	6.3	18
bio_4	5.5	31.3
bio_18	3.1	7.3
DEM	1.6	10.1



The jackknife analysis indicated that temperature seasonality (bio4) had the highest gain when used in isolation, suggesting strong independent explanatory power. In contrast, omission of the human footprint index resulted in the greatest decrease in model gain, highlighting the significant influence of anthropogenic disturbance on the distribution of *Pangshura* spp. Based on habitat suitability classification, the majority of the Ganga Riverscape was predicted to be unsuitable or marginally suitable (~80-85%), while moderately suitable habitats accounted for approximately 10-15%, and highly suitable habitats were limited but more continuous than in several other species (~4-7%). This distribution pattern indicates that Pangshura spp. are well adapted to mainstem river conditions, with a broader habitat range compared to more specialized taxa such as *Chitra indica* or *Melanochelys trijuga*.

6.3.3. Crocodilians

I. Distribution, population count and encounter rate

In the present study, three post-monsoon surveys were conducted during PoM 2018 (2019), PoM 2019 (2020), and PoM 2020 (2021) to assess the population status of gharials and muggers in the Ganga River. Gharials were primarily found to be confined to the HWLS in Uttar Pradesh, with a few isolated sightings recorded at Karanpur Ghat, upstream of Farrukhabad, and another at Doriganj, located downstream of the Ghaghra-Ganga confluence. Further downstream in Bihar, a single gharial was recorded at Ganga Ghat, Sultanganj, upstream of Bhagalpur, and two individuals were observed at Kahalgaon (Figure 6.20).



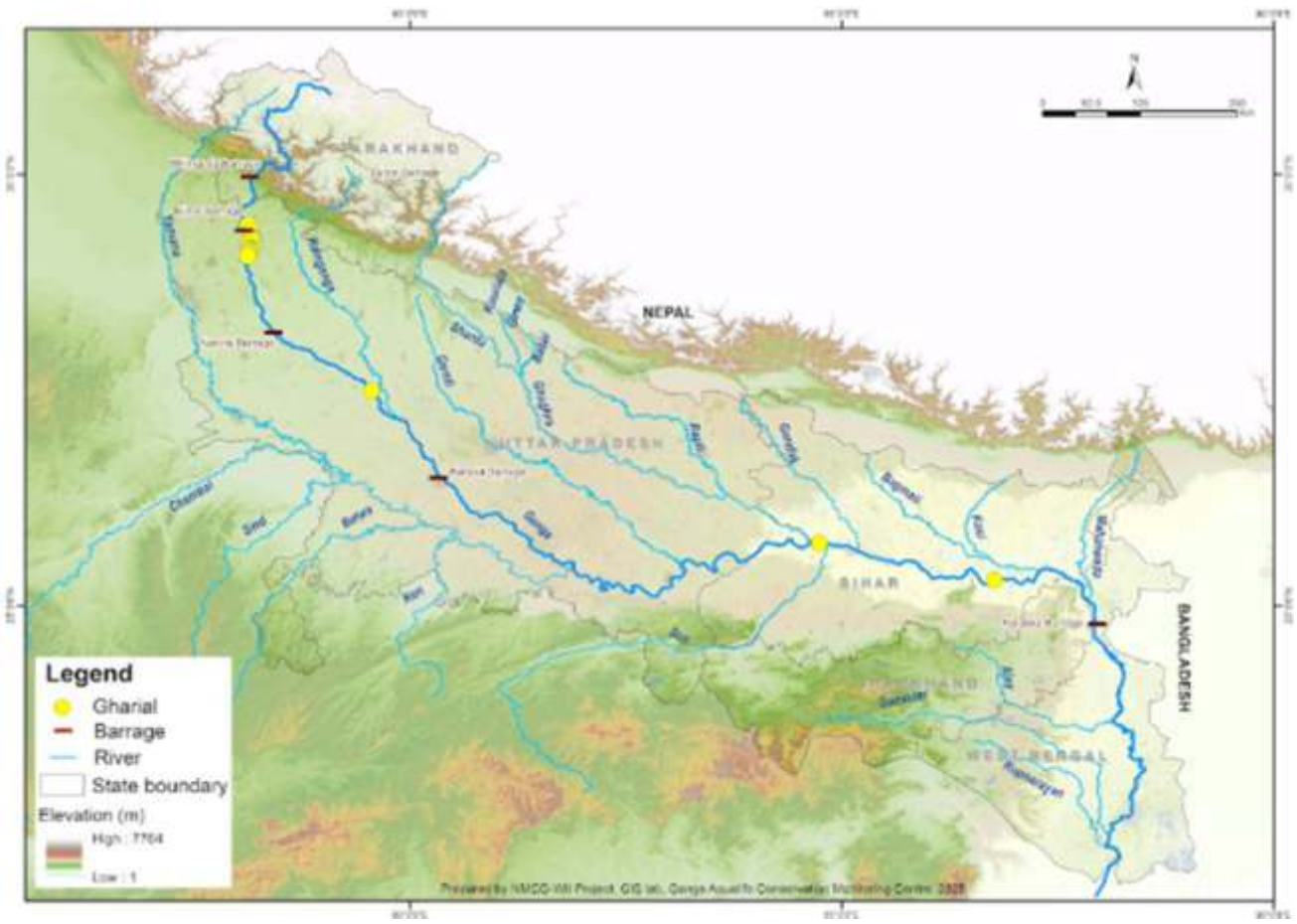


Figure 6.20 Sightings of gharial (*Gavialis gangeticus*) in the Ganga River

A gradual increase in the MPS of gharial was recorded from PoM 2018 to 2020 in the Ganga River (Figure 6.21). During the first survey conducted in PoM 2018, a total of 27 gharial individuals (MPS) across all size classes were recorded, with an overall encounter rate of 0.013 (±0.005 SEM) individuals per km. In the subsequent survey (PoM 2019), 31 gharial individuals were recorded, with an encounter rate of 0.015 (± 0.008) individuals per km. In PoM 2020, MPS increased to 43, with an encounter rate of 0.021 (± 0.007) individuals per km (Figure 6.21).

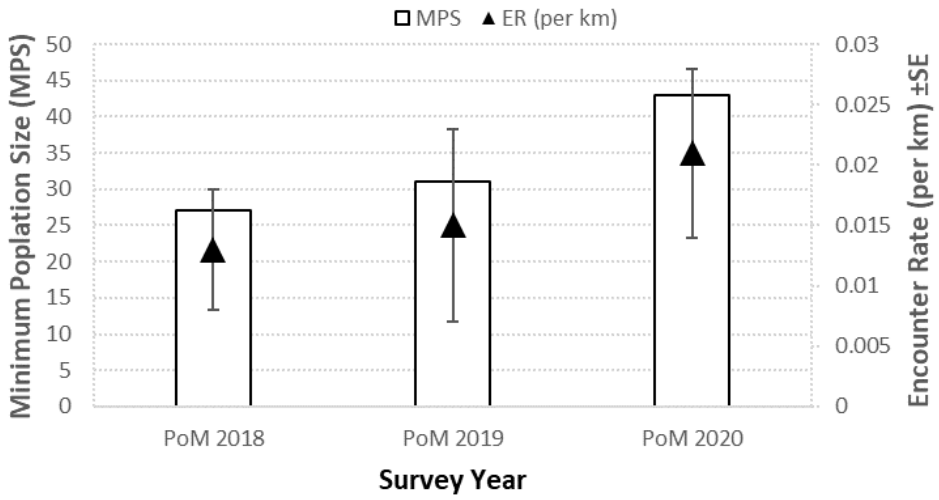


Figure 6.21 Minimum population size (MPS) and encounter rate of gharial in the Ganga River during post-monsoon surveys in 2018, 2019, and 2020

The size-class composition of gharials recorded during the survey showed substantial variation across years (Figure 6.22). No hatchlings were recorded during any of the surveys. During PoM 2018, juveniles constituted the largest proportion of the population (37%), followed by sub-adults (22.2%) and adults (22.2%) and yearling accounted for 18.6% of the population. In PoM 2019, only juvenile and yearlings were recorded, which comprised 74.2% and 25.8% of the sightings, respectively. No sub-adults or adults were recorded during this survey. In PoM 2020, the population structure shifted towards older size classes, with sub-adults forming the largest proportion (62.8%), followed by adults (23.4%) and juvenile (14%). No yearling individuals were recorded during the survey. Mugger sightings were rare during the surveys. Only two individuals were recorded during the PoM 2019 survey, while a single individual was observed during the PoM 2020 survey.

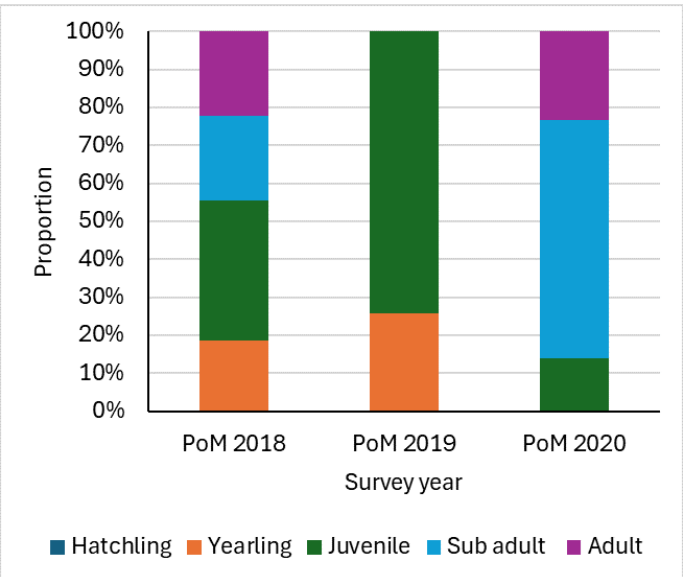


Figure 6.22 Different size class composition of gharial in the Ganga River

II. Trends in Gharial Population

Temporal encounter rates of the gharial showed an increasing trend from 2018 to 2024, although this increase was not significant (R^2 = 0.65, *p = 0.18*; Figure 6.23). Despite the overall positive trend, most BEUs (n = 384, 92.7%) recorded no sightings of gharials during the assessment years. Despite being restricted to the small stretch, the encounter rate increased in 12 BEUs, decreased in 8 BEUs, and remained unchanged in 10 BEUs. Availability of sandbars and sand banks, water parameters, availability of fish stock and predator related threats could always regulate their population. In addition, long-term population trends could be more conclusive. However, the encounter rates of gharial increased from 0.013 (SE 0.005) sightings/km in 2018 to 0.021 (0.007) sightings/km in 2024.



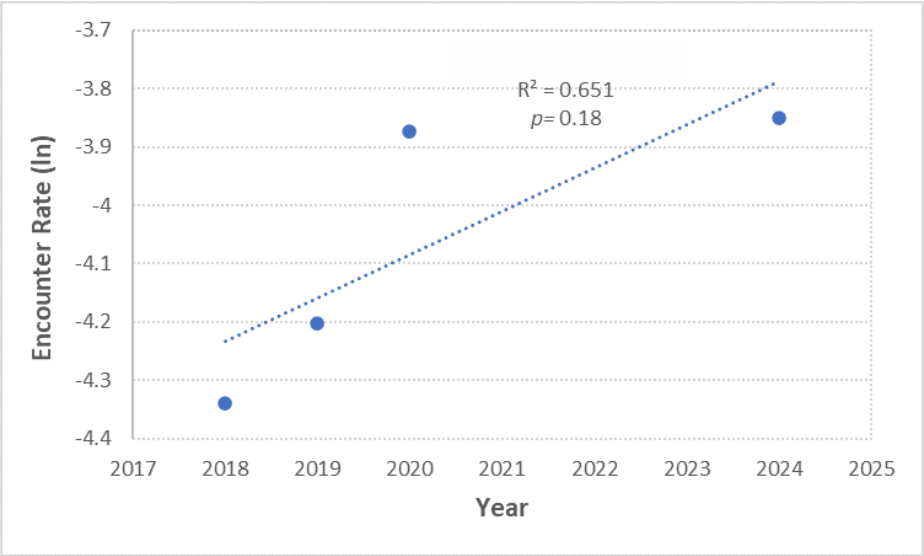


Figure 6.23 Temporal trends in encounter rate (ER) of gharial in the Ganga River between 2018 and 2024 monitoring

6.4. DISCUSSION

The observed variations in amphibian richness and diversity across the sampling sites underscore the critical importance of preserving diverse habitats to sustain populations. The present study, which recorded a total of 27 species from five families, reflects a relatively high amphibian diversity compared to previous studies from the Ganga River system (Chanda, 1991; Sharma, 1991; Kanaujia et al., 2017; Boruah et al., 2020). One recorded taxon could not be identified to species level and retained as Genus (*Minervarya* spp.), such uncertainty is common in amphibian surveys, particularly in morphologically similar groups, and may require further confirmation using detailed morphological or molecular analyses. The occurrence of common species like *Duttaphrynus melanostictus*, *Euphlyctis cyanophlyctis*, *Hoplobatrachus tigerinus*, *Minervarya syhadrensis* and *Microhyla nilphamariensis* indicates that certain region continues to offer favourable habitat for generalist species. However, few sightings of species such as *Amolops jaunsari*, *Duttaphrynus himalayanus*, *Fejervarya cf. moodiei*, *Hylarana tytleri*, *Euphlyctis hexadactylus*, *Uperedon taprobanicus* and *variegatus*, *Minervarya* sp. and *Nanorana minica* indicate the need for habitat-specific conservation intervention. Records of *A. jaunsari* indicate the importance of manistem Ganga River for restricted species in the Himalayan region (Ray, 1992; Ray and Dutta, 2004).

The higher diversity of amphibian recorded in the present study may be attributed to broader geographic coverage, seasonal timing, and refined sampling methodologies. These findings also demonstrate that the range of diversity index varied between moderate and low values (*H'*= 2.35-1.05) across different sampling sites in the Ganga River. Spatial variations in diversity values across the upper, middle, and lower stretches of the river suggest distinct environmental gradients and variations in micro-habitat conditions (Bateman and Merritt, 2020; Chhetrii and Acharya, 2020). This study adds weightage to existing knowledge on the amphibian diversity of the Ganga River (Annexure IV), providing a baseline and highlighting the need of extensive and systematic studies within the riverine ecosystems. It also signifies the need for studies across different seasons, habitat types, and environmental gradients (Buckley and Jetz, 2007). Such research initiatives will yield essential data, facilitating enhanced monitoring of population dynamics, identification of rare and endemic species, and assessment of ecological well-being. Eventually, this will be helpful in understanding the effect of human activities, climate change, and habitat changes on the amphibian communities, aiding in effective conservation strategies for such sensitive taxa and ecosystems (Hamer and McDonnell, 2008; Liu et al., 2021).

The integration of abundance, encounter rates, species composition, and statistical outputs clearly identifies the middle stretch of the Ganga River, particularly HZ-3 (Bithura-Prayagraj) and HZ-4 (Zamania-Varanasi belt), as the primary ecological hotspots for freshwater turtles. These zones consistently exhibited the highest abundance, largest group sizes, and greatest encounter rates across all years. Within these zones, specific sites such as Bithura, Prayagraj, Zamania, and Kahalgaon emerged as critical microhabitats due to the presence of stable islands and sandbanks. In contrast, HZ-2 holds importance as a specialized habitat for rare species such as *Batagur*, despite low overall abundance, while HZ-5 and downstream stretches represent declining or suboptimal habitats. Overall, the results demonstrate that turtle distribution in the Ganga River is highly structured, with clear spatial clustering driven by habitat availability, geomorphology, and species-specific ecological requirements.

Present findings demonstrate that suitable habitats for *Batagur* and *Chitra indica* along the Ganga Riverscape are extremely limited, fragmented, and spatially restricted, making populations highly vulnerable to localized disturbances. Regulation of sand mining, dredging, and riverbank modification is crucial, as these activities directly degrade nesting habitats. Although *Lissemys punctata* is generally considered adaptable, its distribution within the main river channel appears to be strongly constrained by habitat structure and thermal variability. Maintaining natural thermal regimes and flow conditions can be crucial, and activities such as bank modification, dredging, and channel deepening should be carefully regulated. The Ganga Riverscape provides limited suitable habitat for *Melanochelys trijuga*, with distribution restricted to a few isolated patches. This suggests that conservation strategies focusing solely on the main channel of the River may not be sufficient for this species, thus landscape level conservation planning should be adopted. In contrast, *Nilssonia gangetic*a and *Pangshura* spp. have a comparatively broader and more continuous distribution along the Ganga Riverscape, particularly in the upper and middle stretches. Although the species indicated relatively higher adaptability, continued habitat degradation could lead to progressive fragmentation of suitable habitats, underscoring the need for basin-scale conservation planning focused on key mainstem stretches. Given their relatively wider distribution, *Pangshura* spp. can serve as an indicator group for riverine habitat quality, and conservation actions targeting these habitats will likely benefit sympatric turtle species within the Ganga Riverscape.

A combination of VES and net sampling provides a more robust framework to ascertain turtle occurrence, particularly when targeting rare and elusive species. Usually, such species remain undetected or falsely absent in conventional surveys; however, increased sampling effort through netting has improved detection in the Ganga River, yielding records of species such as *B. dhongoka* and *B. kachuga*, whereas VES remains more effective for common/ abundant species. More efforts are required in the lower stretch of the Ganga River, where VES has limitations owing to deep water habitats. Further, for precise abundance estimates, temporal replication within a restricted time window can be applied, which may be achieved through approaches such as the double-observer method or aerial surveys (Brown et al., 2017; Tripathi et al., 2024).

In addition, weather plays a pivotal role in monitoring turtles along the river, since basking is considered as the prime activity during daylight hours, when usually individuals rest along the river banks, implying the necessity of optimum light and weather conditions. Although population trends indicate an increase over years, present findings require further validation through systematic and long-term monitoring. Strengthened patrolling also appears essential to mitigate poaching. Concurrently, expanding both in situ and ex situ conservation initiatives, coupled with community awareness, will be pivotal in addressing the ongoing decline of turtle populations along the Ganga River (Talukdar et al., 2019; Panda et al., 2024; Dubey et al., 2025). The occurrence of multiple threatened species, including *Geoclemys hamiltonii*, *Hardella thurjii*, *Lissemys punctata*, and *Pangshura tecta*, further emphasizes the importance of the Ganga River as a critical biodiversity corridor (Rai et



al., 2024; Rao, 2001; Sonkar et al., 2019). However, these species face persistent threats such as illegal wildlife trade, net entanglement, habitat fragmentation, sand mining, and pollution, which continue to undermine population stability. The sporadic distribution of several taxa suggests that populations are becoming increasingly fragmented, necessitating active conservation management (Karamanlidis, 2023; Lasala et al., 2023; Sani et al., 2024).

Present study indicates that the Ganga River supports a small but significant population of gharial, primarily concentrated within the HWLS. Other occasional sightings of individuals suggest that gharials occur sporadically along the river in HWLS and potentially dispersing from other tributaries, likely facilitated by seasonal hydrological dynamics such as monsoon floods. The MPS recorded during the surveys show a gradual increase over the three periods. A similar increasing trend was observed in encounter rates among different temporal periods (2018, 2019, 2020 & 2024). Although these results suggest a possible increase in the number of gharials detected in the surveyed stretches, the major proportion remains confined within HWLS. Another crocodilian species, mugger, was encountered occasionally along the Ganga River. Being a generalist species, it can thrive on a wide variety of freshwater habitats such as ponds, marsh, lakes and a range of prey species starting from small fishes to large mammals (Stevenson, 2019; Sharma et al., 2024). In contrast, the gharial persists in specific habitats with restricted dietary options like fishes and other small crustaceans (Katdare et al., 2011). Given the small population of gharial in the Ganga River, prudent conservation strategies need to be adopted to avoid any probable competition between these two sympatric species, in which mugger can outcompete gharial (Sharma et al., 2024).

The distribution pattern and population count during the surveys reinforce the importance of the HWLS stretch as the primary refuge for gharials within the Ganga River. This along with observation of concentrated sightings in the HWLS indicate the presence of suitable sandbanks, relatively lower disturbance within the Sanctuary, and continuous release of gharial individuals under 'grow and release' program (Yadav et al., 2013). Further the absence of small size class individuals (hatchlings) during all three surveys indicate that nesting or successful recruitment may be limited within the surveyed stretches in the Ganga River. Overall, the results indicate that while the Ganga River continues to support a small number of gharials, the population appears to be fragmented and dependent on a few localized stretches, particularly within HWLS. The sporadic occurrence of individuals in downstream sections highlight the potential role of the river as a dispersal corridor rather than a major breeding habitat. Continued monitoring of population trends, protection of suitable sandbank habitats, and mitigation of anthropogenic pressures such as fishing and sand mining will be essential for ensuring the long-term persistence of gharials within the Ganga River system.











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CHAPTER 7

STATUS AND TRENDS OF AVI-FAUNA

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SUMMARY

Riverine ecosystems are dynamic and ecologically rich environments that support a wide variety of biodiversity, particularly avifauna. The avi-faunal diversity in riverine habitats is essential to maintain ecological balance. Several migratory bird species in the Ganga River Basin mainly arrive through the Central Asian Flyway, in which the mainstem Ganga River provides breeding habitats to different waterbirds. A comprehensive assessment of avifaunal diversity along the Ganga River was conducted using an integrated approach combining systematic literature review and field-based monitoring. The review, covering studies from 1861 to 2023, highlighted temporal trends, spatial coverage, and research gaps in waterbird studies across the Ganga River Basin. Primary data were collected from 28 monitoring sites between Bijnor and Haldia during two phases (2017-18 and 2024-25). The literature review identified 236 waterbird species across 32 families and 14 orders, including 52 threatened or Near Threatened species. However, only ~26% of studies focused on riverine habitats, indicating a bias toward wetlands. Research efforts increased significantly after the 1990s, though only 18% of screened studies were directly relevant. Most studies lacked quantitative abundance estimates and long-term datasets, limiting their utility for conservation planning. Poaching and hunting emerged as the most prominent threats to waterbirds in the Ganga River.

Field surveys recorded a total of 19,110 individuals belonging to 84 species across both monitoring periods. Species richness remained relatively stable (70 species in 2017-18; 65 sp. in 2024-25), but total abundance declined sharply by ~59% in 2024-25. Thirteen species were categorized as threatened (4 sp.- Endangered, 3 sp.- Vulnerable, and 6 sp.- Near Threatened). Spatial variation was evident, with certain sites such as Narora, Samshabad, and Kachla showing high diversity, while others like Haldia consistently lacked aquatic avi-faunal presence. Categorically, waterbirds constituted the majority of recorded species (86-88%), whereas water-associated species contributed a smaller fraction with comparatively low diversity. Relative abundance patterns indicated dominance shifts between years, with small pratincole and great cormorant dominating in 2017-18, and black-headed gull and ruddy shelduck in 2024-25. In addition, feeding guild analysis revealed a strong dominance of carnivorous species (>69%), reflecting the trophic structure of riverine ecosystems.

Trend analysis showed mixed patterns in species richness and diversity across sites, with

approximately half of the sites exhibiting declines. Although diversity increased in some locations, the overall decline in abundance suggests potential ecological stress or changing habitat conditions. Temporal analysis of key species-black-bellied tern, river tern, and river lapwing-indicated non-significant declining trends, whereas Indian skimmer showed non-significant increasing trend, highlighting the need for long-term monitoring. Further, island nesting surveys conducted during 2023 and 2024 revealed substantial interannual variation, with limited nesting in 2023 due to flooding. Six species were recorded nesting across 300 islands in 2024, emphasizing the ecological importance of river islands as breeding habitats. However, these habitats remain highly vulnerable to anthropogenic pressures such as sand mining, agriculture, and hydrological alterations.

Overall, the study accentuates that the Ganga River supports a significant proportion of basin-level avifaunal diversity, including a considerable presence of threatened species. Despite relatively stable species richness, declining abundance and site-specific variability highlight emerging conservation concerns. The findings emphasize the need for long-term, standardized monitoring, focused studies on riverine habitats, and targeted conservation of critical breeding sites. Strengthening institutional collaboration and incorporating citizen science could further enhance monitoring efforts and support management strategies in the face of rapid environmental changes.

7.1. INTRODUCTION

Avi-faunal diversity in riverine habitats is essential to maintain ecological balance (Ormerod and Tyler 1991, 1993). Riverine ecosystems are dynamic and ecologically rich environments that support a wide variety of biodiversity, particularly avifauna. These habitats-comprising floodplains, sandbars, wetlands, and riverbanks-are crucial for the survival of water-dependent bird species, providing them with nesting grounds, foraging areas, and migratory stopovers (Tockner & Stanford, 2002). Among the major river systems of South Asia, the Ganga River stands out for its immense ecological, cultural, and economic importance. Stretching over 2,500 kilometres, the Ganga supports a vast network of aquatic and terrestrial life, playing a vital role in maintaining biodiversity across northern India (Gopal, 2014). The Ganga River traverses the five Indian states that cover three Biogeographic zones, namely the Himalaya, the Gangetic plain, and the coast. There are several Protected Areas in and around its mainstem, such as Rajaji National Park, Hastinapur Wildlife Sanctuary, Kacchua Wildlife Sanctuary, Vikaramshila Wildlife Sanctuary. The Ganga River is known to harbour around 177 waterbird and water associated bird species, of which ~20% are migrants. A total of 86 species of water and water-associated bird species were recorded by WII-NMCG (2019). The migratory species in the Indian sub-continent mainly arrive through the Central Asian Flyway, and the Ganga River Basin forms a larger part of this flyway. The winter migratory birds remain in the Basin for the entire winter season (Gopi et al., 2014).

The earliest record of waterbird study from the mainstem Ganga River dates back to the late 19th century focusing occurrence of sandbar nesting bird species like river lapwing (*Vanellus duvaucelii*) and small pratincole (*Glareola lactea*) (Jesse, 1899). A limited number of studies have been conducted on waterbirds along the Ganga River, and most of them focus on small stretches rather than covering the entire river. In the upper and middle



stretches, from Rishikesh to Kanpur, a study conducted between 1993-95 by Rao (2001) recorded 42 waterbird species. Previous research conducted in the middle stretch by Rahmani (1981) between Narora and Rajghat recorded 120 bird species including 28 waterbird species. Another study by Bashir et al. (2012) covered a 165 km stretch from Bijnor to Narora and documented 47 species of waterbirds. More recently, Vasudev et al. (2020) observed 70 waterbird species along a 24 km stretch of the Ganga River from Karnwas to Seensai, dominated by the Anatidae family. In Bihar, a total of 38 species were recorded over a significantly longer 526 Km stretch between Sahibganj and Chausa (Kumari et al., 2020). Similarly, Alam et al. (2022) reported 55 species in the middle stretch of the Ganga River from the Danapur to Fatuha in Patna (Bihar). In another comprehensive survey, Mohan et al. (2024) recorded 77 waterbird species along the stretch from Tela village in Prayagraj district to Sitabbiara village in Ballia, Uttar Pradesh, including 17 Near-Threatened species.

Past sporadic studies have also focused on barrages along the Ganga River, including the Bhimgoda Barrage (Haridwar, Uttarakhand), Narora Barrage (Bulandshahr, Uttar Pradesh), and Farakka Barrage (Murshidabad, West Bengal) (Arya et al., 2019, 2020; Jha, 2006). Pathak (2005) recorded 18 waterbird species at the Bhimgoda barrage. A recent study by Joshi et al. (2024) observed 22 waterbird species at the Bhimgoda barrage and Ganga ghat. In the middle stretch of the Ganga River, Khan et al. (2013) recorded 58 species of waterbirds from the Hastinapur wildlife sanctuary. Similarly, 115 species were recorded from the Vikramshila Gangetic Dolphin Sanctuary, a ~65 km stretch of the Ganga River between Sultanganj and Kahalgaon (Dey et al., 2014). From the Farakka Barrage, a few rare waterbird species, including near-threatened species such as the ferruginous pochard (*Aythya nyroca*) and black-bellied tern (*Sterna acuticauda*), were recorded (Jha, 2006). These studies highlight the importance of riverine wetlands for migratory and breeding waterbirds. The Protected Areas located along different zones of the Ganga River provide excellent habitat to waterbirds.

Species like black-bellied tern, Indian skimmer, river tern (Sterna aurantia), and river lapwing breed during the spring and summer seasons along the river islands in the Ganga River Basin (Mishra et al., 2018; Ankit et al., 2024). The riverine habitats in the Ganga River provide refuge to 177 water and water-associated species of birds, of which 20-30% species breed in river islands and banks, where their breeding activities collide with anthropogenic factors. A substantial body of literature in the different rivers of India highlights concerns regarding the impact of anthropogenic activities on nesting birds (Kar et al., 2012; Shaikh et al., 2018; Kar & Debata, 2019; Debata & Kar, 2021; Arjun et al., 2023; Ankit et al., 2024). Among nesting waterbirds of the Ganga River, the Indian skimmer and black-bellied tern are two endangered species, which are globally threatened with a high risk of extinction (Debata et al., 2017; Ankit et al., 2024). Long term monitoring of such species enables ecological understanding and informs management to safeguard threatened species and their habitats.

7.2. METHODS

To study the avifaunal diversity of the Ganga River, a multi-pronged strategy consisting of primary and secondary data was undertaken. A systematic review of peer-reviewed studies was conducted to collect information on past studies of waterbirds (1861 to 2023) of the Ganga River Basin (Mahar et al., 2025). Primary data were collected through waterbird monitoring; the total count method was used to assess the diversity and abundance of water and water-associated bird species at 28 monitoring sites along the Ganga River during daylight hours (0700-1700 hrs) for at least 15-20 minutes at each point (Bibby et al. 1992, WII-NMCG 2019). A total of 28 monitoring sites were sampled by two observers during 2017-18 and 2024-25. The bird identifications were done using 50×10 binoculars, followed by identification with the help of the field guide by Grimmett et al. (2012). A detailed guild-wise (Kumar et al. 2005) and IUCN Red List status-based checklist of recorded species was prepared (BirdLife International, 2025; Praveen & Jaypal, 2025). The abundances of different waterbird species were calculated using relative abundance. Shannon-Weiner diversity index (*H'*) (Clarke & Warwick, 2001) was used to calculate the diversity of waterbird species in R software using the package 'vegan' (Oksanen et. al., 2020; R Core Team, 2025).

Intensive monitoring of island nesting waterbirds was also conducted, covering the middle and lower stretches of the Ganga River between Haiderpur to Farraka. The island monitoring was undertaken through continuous boat surveys during the pre-monsoon seasons of 2023 and 2024 (WII-GACMC 2025). Trends in waterbird diversity and richness were also assessed using 2017-18 and 2024-25 monitoring data. Additionally, to assess trends in population change of three key species- black-bellied tern, river tern, and river lapwing, continuous abundance data were collected for four temporal periods (2018, 2019, 2022, and 2024) in the Ganga River, and natural log-transformed encounter rates of key species were used for trend analysis.

7.3. RESULTS

7.3.1. Review of Literature

The review revealed that the waterbird centric scientific studies were initiated in the early 21st century, in the basin; however, hunting and individual observations were available from as early as the 19th century. Overall, a positive trend was observed in peer-reviewed studies conducted after the 1990s (Figure 7.1a). Out of 3157 peer-reviewed studies obtained from different sources, only 18%, which covered topics like status, diversity, composition, and behaviour, were selected for the review. Till 2023, 573 peer-reviewed studies were conducted in the

different types of wetlands in the basin, of which 234 were used to prepare the waterbird checklist. In quality assessment, 25% of peer-reviewed studies were indexed with SCI or SCOPUS; the rest were indexed with NAAS or non-indexed journals.

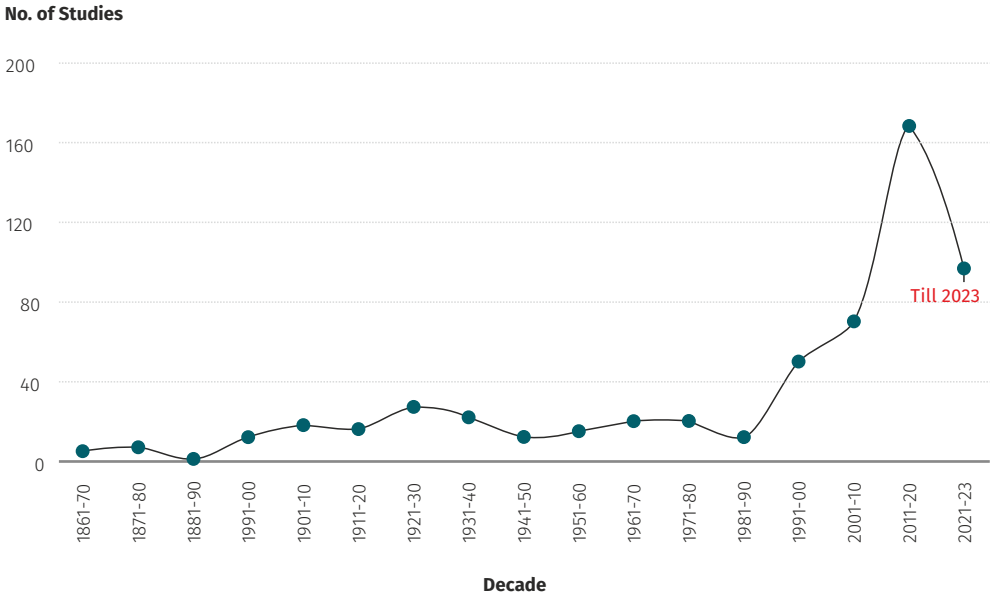


Figure 7.1a Trend in waterbird centric peer-reviewed publications of the Ganga River Basin

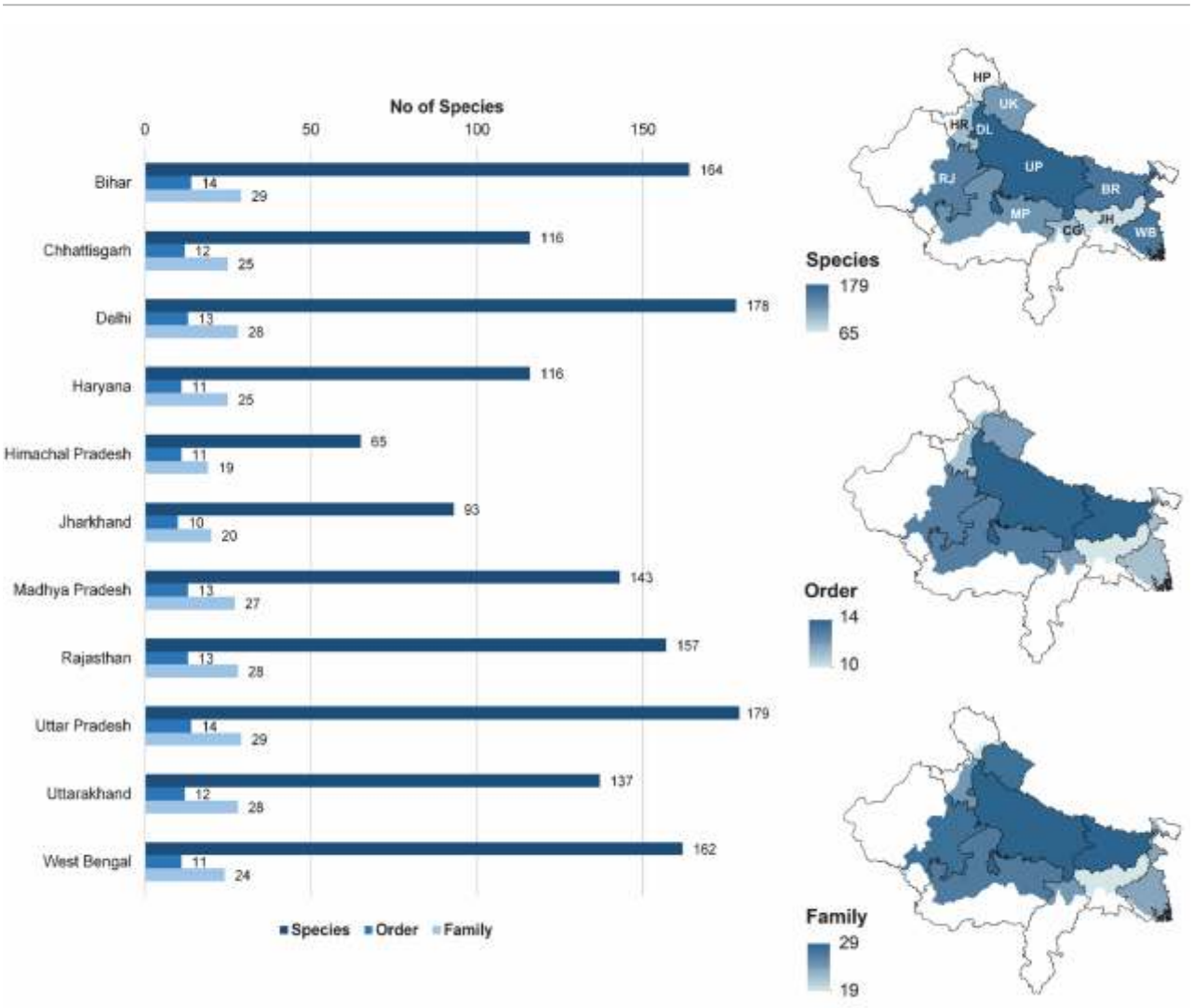


Figure 7.1b Review-based assessment of waterbird richness in the different Ganga River Basin states of India

The review confirmed the presence of a total of 236 waterbird species belonging to 32 families and 14 orders from different wetlands of the Ganga River Basin, which included 52 Threatened or Near-Threatened species as per the IUCN Red List. Most of the studies were conducted in the rural and urban wetlands of Uttar Pradesh and Bihar. Scolopacidae (n= 37 species, 16%), Anatidae (37 sp., 16%), and Laridae (20 sp., 8%) were the most dominant families in the basin, while Charadriiformes (n=87 species, 37%), Anseriformes (37 sp., 16%) and Pelecaniformes (26 sp., 11%) were the most dominant orders in the basin. Out of a total of 573 studies, ~26% were carried out in the riverine habitats of the Ganga River and its tributaries. Most of the studies were conducted in the state of Uttar Pradesh (135) and Uttarakhand (81). Most of the abundance studies were limited to categorization (high, low, medium), which could not provide the actual status of waterbirds that could have been used for management interventions. Most of the studies were limited to the preparation of checklists, while a couple of studies focused on the migration patterns of waterbirds, especially bar-headed geese (Takekawa et al., 2009; Kalra et al., 2011). Basin states such as Uttar Pradesh and Delhi harboured the highest number of species, while states like Jharkhand and Himachal Pradesh harboured the lowest species numbers (Figure 7.1b). This comprehensive review highlighted the need for waterbird focused use of robust techniques for studying status, distribution, and behaviour. Long-term study requirements were also realised while looking for trends in population and the status of waterbirds. Long-term data were unavailable throughout the basin, except for a few species such as the sarus crane (Antigone antigone) and the Siberian crane in human-dominated landscapes of Uttar Pradesh, Haryana, and Rajasthan, which included multi-decadal data (Roy et al., 2022; Boldyrev et al., 2023). The review also highlighted threats related to waterbirds and their habitats. Out of 23 identified categories of threats, poaching/hunting was found to be a prime threat (15.54%) to waterbirds.

7.3.2 Richness and Diversity

A total of 19110 individuals of 84 water and water-associated bird species were recorded from the Ganga River belonging to 11 orders and 22 families (Figure 7.2 a,b; Annexure VII) from 28 Ganga River monitoring sites between Bijnor and Haldia with a total survey effort of 343.98 hours/observer during 2017-18 and 2024-25, of which 70 species were recorded during the assessment of 2017-18 and 65 species during 2024-25. Out of 84 recorded species, four are listed as Endangered (EN), three as Vulnerable (VU), and six as Near Threatened (NT) categories (Table 7.1).



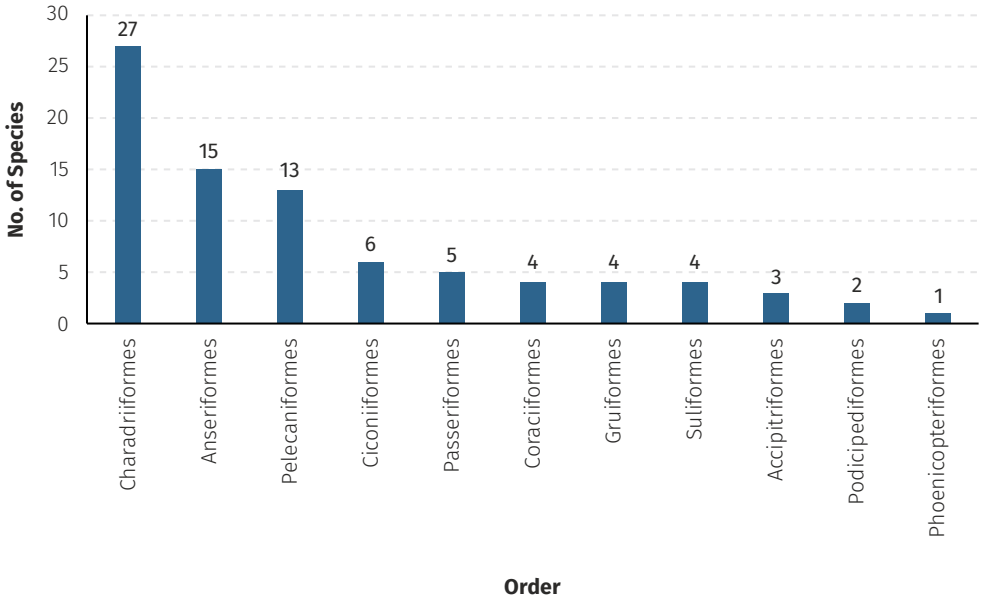


Figure 7.2a Distribution of water and water-associated bird species along the Ganga River across taxonomic orders

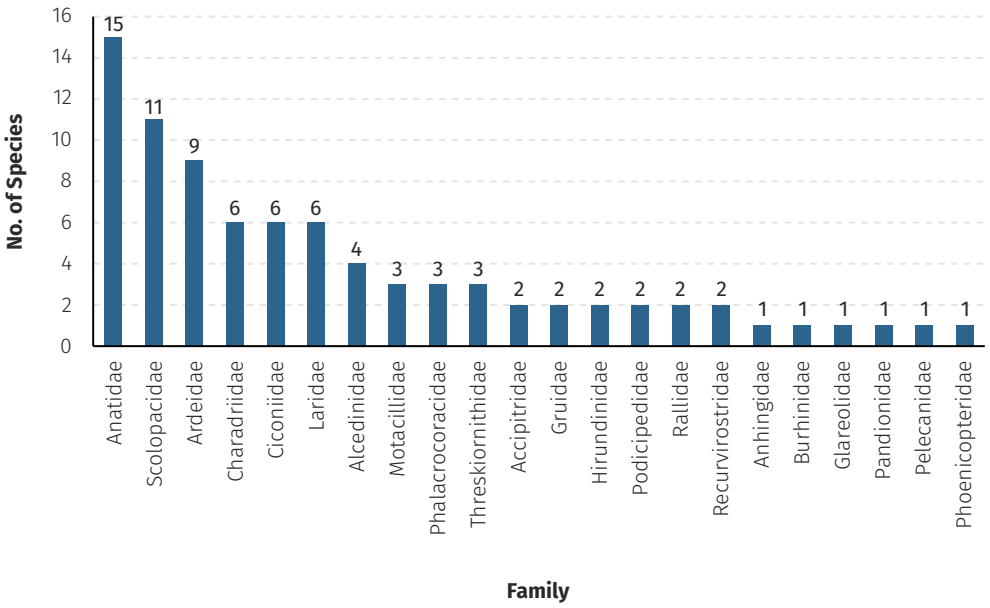


Figure 7.2b Distribution of water and water-associated bird species along the Ganga River across taxonomic families

Table 7.1 Threatened and Near Threatened Species in the Ganga River during two assessments

S.N.	Order	Family	English Name	Scientific Name	IUCN	IWPA
1	Charadriiformes	Laridae	Black-bellied tern	*Sterna acuticauda* (Gray, 1831)	EN	Sch.-I
2	Charadriiformes	Laridae	Indian skimmer	*Rynchops albicollis* (Swainson, 1838)	EN	Sch.-I
3	Accipitriformes	Accipitridae	Pallas's fish eagle	*Haliaeetus leucoryphus* (Pallas, 1771)	EN	Sch.-I
4	Accipitriformes	Accipitridae	Steppe eagle	*Aquila nipalensis* Hodgson, 1833	EN	Sch.-I
5	Anseriformes	Anatidae	Common pochard	*Aythya ferina* (Linnaeus, 1758)	VU	Sch.-I
6	Gruiformes	Gruidae	Sarus crane	*Antigone antigone* (Linnaeus, 1758)	VU	Sch.-I
7	Charadriiformes	Laridae	River tern	*Sterna aurantia* Gray, 1831	VU	Sch.-I
8	Anseriformes	Anatidae	Ferruginous duck	*Aythya nyroca* (Güldenstädt, 1770)	NT	Sch.-II
9	Charadriiformes	Burhinidae	Great thick-knee	*Esacus recurvirostris* (Cuvier, 1829)	NT	Sch.-II
10	Charadriiformes	Charadriidae	River lapwing	*Vanellus duvaucelii* (Lesson, 1826)	NT	Sch.-II
11	Charadriiformes	Scolopacidae	Eurasian curlew	*Numenius arquata* (Linnaeus, 1758)	NT	Sch.-II
12	Ciconiiformes	Ciconiidae	Asian woolly-necked stork	*Ciconia episcopus* (Boddaert, 1783)	NT	Sch.-II
13	Ciconiiformes	Ciconiidae	Lesser adjutant	*Leptoptilos javanicus* (Horsfield, 1821)	NT	Sch.-I

Assessment during 2017-18

Altogether, 13559 individuals of 70 species belonging to 10 orders and 21 families were recorded during 2017-18 assessment held between December, 2017 and January, 2018. Of recorded 70 species, three species are listed as EN, three as VU, five as NT and 59 as LC categories of the IUCN Red List. Among 28 monitoring sites in the middle and lower Ganga River, the overall species richness of water and water-associated species was found to be the highest in Fatehpur (S12 = 21 species), followed by Balia (S19 = 20 sp.) and Samshaba (S13= 19 sp.) (Figure 7.3). No species was found in Haldia (S32). Overall species diversity was highest in Narora (S7 H'= 2.40), followed by Balia (S14= 2.22) and Bhadoi (S9= 2.21), while Varanasi was the least diverse site (S17= 0.50) and there was no diversity of species in Jiaganj (S27), monitoring sites (Figure 7.3).

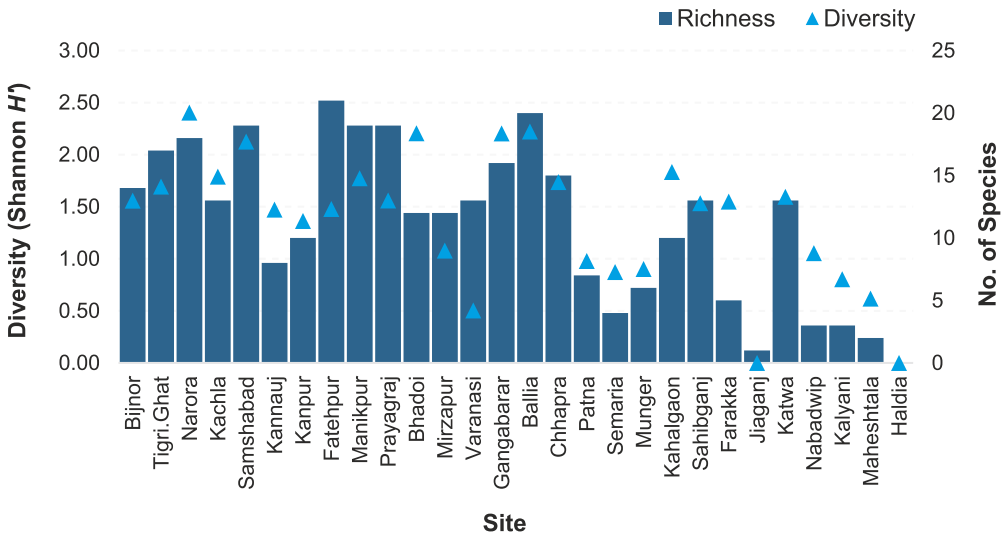


Figure 7.3 Richness and Diversity of water and water-associated birds in the Ganga River during First Monitoring (2017-18)

Assessment during 2024-25

A total of 5551 individuals of 65 water and water-associated species belonging to 11 orders and 19 families were recorded from the Ganga River during 2024-25 assessment conducted between November, 2024 and December, 2024. Of recorded 65 species, three species are listed as EN, two as VU and six as NT on the IUCN Red List. Kachlla (S8) had the highest species richness with 22 species, followed by Samshabad (S13) with 21 species. Sahibganj (S25) was found to have the least species richness (2 species), followed by Patna (S21) and Jiaganj (S27) with 3 species at each site. Haldia (S32) was devoid of avi-fauna (Figure 7.4). In terms of species diversity, Samshabad (S13= 2.46) was identified as the most diverse site, followed by Tigri Ghat (S6= 2.35) and Kannauj (S14= 2.32). Semaria (0.34) and Varanasi (0.37) were identified as the least diverse sites (Figure 7.4).

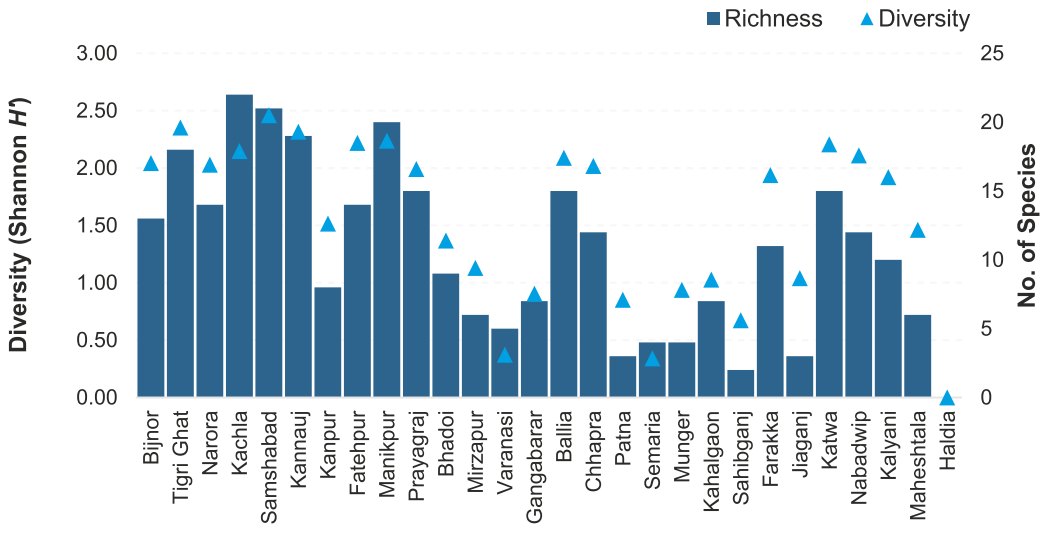


Figure 7.4 Richness and Diversity of water and water-associated birds in the Ganga River during Second Monitoring (2024-25)

Waterbirds

Of 70 species observed in 28 monitoring sites during 2017-18, 60 species (86%) were categorized in the waterbird group. The highest richness of waterbird species was recorded in Fatehpur (S12) with 20 species, followed by Samshabad (S9) with 18 species, and three sites viz. Tigri Ghat (S6), Narora (S7) and Balia (S19) with 17 species each. The highest species diversity value was found in Narora (S7= 2.31), followed by Gangabarar (S18) and Ballia (S19) with 2.13 each, and Bhadoi with 2.12. Whereas, Kalyani (S30 = 0.41) and Varanasi (S17 = 0.43) were the least diverse sites.

For 2024-25 assessment, of the 65 species, a total of 58 species (88%) were categorized as waterbirds. Kachlla (S8), Samshabad (S9) and Manikpur (S13) harboured the highest waterbird species richness with 20 species each. Whereas, Haldia was devoid of species, and Semaria (S22) had the lowest richness with two species. Samshabad (S9= 2.43) was recorded as the most diverse site, followed by Tigri Ghat (S6= 2.35) and Kannauj (S10= 2.30). While Varanasi (S17= 0.31) was the least diverse site, and Haldia (S32= 0) was devoid of waterbirds.

Water-associated species

Only 10 species (14%) out of 70 species were identified as the water-associated species in the assessment of 28 monitoring sites, during 2017-18. These water-associated species had a low diversity value (H' < 1.40). The highest species richness of water-associated species was in Manikpur (S13), Gangabarar (S18) and Sahibganj (S25) with 4 species each. While in Prayagraj (S14) and Balia (S19), three species were recorded. None of the species was recorded in 11 sites, while only one species was recorded in nine sites. Manikpur (S13 = 1.33) was the most diverse site, followed by Sahibganj (S25 = 1.14) and Gangabarar (S18 = 1.04). Whereas Kanpur (0.01) was the least diverse site.

Akin to the 2017-18 assessment, a small proportion (eight species, 12%) of the avifaunal category belonged to water-associated species. The highest species richness was recorded in Nabadwip (S29) with five species, and 12 sites were devoid of any water-associated species. Nabadwip (S29 = 1.14) was also the most diverse site among all 28 monitored sites, followed by Kalyani (S30= 0.64), Maheshtala (S31= 0.56). While Semaria (S22= 0.08) was the least diverse site.

7.3.3 Relative abundance

Assessment during 2017-18

In terms of combined relative abundance of water and water-associated species, small pratincole (22%) was recorded as the most abundant species, followed by great cormorant (18%), gadwall (8%) and grey-throated martin (8%). While Pallas's fish eagle and great-white pelican (0.007%) were the least abundant species, with only one individual of each species (Annexure VIII). Varanasi (S17 = 24%) was recorded as the most abundant site in the Ganga River, followed by Kanpur (S11= 15%) and Prayagraj (S14= 15%) (Table 7.2). Jiaganj (S27 = 0.007%) was the least abundant site with just one individual of the little cormorant.

Waterbirds

Of 60 waterbird species during 2017-18, small pratincole (25%) was the most abundant species, followed by great cormorant (20%) and gadwall (9%), while great-white pelican (0.01%), common merganser (0.02%), great thick-knee (0.02%), common snipe (0.02%), and black stork (0.02%) were some least abundant species (Annexure VIII). In site-wise abundance estimation, Varanasi (S17= 26%) harboured the highest number of waterbirds, followed by Prayagraj (S14= 16%) and Kanpur (S11= 8.67%), while Haldia was devoid of any species, and Kalyani (0.11%) and Maheshtala (0.10%) were the least abundant monitoring sites (Table 7.2).

Water-associated species

Out of 10 water-associated species, grey-throated martin (90%) was the most abundant species during the 2017-18, with a small proportion constituted by barn swallow (4%) and white wagtail (2%) (Annexure VIII). Pallas's fish eagle (0.08%) and citrine wagtail (0.17%) were the least abundant species. In site-wise, 11 sites were devoid of water-associated species, Kanpur (S11= 85%) was recorded as the most abundant site, followed by Narora (S7= 5%) and Varanasi (S17= 4%) (Table 7.2). Patna (S21= 0.08%) was the least abundant site in the Ganga River.

Assessment during 2024-25

Overall, black-headed gull (19%) was recorded as the most abundant species during 2024-25, followed by ruddy shelduck (11%) and grey -throated martin (~11%), whereas Indian skimmer, lesser adjutant, purple heron, striated heron and stork-billed kingfisher were the least abundant species with only one individual. In terms of site-wise relative abundance, Ballia (S19=29%) was recorded as the most abundant site, followed by Tigri Ghat (S6= 7%) and Prayagraj (S14= ~7%). Sahibganj (S25= 0.09%) was the least abundant (Table 7.2).



Waterbirds

Among 58 species of waterbirds recorded during 2024-25, black-headed gull (21%), ruddy shelduck (13%) and great cormorant (10%) were the three most abundant species, whereas Indian skimmer c, lesser adjutant, purple and striated herons were the rare and least abundant species with one individual (0.02%) each in the Ganga River (Annexure VIII). In site-wise assessment, Gangabarar (S18= 22%) was the most abundant site, followed by Narora (S7= 8%) and Prayagraj (S14= ~8%). Semaria (S22 = 0.1%) and Sahibganj (S25= 0.1%) were the least abundant sites in the Ganga River (Table 7.2).

Water-associated species

Among eight water-associated species recorded during the 2024-25, grey-throated martin (92%) was the most abundant species, akin to the 2017-18 assessment (Annexure VIII). Pied kingfisher (3%) and barn swallow (~3%) were the other abundant species recorded during the 2024-25 assessment. Site-wise, S18 was the most abundant species with a major proportion (77%) of the relative abundance. While water-associated birds were completely absent from 12 monitoring sites of the Ganga River (Table 7.2).

Table 7.2. Site-wise Relative abundance (%) of waterbirds and water-associated birds during two monitoring years

Category	Waterbirds		Water-associated birds	
Site/Year	2017-18	2024-25	2017-18	2024-25
Bijnor (S5)	1.11	2.67	0.17	0
Tigri Ghat (S6)	3	8	0	0
Narora (S7)	5.1	5.5	5.1	0
Kachla (S8)	1.28	5.61	0	0.92
Samshabad (S9)	1.75	5.8	0.17	0.31
Kannauj (S10)	0.6	4.9	0	0.15
Kanpur (S11)	8.67	3.67	85.05	0.31
Fatehpur (S12)	7.32	4.96	0.17	0
Manikpur (S13)	1.67	6.8	0.42	0
Prayagraj (S14)	16.5	7.66	0.51	0
Bhadoi (S15)	0.36	1.55	0.17	0
Mirzapur (S16)	8.1	2.7	0	0
Varanasi (S17)	26.4	1.76	4.25	0.15
Gangabarar (S18)	1.62	22.64	0.34	76.57
Ballia (S19)	2.5	2.57	0.76	0.46
Chhapra (S20)	2.5	1.9	0.17	3.37
Patna (S21)	0.41	1.27	0.08	0
Semaria (S22)	0.2	0.1	0	9.8
Munger (S23)	0.57	0.22	0.42	0.31
Kahalgaon (S24)	1	3.1	0	2.3
Sahibganj (S25)	1.7	0.1	1.78	0
Farakka (S26)	0.06	0.63	0	0.15
Jiyaganj (S27)	0	0.2	0	0
Katwa (S28)	6.96	3.18	0.17	0.77
Nabadwip (S29)	0.04	0.51	0	3.37
Kalyani (S30)	0.11	1.41	0.25	0.46
Maheshtala (S31)	0.1	0.35	0	0.61
Haldia (S32)	0	0	0	0



7.3.4 Feeding Guilds

Overall, Carnivore (69.05%, 58 species) was found as the most dominant feeding guild in the Ganga River, followed by Herbivore/Carnivore (12%, 10 species) and Carnivore/Herbivore (10.71%, 9 species) (Figure 7.5). While a small guild proposition of water and water-associated bird species belonged to Insectivore and Herbivore (2.38%, 2 species). During the 2017-18 assessment, Carnivore (70%, 49 species) was the most dominant feeding guild of waterbirds, followed by Herbivore/Carnivore (12.86%, 9 species) and Carnivore/Herbivore (10%, 7 species) guilds (Figure 7.6). Omnivore guild (1.43%, 1 species) was represented by the least number of waterbird species. Akin to the 2017-18, Carnivore (69.70%, 46 species) was found as the most dominant guild of waterbirds during 2024-25, followed by Herbivore/Carnivore (12.12%, 8 species) and Carnivore/Herbivore (7.58%, 5 species) guilds (Figure 7.7). Herbivore and Insectivore (3.03%, 2 species) were found to be the least dominant guilds of waterbirds.

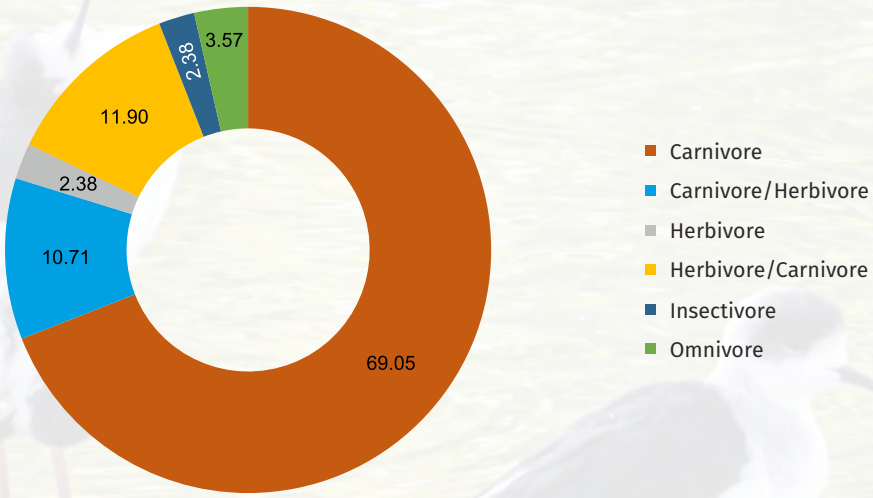


Figure 7.5. Proportion of the different feeding guilds of the waterbirds in the Ganga River

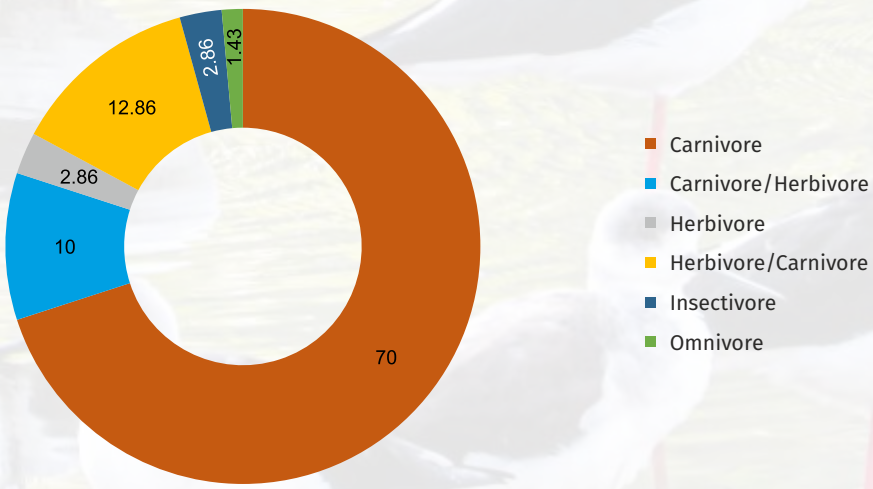


Figure 7.6. Proportion of the different waterbird feeding guilds during 2017-18

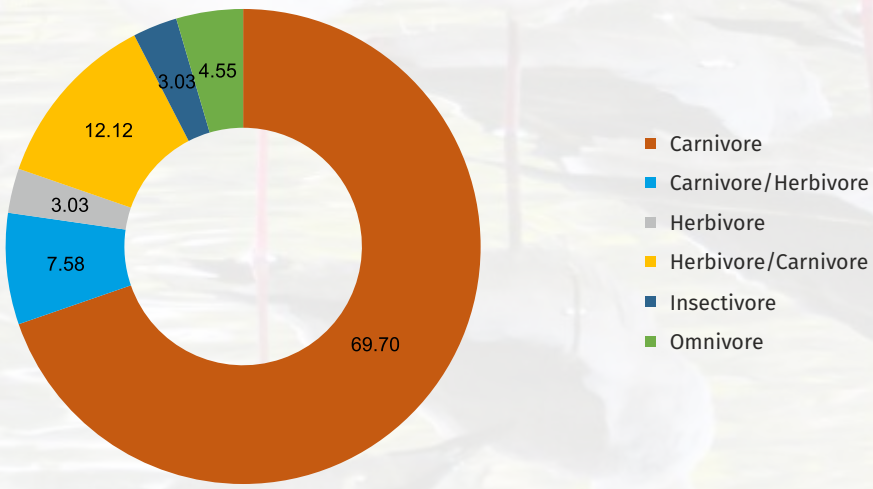


Figure 7.7. Proportion of the different waterbird feeding guilds during 2024-25

7.4 TREND ANALYSIS

In toto, the richness and abundance of water and water-associated species were higher during 2017-18 than in the second assessment conducted in 2024-25. The abundance remained less than half (-59.1%) during 2024-25 (n= 5551) than 2017-18 (n= 13559). While comparing 2017-18 and 2024-25 findings, the overall species richness remained similar with differences of only five species, 70 species and 65 species during the first, and second monitoring, respectively. A mixed trend (increase and decrease) was observed in the waterbird diversity and richness of the Ganga River (Figure 7.8). During both monitoring years, Haldia (S32) monitoring site was found to be devoid of any water or water-associated species. Between 2017-18 and 2024-25, half of the sites (50%) exhibited a decrease in species richness, while 39% sites showed an increase in richness, which included Kachla, Fatehpur, Nawadwip, and Kalyani (Figure 7.8a). Narora, Fatehpur, Prayagraj, Bhadoi, Mirzapur, Varanasi showed a sharp decline in the waterbird richness. Diversity values increased in 39% sites and decreased in 32% sites between 2017-18 and 2024-25 (Figure 7.8b), and remained unchanged for the rest of the sites. Bijnor, Tigri Ghar, Kachla, Samsabad, Kannauju, Fatehpur, Manikpur, Chhapra, Katwa and Nabadwip had the diversity value of HI > 2. Whereas sites like Gangabarar, Bhadoi, Semaria, Kahalgaon and Sahibganj sharply declined in their species diversity. Species diversity for Mirzapur and Munger remained almost the same between both the assessment years (Figure 7.8b).

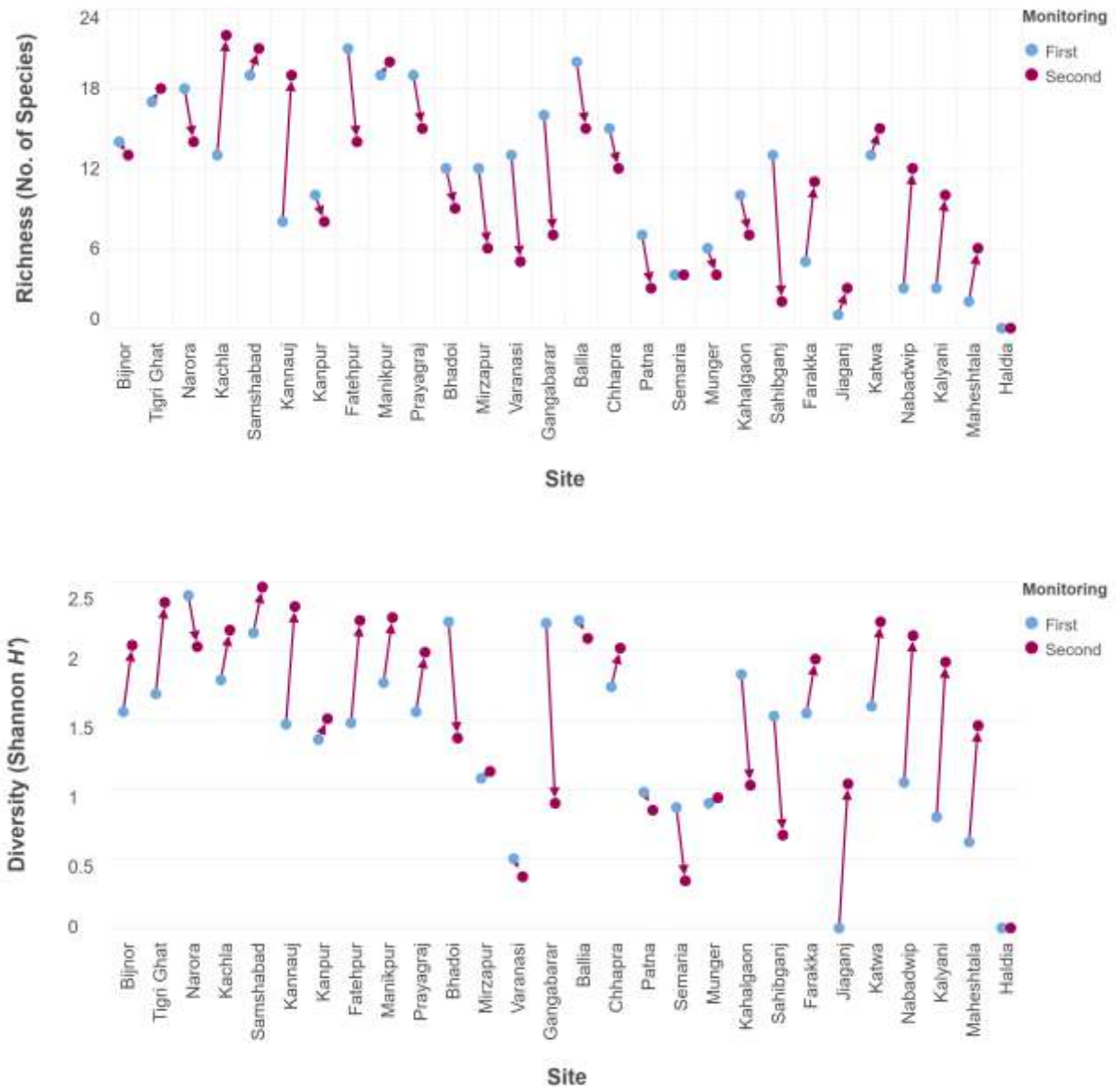


Figure 7.8. Trends in (a) Species Richness and (b) Diversity between two monitoring phases (*First: 2017-18; Second: 2024-25)

7.4.1 Island Nesting Waterbirds

During the 2023 island nesting monitoring, three nesting species were recorded along the Ganga River in 38 islands, while six nesting species were recorded from 300 islands during 2024. Only 18 nesting events were recorded during 2023, and 252 events during 2024 (Table 7.3). The restricted monitoring efforts during 2023 were attributed to flooded river islands in the middle stretch of the Ganga River, which prevented nesting activities. Indian skimmer and little tern were found nesting in the middle stretch of the Ganga River only during 2024, revealing that Indian skimmer utilized only the islands of middle stretch for nesting. Mean clutch size of the small pratincole was slightly higher during 2023 (2.50±0.50 SE) than 2024, whereas the little tern's clutch size was recorded slightly higher during 2024 (2.45±0.08) than 2023.

Table 7.3 Summary of island nesting bird species and nests observed in the Ganga River (2023 & 2024)

Year	Species Name	Nesting event (number)	Clutch size (number)	Unhatched eggs (number)	Hatchling (number)	Fledgling (number)
2023	Black-winged stilt	1	4	4	-	-
	Little tern	15	1-3	27	7	2
	Small pratincole	2	2-3	4	2	54
	Total	**18**		**35**	**9**	**56**
2024	Black-winged stilt	3	4	12		
	Indian skimmer	21	1-3	30	4	5
	Little tern	80	1-4	166	25	1
	Red-wattled lapwing	1	1	1		
	River lapwing	4	1-4	11		
	Small pratincole	143	1-5	264	28	6
	Total	**252**		**484**	**57**	**12**



7.4.2 Population trend of key avifaunal species

Apart from the overall trend analysis of avifaunal diversity and richness, three key breeding species were also targeted for the trend analysis in the Ganga River: black-bellied tern, river tern, and river lapwing. The encounter rates for these species were collected during four different years (2018, 2019, 2020, and 2024) (WII-GACMC 2025). Temporal trends indicated that species such as black-bellied tern (p = 0.71, R^2 = 0.08), river lapwing (p =0.21, R^2= 0.63), river tern (p= 0.98, R^2= 0.0006) and Indian skimmer (p= 0.86, R^2= 0.02) showed a non-significant decline in encounter rates between 2018 and 2024 (Figure 7.9). In the BEU level trend analysis of black-bellied tern, relatively 31 BEUs showed an increase, 20 showed a decrease, and no change was recorded in 24 BEUs. River lapwing showed a decreasing pattern in 114 BEUs, an increase in 72 BEUs, and no change in 49 BEUs. While the river tern showed a decrease in 30 BEUs, an increase in 28, and no change in 12 BEUs.

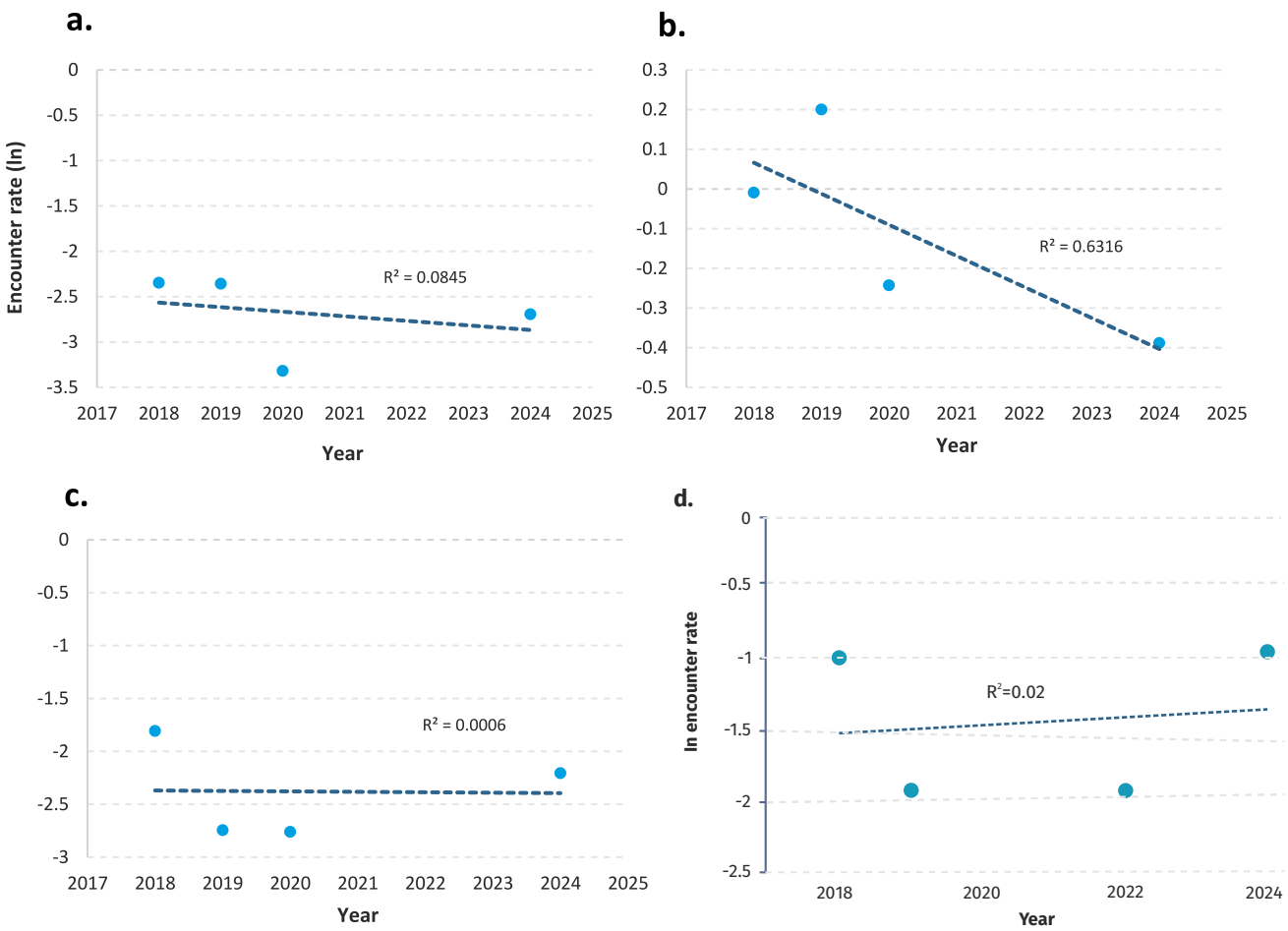


Figure 7.9. Temporal trends in encounter rate (ER) of breeding waterbirds (**a.** black-bellied tern, **b.** river lapwing, **c.** river tern, **d.** Indian skimmer) in the Ganga River between 2018 and 2024



7.5 DISCUSSION

Literature based assessment highlights the urgency of quality studies on the waterbirds from the riverine habitats of the Ganga River Basin. Information on island nesting birds along the rivers in the Ganga basin is scant and sporadic. As most of the studies were not even published in quality journals, the reliability of published data also raises questions and indicates dubious findings. The river habitats are understudied and require dedicated river-centric studies in the Ganga River Basin. Under the National Mission for Clean Ganga (NMCG), WII has been studying the mainstem Ganga River and its tributaries since 2017 (WII-NMCG, 2019). Through the compilation of policies and laws related to waterbirds, this review also underscored policy caveats and required interventions on the Ganga River Basin and individual basin state levels (Mahar et al., 2025). Through the comprehensive review and field-based studies, the present study confirmed that the Ganga River harbours 35.59% of the species, and 25% of threatened species of the entire Ganga River Basin.

Field-based monitoring of waterbirds in the Ganga River revealed that there was a difference in the occurrence of five avi-faunal species between the two temporal periods, indicating a small fluctuation. The only visible difference was in the abundance, where counts declined by more than half (-59.1%) in 2024-25 than in 2017-18. Furthermore, population change in one of the most abundant species, the great cormorant, showed a decline of 80% from 2017-18 to 2024-25. Although short term trends are inconclusive to determine the actual change in the status of waterbirds, several factors influence the annual movement of waterbirds in the Indian-subcontinent and elsewhere (Butler, 2003; Hazra et al., 2012). Sometimes variations in the annual temperature regimes in the temperate regions are attributed to early or delayed "to and fro migration" of waterbirds between Central Asia and the Indian sub-continent. Additionally, site-specific alterations influence the abundance and richness of waterbirds. To confirm reliable trends of waterbirds, long-term monitoring should be included, and annual monitoring should be conducted in waterbird habitats, especially in rivers and associated wetlands.

The present study also highlighted the demand of long-term monitoring of specialist and threatened species in the Ganga River. Although population trends of three key species were not statistically significant, it warrants special attention in a rapidly changing scenario. The endangered black-bellied tern is one of the most threatened inland waterbird species in India and elsewhere, which is also a habitat specialist species that mostly prefers river sand bars. Altogether, <1500 individuals of black-bellied tern are in India (BirdLife International, 2022). Any alteration in the sand bars, especially due to cucurbit crops and mining, could reduce the chances of their survival. Globally, there is a declining trend in their population at an unknown rate. Another threatened species, the river tern, is also a habitat specialist and usually prefers sandbar habitats in the riverine ecosystem. Overall, it has witnessed a declining population trend due to breeding failure and habitat alteration. While river lapwing occurs in sand bars as well as on river banks, and in other types of habitats. Their population sustenance also depends on the breeding productivity, recruitment rate, and local movement, which are often affected by human-induced factors. The difference in the status of nesting island waterbirds could be attributed to flooding in the middle stretch of the Ganga River during 2023 monitoring, which requires the urgent attention of the concerned authorities (irrigation and forest dept.), and they should work in synergy during the peak nesting season of island-dependent waterbirds. Species like the black-bellied tern and Indian skimmer need micro-level monitoring and management interventions.

The study of island nesting waterbirds established baseline data on the nesting species of the Ganga River; now, more systematic studies are recommended in the future, specifically targeting endangered and habitat specialist species that are prone to alteration of habitat in the near future. The islands in the Ganga River hold immense ecological values, and yet these are the most ignored in terms of conservation measures. These river islands are also amongst the most fertile landscapes and are heavily exploited, particularly for water fluctuation, farming, settlements, and mining. Present assessment suggests that there is a need to study the breeding biology of the threatened species, nesting/hatching/fledging success (breeding success), nest survival, and other aspects that will unveil the requirements of the nesting species and related threats to cope with. At the same time, it is equally important to protect these habitats through policy measures, collaborations, awareness, and public support.

Short term monitoring of the Ganga River has unveiled some important findings in the last five years. Species diversity and richness have witnessed a few changes, where most of the sites have shown an increase in species diversity between the two monitoring periods. Long-term monitoring exercises are recommended for assessing any significant changes in the population dynamics and species diversity. The State Forest Departments need to collaborate and encourage the regional/local institutions to conduct annual monitoring. Citizen science could also play a vital role in such a type of monitoring (Masto et al., 2025). Snapshot of monitoring on regular intervals might reveal precise trend changes in the species diversity of river ecosystems, and subsequently pave the way to resolve management and conservation-related issues. Such information will also be crucial to unravel changes in the near future and in climate change studies.

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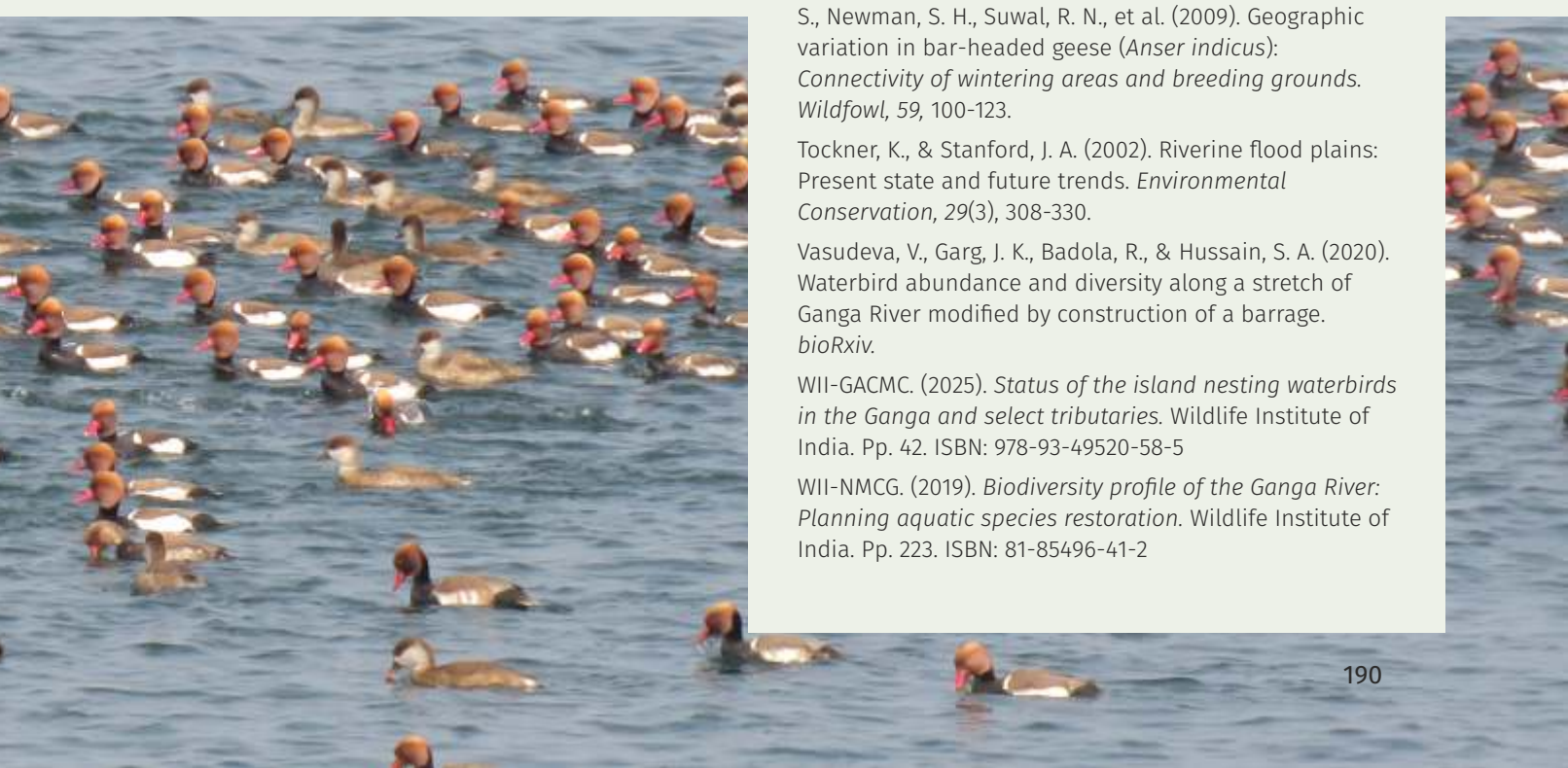
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CHAPTER 8

AQUATIC AND SEMI-AQUATIC MAMMALS OF THE GANGA RIVER

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SUMMARY

The freshwater mammalian assemblage of the Ganga River comprises the Gangetic dolphin (*Platanista gangetica*) and three otter species. As apex and mesopredators, these taxa play a pivotal role in structuring aquatic ecosystems, regulating prey populations, and serving as indicators of ecological health, reflecting the condition of hydrological processes, habitat connectivity, and trophic dynamics within the river system. India's only obligate freshwater cetacean; the Gangetic dolphin occupies a unique evolutionary niche among river dolphins globally. The otters represent an ecologically important guild of semi-aquatic predators with distinct habitat associations across the Ganga River.

The assemblages and distribution of these species was studied along the mainstem Ganga River, through boat-based visual encounter method. In addition, species distribution modeling was conducted using the Maximum Entropy algorithm via MaxEnt software, to determine the potential distribution of three species of otters in the Ganga River mainstem.

The present study revealed a heterogeneous spatial distribution, with consistently higher encounter rates of the Gangetic dolphin in the middle stretches of the Ganga River, particularly between Prayagraj and Kahalgaon. These River zones likely represent ecological refugia characterized by conducive flow regimes, prey availability, and relatively lower anthropogenic disturbances. In contrast, upstream and downstream stretches indicate relatively lower sightings, indicating possible habitat fragmentation and suboptimal ecological conditions. Temporal trends from 2018 to 2024 showed a gradual increase in encounter rates of Gangetic dolphin and spatial expansion, suggesting localized improvements in habitat quality, possibly linked to enhanced flow conditions or conservation interventions. However, stretches with no sightings, and uneven population distribution attributed to anthropogenic pressures, such as barrages, altered flow regimes, and degraded habitats disrupting longitudinal movement and gene flow.

The smooth-coated otter was found to be widely distributed in the middle and lower stretches, reflecting its adaptability to productive, human-influenced landscapes. In contrast, the Eurasian otter was largely confined to relatively pristine upper Himalayan stretches, where cold, fast-flowing waters and intact riparian zones exist. The Asian small-clawed otter exhibited a patchy distribution, strongly linked to wetland-rich and deltaic

ecosystems, indicating specialist characteristics. Species distribution modelling highlighted that climatic variables, hydrology, and human disturbance collectively shape otter distributions in the Ganga Riverscape, with anthropogenic pressures emerging as a key limiting factor, especially for the more sensitive species like the Gangetic dolphin, Asian small-clawed and Eurasian otters.

Despite their ecological importance, the Gangetic dolphin and otters face multiple threats across the Ganga Riverscape. River regulation through dams and barrages alters natural flow regimes, reduces habitat heterogeneity, and fragments populations. Pollution from industrial, agricultural, and urban sources compromises water quality and bioaccumulates in higher trophic levels, directly affecting these predators. Fisheries interactions, particularly bycatch in gill nets, represent a major mortality factor for dolphins, while otters have been impacted by anthropogenic pressures viz., habitat encroachment and other human pressures. Emerging threats such as underwater noise, vessel traffic, and climate-induced hydrological variability further exacerbate ecological stress for dolphins. The co-occurrence and distribution patterns of dolphins and otters highlight the importance of maintaining habitat connectivity, ecological flows, and floodplain integrity. Conservation priorities should be focused on restoring longitudinal connectivity or augmentation, safeguarding high suitability habitats, mitigating bycatch and pollution, and protecting wetlands and riparian corridors. Integrating species-specific conservation within basin-scale management frameworks is essential to sustain not only these flagship species but also the broader ecological resilience of the Ganga River.

8.1 INTRODUCTION

The aquatic and semi-aquatic freshwater mammals of India are represented by four species, which include the Gangetic dolphin and the three otter species, all of which are recorded along the Ganga River (WII-NMCG, 2018). Within this assemblage, the Gangetic dolphin assumes particular ecological and conservation significance as the country's only obligate freshwater cetacean, thereby situating it within the broader evolutionary and biogeographic context of river dolphins globally.

River dolphins are a polyphyletic group of freshwater and brackish water mammals distinct from marine dolphins (Hamilton et al., 2001). Currently, four recognized species of river dolphins inhabit disjunct river systems globally. These are the Amazon River Dolphin (*Inia geoffrensis*), the La Plata River Dolphin (*Pontoporia blainvillei*), the Gangetic Dolphin (*Platanista gangetica*), and the Indus River Dolphin (*Platanista minor*) (Rice, 1998; Braulik et al., 2021). A fifth species of river dolphin, the Yangtze River Dolphin (*Lipotes vexillifer*), once abundant in the central and lower Yangtze River and its lakes, is now considered functionally extinct (WWF, 2010). According to the IUCN Red List, the river dolphin populations are decreasing worldwide. Of the four river dolphin species, three species are thus placed under the Endangered category of IUCN Red List, except the La Plata River Dolphin, which is Vulnerable. River dolphin survival is threatened by unsustainable fishing, habitat disruption, and pollution from various human activities, necessitating global conservation efforts (WWF, 2019).

Gangetic dolphin (*Platanista gangetica* (Lebeck, 1801)) is one of the evolutionary primitive and obligatory river cetaceans endemic to the Indian subcontinent, inhabiting the Ganga, Brahmaputra, Karnaphuli-Sangu, and Meghna River systems and their tributaries in India, Bangladesh and Nepal, (Anderson, 1879; Jones, 1982; Sinha et al., 2000; Smith et al., 2000). The Gangetic dolphin, commonly known as 'susu', 'sishuk', and 'phoo' in different parts of its distribution range, is regarded as an indicator of healthy river systems. They have a greyish-brown skin tone, elongated snout, rounded belly, flexible neck, stocky body, and large triangular pectoral flippers and tail flukes. Functionally blind, they have tiny eyes above their mouth line and they rely on echolocation for navigation, hunting, and communication. The species is primarily piscivorous, but they also feed on crustaceans. Typically observed alone or in pairs, occasionally in small groups, they often gather near meanders, counter-current pools, confluences, mid-river islands, and bridge pilings (Sinha & Kannan, 2014).

The Gangetic dolphin, like other cetaceans, is a top predator of the system they occupy, influences the food chain structure, and thereby plays a critical role in maintaining the vital ecological processes of the river ecosystems (Behera, 1995; Singh, 2001; Gomez-Salazar et al., 2012). However, increasing dependence on river resources, pollution, and overexploitation have contributed to its population decline and shrinking range (Behera et al., 2008; WWF, 2010; Das et al., 2022). The species is threatened by a range of spatial and temporal stressors such as fragmentation by dams and barrages (Baruah et al., 2012; Braulik et al., 2012), altered flow regimes, and habitat degradation due to loss of connectivity (Choudhary et al., 2012; WII-GACMC, 2018; Sinha et al., 2000) and pollution (Kannan et al., 1997; Qureshi et al., 2017).

While the Gangetic dolphin represents an obligate aquatic apex predator, otters - the semi-aquatic mammals, constitute a parallel functional group within the freshwater ecosystem of India. Otters are distinctive members of the Mustelidae family. As semi-aquatic mammals, they are well-adapted to life in and around water. As top predators in aquatic ecosystems, they shape the faunal species composition of the ecosystems they inhabit and also act as key indicators of wetland and

riverine health due to their sensitivity to habitat degradation and disruptions in the food chain (Erlinge, 1972; Mason & Macdonald, 1987; Kruuk et al., 1993). Out of the 13 otter species found globally, India is home to three species of otters: the Smooth-coated otter (*Lutrogale perspicillata*), Eurasian otter (*Lutra lutra*), and Asian small-clawed otter (*Aonyx cinereus*) (Hussain et al., 2011; Raha & Hussain, 2016). These species occupy a variety of freshwater and coastal ecosystems across the country and play an important ecological role as apex or mesopredators in aquatic food webs (Khan et al., 2014; Baskaran et al., 2022). The Ganga River Basin historically supported populations of all three otter species due to the availability of diverse aquatic habitats, including large rivers, tributaries, wetlands, floodplains, irrigation canals, and riparian forests (Khan et al., 2014).

Despite their ecological importance, otter populations across their range are experiencing significant declines due to multiple anthropogenic threats, including habitat degradation, water pollution, depletion of prey resources, illegal hunting, and trade in otter pelts and body parts. Consequently, the Smooth-coated otter and Asian small-clawed otter are currently listed as Vulnerable, while the Eurasian otter is listed as Near Threatened on the IUCN Red List (Basnet et al., 2020; Gupta et al., 2020; Gomez & Nguyen, 2023). In large and densely populated river basins such as the Ganga, these pressures are further intensified by increasing infrastructure development, sand mining, and riverbank modification, which collectively reduce the availability of suitable habitats for otters (Nawab & Hussain, 2012; Talegaonkar et al., 2021).

Understanding the current distribution and habitat suitability of Gangetic dolphin and otters within the Ganga River is therefore critical for their conservation. This chapter provides insights into the distribution of the Gangetic dolphin based on the multiple surveys conducted along the mainstem Ganga River and for otters MaxEnt based species distribution modelling was undertaken to assess their potential distribution. Otters are typically found at low densities, are elusive by nature, and are primarily nocturnal, making direct observations challenging. Consequently most existing studies rely on opportunistic sightings supported by indirect signs of their presence (Hussain, 2002). In view of these limitations, the potential distribution of all three otter species in the Ganga River was modelled using MaxEnt approach.

8.2 METHODS

The entire length of the Ganga River was divided into 5 km length BEUs (as described in Chapter 2). These BEUs were surveyed post-monsoon in 2018, 2019, 2020 and 2024 employing a boat-based visual encounter method (Smith & Reeves, 2000; Sinha & Sharma, 2003a) to note the presence of Gangetic dolphins. Surveys were performed during daylight hours, from 8:00 to 12:00 and 15:00 to 17:00, using an inflatable boat with a Yamaha 25 hp engine. Given the intermittent shallow and deep pools in the river stretches, Gangetic dolphins were observed moving up to about 25 km daily. To ensure thorough sightings of surfacing dolphins, the boat maintained a constant speed of 6-8 km/hr, navigating the river's deeper channel (thalweg). A team of four trained observers, equipped with binoculars (NIKON 8×42), GPS (GARMIN e-Trex 30), a depth sounder (HONDEX PS7), and a range finder (HAWKE Endurance LRF-1000), worked from the front of the boat. Three observers focused on spotting dolphins, while the fourth recorded habitat variables at each sighting (Smith et al., 2006; Oliveira et al., 2019). To prevent the bias of double-counting dolphins within a group, careful attention was given to their spatio-temporal movement, body color, size, and snout



morphology (notably longer and upturned in females) (Mohan et al.,1997; Bashir et al., 2010). Field conditions presented several practical challenges that influenced detection probability and survey efficiency. Shallow braided reaches restricted boat manoeuvrability, leading to temporary deviations from the planned transect path. Additionally, the performance of depth sounders was occasionally compromised in highly sediment-laden waters, and strong currents in confluence zones made it difficult to maintain a stable observation platform. These challenges were systematically accounted for by slowing boat speed, increasing observer rotation frequency, and using repeated scanning cycles to reduce the likelihood of missed detections (Smith & Reeves, 2000; Smith et al., 2006; Braulik et al., 2012; Richman et al., 2014).

For otters, a boat-based visual encounter survey was conducted across the pre-defined BEUs along the Ganga River. During field survey, boat speed was strictly maintained between 6 to 8 km/h to standardise survey effort, minimise disturbance, and ensure comprehensive visual coverage of both riparian zones (Das et al., 2022). Each survey unit comprised two primary observers equipped with NIKON 8 × 42 binoculars. Upon the direct sighting of an otter, observers recorded species identification, group size, demographic composition, observed behavior, and precise geographical coordinates via handheld GPS. Concurrent with the direct encounter protocol, observers systematically scanned for indirect evidence of otter presence, specifically targeting spraints (feces), tracks (pugmarks), terrestrial grooming sites, and active dens. Potential signs detected from the vessel were ground-truthed via localized foot patrols to verify species identity, mapped using GPS, and assigned to their respective BEU (Raha & Hussain, 2016). For spatial modelling, occurrence data was compiled from primary field records (direct sightings and verified signs; denoted as PQ) and secondary data (denoted as RS) sourced from the Global Biodiversity Information Facility (GBIF, accessed March 2026), published peer-reviewed literature, and technical reports. Secondary occurrence records were actively ground-truthed during the field phase to validate continued species presence in historical locations (Carmona et al., 2023). To mitigate spatial autocorrelation, sampling bias, and model overfitting, spatial rarefaction was applied to retain only a single occurrence point per predefined geographic grid cell. To predict habitat suitability, an initial suite of 26 environmental variables encompassing climatic, topographic, hydrological, and anthropogenic disturbance factors was selected based on established otter ecological requirements. All spatial covariate layers were uniformly resampled to a 1 km² spatial resolution within a standardized coordinate reference system. A Variance Inflation Factor (VIF) analysis was subsequently conducted to detect and eliminate highly collinear covariates. Variables exhibiting a VIF ≥ 5 were sequentially removed, resulting in the retention of all the uncorrelated environmental predictors for the species distribution model (Jamwal et al., 2022).

Species distribution modeling was conducted using the Maximum Entropy algorithm via MaxEnt software (version 3.4.4) (Tong et al., 2023). The model was parameterized with 10,000 randomly generated pseudo-absence (background) points within the 10 km buffer of the Ganga River. Auto-features were enabled to apply linear, quadratic, product, threshold, and hinge features appropriate for the sample size, and the regularization multiplier was set to 1.0. A cross-validation approach was employed to evaluate the model, partitioning the finalized occurrence dataset into training data (75%) and testing data (25%). The model was executed utilizing 10 bootstrap replicates, with the final predictive map representing the mean output of these iterations. Model performance was evaluated using receiver operating characteristic (ROC) analysis. The Area Under the Receiver Operating Characteristic Curve (AUC) was used for predictive accuracy and overall model performance. Finally, the relative contribution and permutation importance of the 16 retained environmental covariates were quantified using the MaxEnt Jackknife test to identify the primary drivers of otter distribution within 10 km buffer of the Ganga riverscape.



8.3 RESULTS

8.3.1 Gangetic dolphin - distribution and encounter rate



A total of 1290 sightings of Gangetic dolphins were recorded during post-monsoon season 2018 in the Ganga River, with an estimated encounter rate of 0.65 ± 0.05 sightings/km (Figure 8.1). The highest encounter rate was observed in the Ghazipur-Sitabdiara stretch at 2.32 ± 0.43 sightings/km, followed by Varanasi-Ghazipur (1.67 ± 0.37) and Prayagraj-Mirzapur (1.29 ± 0.27). In contrast, stretches such as Farukkabad-Kannauj and Ahiran-Behrampore reported no sightings. Moderate encounter rates were documented in stretches like Patna-Simaria Ghat (0.93 ± 0.17), Simaria-Sultanganj (0.82 ± 0.14), and Sahibganj-Farakka (0.41 ± 0.11) (Table 8.1).

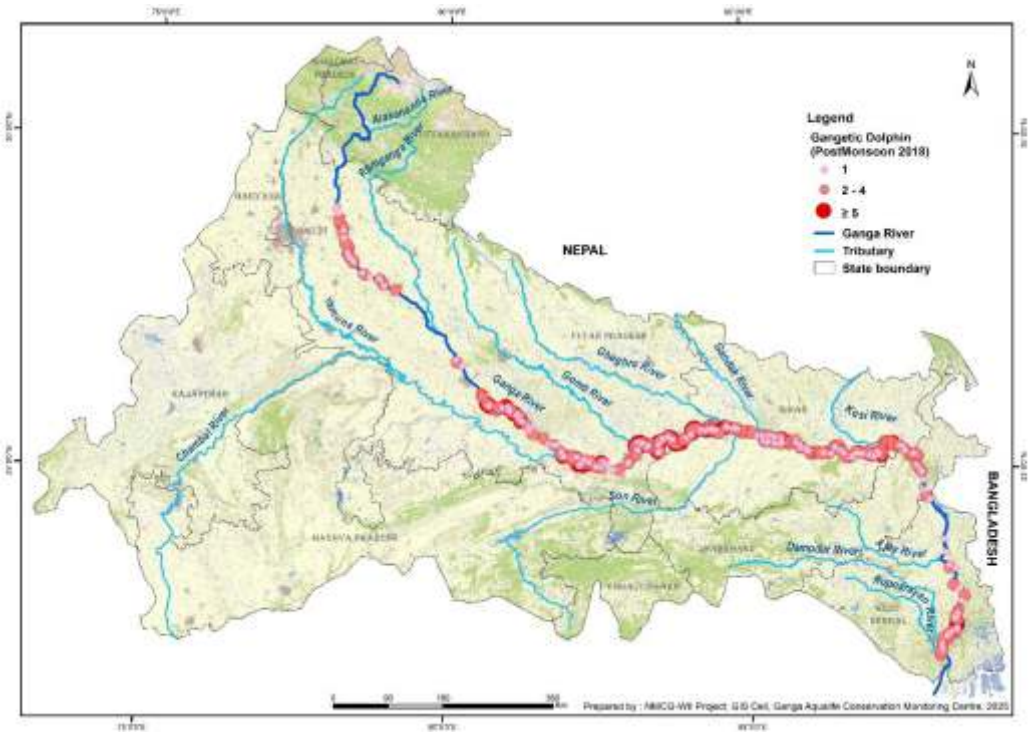


Figure 8.1 Gangetic dolphin distribution in the Ganga River recorded during post-monsoon 2018

In the post-monsoon season of 2019, a total of 1303 Gangetic River dolphins were sighted (Figure 8.2). The mean encounter rate was 0.65 ± 0.06 sightings/km. The encounter rate was highest in the stretches between Ghazipur to Sitabdiara (2.62 ± 0.54 sightings/km) followed by Prayagraj to Mirzapur (1.75 ± 0.34 sightings/km), Varanasi to Ghazipur (1.66 ± 0.46 sightings/km), Sultanganj to Kahalgaon (1.25 ± 0.29 sightings/km) and Simaria to Sultanganj (0.93 ± 0.18 sightings/km). The lowest encounter rates were recorded between the stretches Kachhla to Farukkabad and Kannauj to Kanpur (0.02 ± 0.01 sightings/km) followed by Farakka to Ahiran (0.06 ± 0.04 sightings/km), Narora to Kachhla (0.07 ± 0.04 sightings/km), Ahiran to Behrampore (0.07 ± 0.03 sightings/km) and Behrampore to Katwa (0.09 ± 0.04 sightings/km) (Table 8.1).

In the post-monsoon season of 2020, a total of 1317 Gangetic River dolphins were sighted across the surveyed stretches of the Ganga River (Figure 8.3). The mean encounter rate was 0.66 ± 0.06 sightings/km. The encounter rate was highest in the stretch between Sultanganj and Kahalgaon (2.02 ± 0.46 sightings/km), followed by Prayagraj to Mirzapur (1.82 ± 0.36 sightings/km), Sitabdiara to Patna (1.56 ± 0.34 sightings/km), Ghazipur to Sitabdiara (1.21 ± 0.34 sightings/km), and Sahibganj to Farakka (1.13 ± 0.24 sightings/km). Notable dolphin concentrations were also observed between Mirzapur and Varanasi (0.68 ± 0.34 sightings/km) and Simaria to Sultanganj (0.96 ± 0.16 sightings/km). Least sightings were noted between Kachhla to Farukkabad (0.02 ± 0.02 sightings/km), Farakka

to Ahiran (0.03 ± 0.03 sightings/km), Narora to Kachhla (0.05 ± 0.05 sightings/km), and Ahiran to Behrampore (0.07 ± 0.03 sightings/km). Similarly low encounter rates were documented between Bijnor and Brij Ghat (0.15 ± 0.04 sightings/km) and Bandel to Noorpur (0.10 ± 0.05 sightings/km) (Table 8.1). The spatial distribution pattern indicates that the middle stretch of the Ganga River, particularly between Prayagraj and Kahalgaon, supports substantially higher dolphin populations compared to the upstream and downstream reaches.

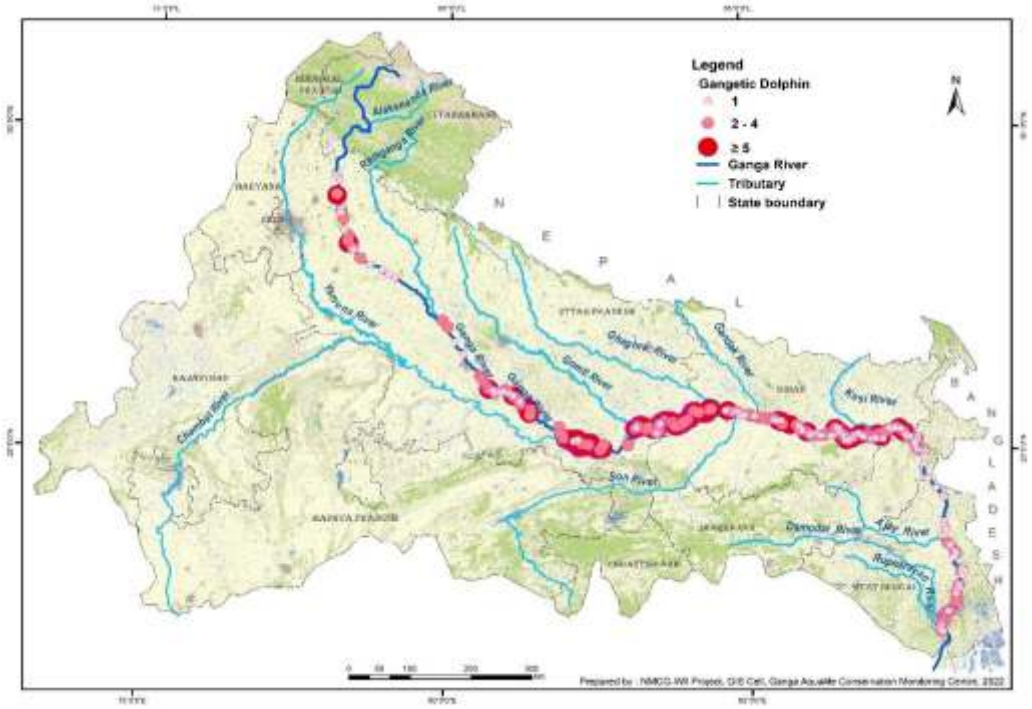


Figure 8.2 Gangetic dolphin distribution in Ganga River recorded during post-monsoon 2019

A total of 1547 sightings of dolphins were recorded during post-monsoon 2024, with an overall encounter rate of 0.77 ± 0.06. The highest numbers of sightings were recorded in the Ghazipur to Sitabdiara stretch of Uttar Pradesh (371 sightings, ER 2.97 ± 0.55), followed by the Sultanganj to Kahalgaon stretch of Bihar (129 sightings, ER 2.15 ± 0.28), and Kahalgaon to Sahibganj stretch (75 sightings, ER 1.36 ± 0.21). Moderate sightings occurred in Varanasi to Ghazipur, Sitabdiara to Patna, and Simaria to Sultanganj, each with an encounter rate above 1 (Table 8.1). While no dolphins were observed in the stretch between Farukkabad to Kannauj and Farakka to Ahiran (Table 8.1; Figure 8.4).

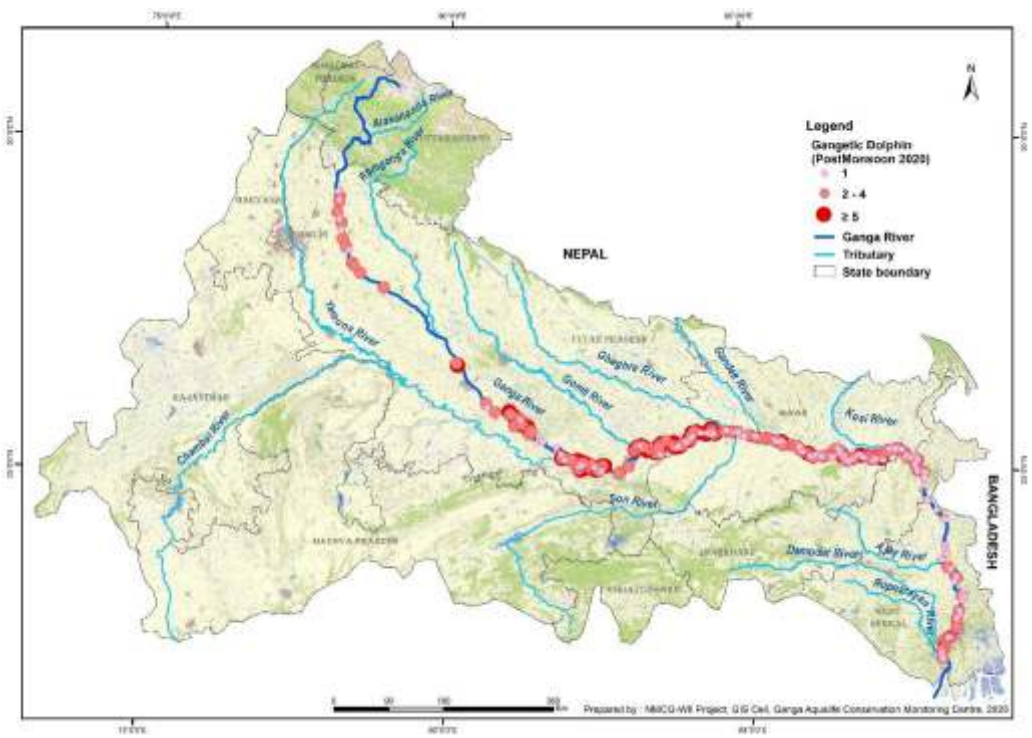


Figure 8.3 Gangetic dolphin distribution in the Ganga River recorded during post-monsoon 2020

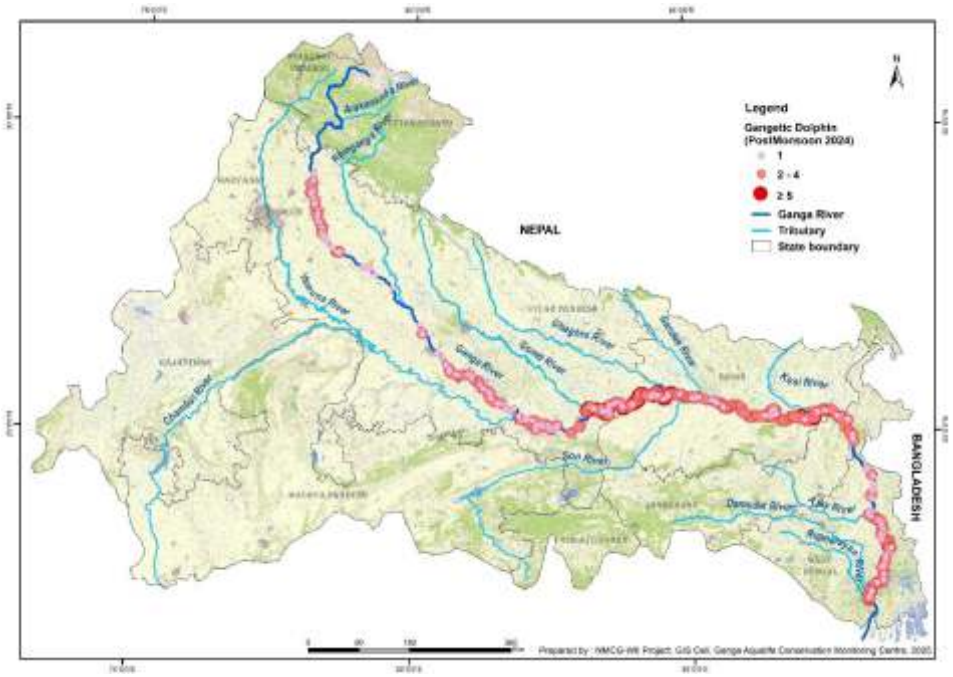


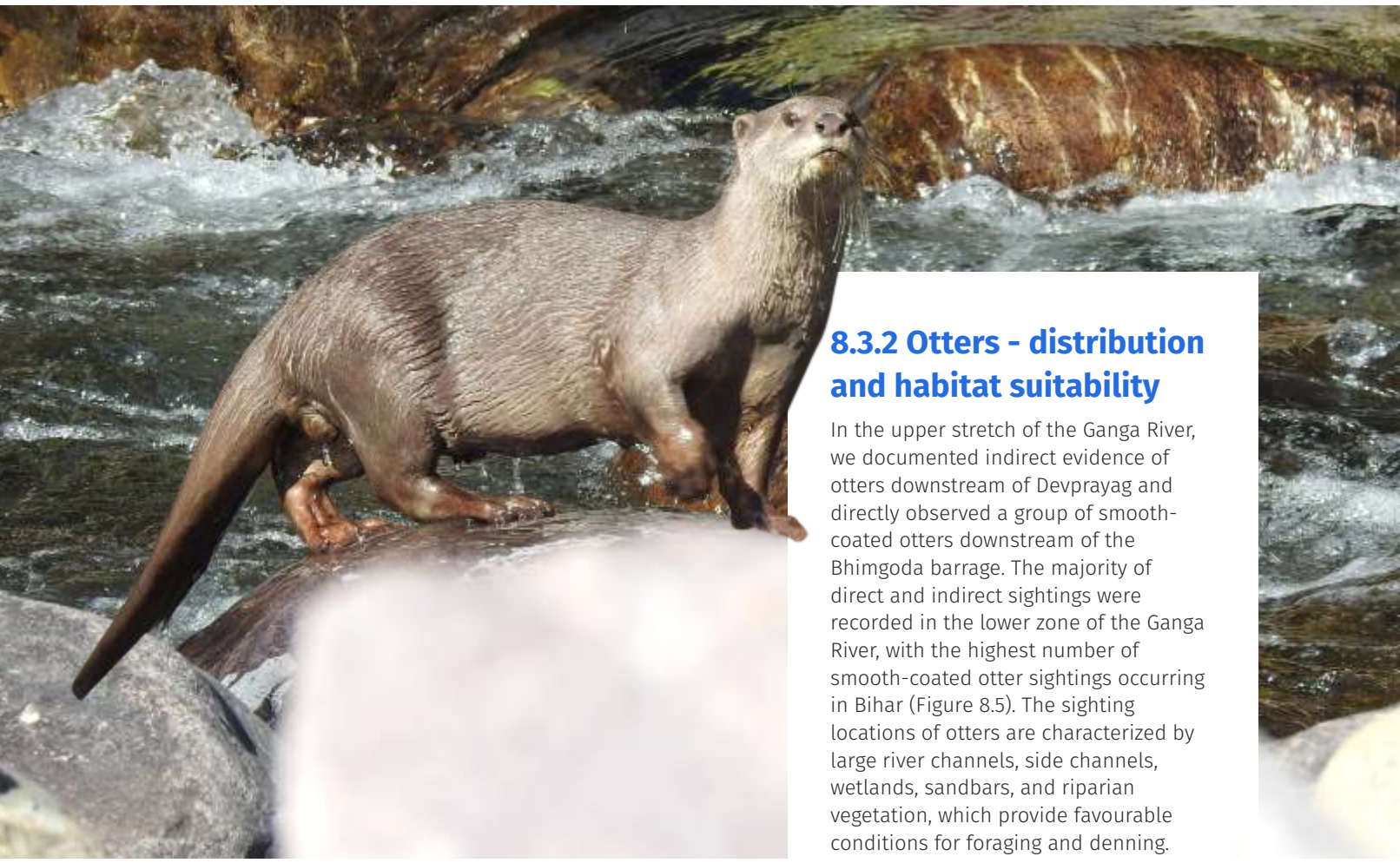
Figure 8.4 Gangetic dolphin distribution in the Ganga River recorded during post-monsoon 2024

Table 8.1 Summary of Gangetic dolphin occurrence and encounter rate (ER) in Post-Monsoon 2018, 2019, 2020 and 2024

S. No	Stretch	Length (km)	Post-monsoon 2018	
			No of Sightings	ER (Sightings/km) ± SE
1	Bijnor - Brij Ghat	85	8	0.09 ± 0.03
2	Brij Ghat - Narora	75	38	0.51 ± 0.11
3	Narora - Kachhla	60	8	0.13 ± 0.07
4	Kachhla - Farukkabad	105	6	0.06 ± 0.04
5	Farukkabad - Kannauj	60	0	0
6	Kannauj - Kanpur	95	4	0.04 ± 0.02
7	Kanpur - Fatehpur	25	6	0.24 ± 0.16
8	Fatehpur - Prayagraj	195	126	0.65 ± 0.13
9	Prayagraj - Mirzapur	110	142	1.29 ± 0.27
10	Mirzapur - Varanasi	75	28	0.37 ± 0.15
11	Varanasi - Ghazipur	115	192	1.67 ± 0.37
12	Ghazipur - Sitabdiara	125	290	2.32 ± 0.43
13	Sitabdiara - Patna	70	60	0.86 ± 0.18
14	Patna - Simaria Ghat	90	84	0.93 ± 0.17
15	Simaria-Sultanganj	90	74	0.82 ± 0.14
16	Sultanganj - Kahalgaon	60	64	1.07 ± 0.26
17	Kahalgaon - Sahibganj	55	66	1.2 ± 0.22
18	Sahibganj - Farakka	70	29	0.41 ± 0.11
19	Farakka - Ahiran	35	3	0.09 ± 0.06
20	Ahiran - Behrampore	75	0	0
21	Behrampore - Katwa	75	4	0.05 ± 0.03
22	Katwa - Nabadwip	60	3	0.05 ± 0.03
23	Nabadwip - Bandel	90	5	0.06 ± 0.03
24	Bandel - Noorpur	105	50	0.48 ± 0.08
	Total	**2000**	**1290**	**0.65 ± 0.05**



Post-monsoon 2019		Post-monsoon 2020		Post-monsoon 2024	
No of Sightings	**ER (Sightings/km) ± SE**	**No of Sightings**	**ER (Sightings/km) ± SE**	**No of Sightings**	**ER (Sightings/km) ± SE**
15	0.18 ± 0.07	13	0.15 ± 0.04	34	0.4 ± 0.09
21	0.28 ± 0.09	9	0.12 ± 0.05	40	0.53 ± 0.13
4	0.07 ± 0.04	3	0.05 ± 0.05	13	0.22 ± 0.14
2	0.02 ± 0.01	2	0.02 ± 0.02	6	0.06 ± 0.02
6	0.1 ± 0.07	0	0	0	0
2	0.02 ± 0.01	11	0.12 ± 0.08	7	0.07 ± 0.04
4	0.16 ± 0.1	0	0	9	0.36 ± 0.1
100	0.51 ± 0.11	154	0.79 ± 0.31	92	0.47 ± 0.06
192	1.75 ± 0.34	200	1.82 ± 0.36	67	0.6 ± 0.1
17	0.23 ± 0.12	51	0.68 ± 0.34	19	0.25 ± 0.12
191	1.66 ± 0.46	139	1.21 ± 0.34	144	1.25 ± 0.26
327	2.62 ± 0.54	195	1.56 ± 0.34	371	2.97 ± 0.55
42	0.6 ± 0.13	79	1.13 ± 0.22	87	1.24 ± 0.25
68	0.76 ± 0.21	84	0.93 ± 0.32	85	0.94 ± 0.2
84	0.93 ± 0.18	86	0.96 ± 0.16	112	1.24 ± 0.19
75	1.25 ± 0.29	121	2.02 ± 0.46	129	2.15 ± 0.28
44	0.8 ± 0.22	62	1.13 ± 0.24	75	1.36 ± 0.21
32	0.46 ± 0.12	42	0.6 ± 0.13	44	0.63 ± 0.16
2	0.06 ± 0.04	1	0.03 ± 0.03	0	0
5	0.07 ± 0.03	5	0.07 ± 0.03	9	0.12 ± 0.05
7	0.09 ± 0.04	15	0.2 ± 0.07	11	0.15 ± 0.05
8	0.13 ± 0.06	22	0.37 ± 0.14	41	0.68 ± 0.22
10	0.11 ± 0.05	13	0.14 ± 0.06	50	0.56 ± 0.14
45	0.43 ± 0.11	10	0.1 ± 0.05	102	0.97 ± 0.97
1303	**0.66 ± 0.06**	**1317**	**0.66 ± 0.06**	**1547**	**0.77 ± 0.06**



8.3.2 Otters - distribution and habitat suitability

In the upper stretch of the Ganga River, we documented indirect evidence of otters downstream of Devprayag and directly observed a group of smooth-coated otters downstream of the Bhimgoda barrage. The majority of direct and indirect sightings were recorded in the lower zone of the Ganga River, with the highest number of smooth-coated otter sightings occurring in Bihar (Figure 8.5). The sighting locations of otters are characterized by large river channels, side channels, wetlands, sandbars, and riparian vegetation, which provide favourable conditions for foraging and denning.

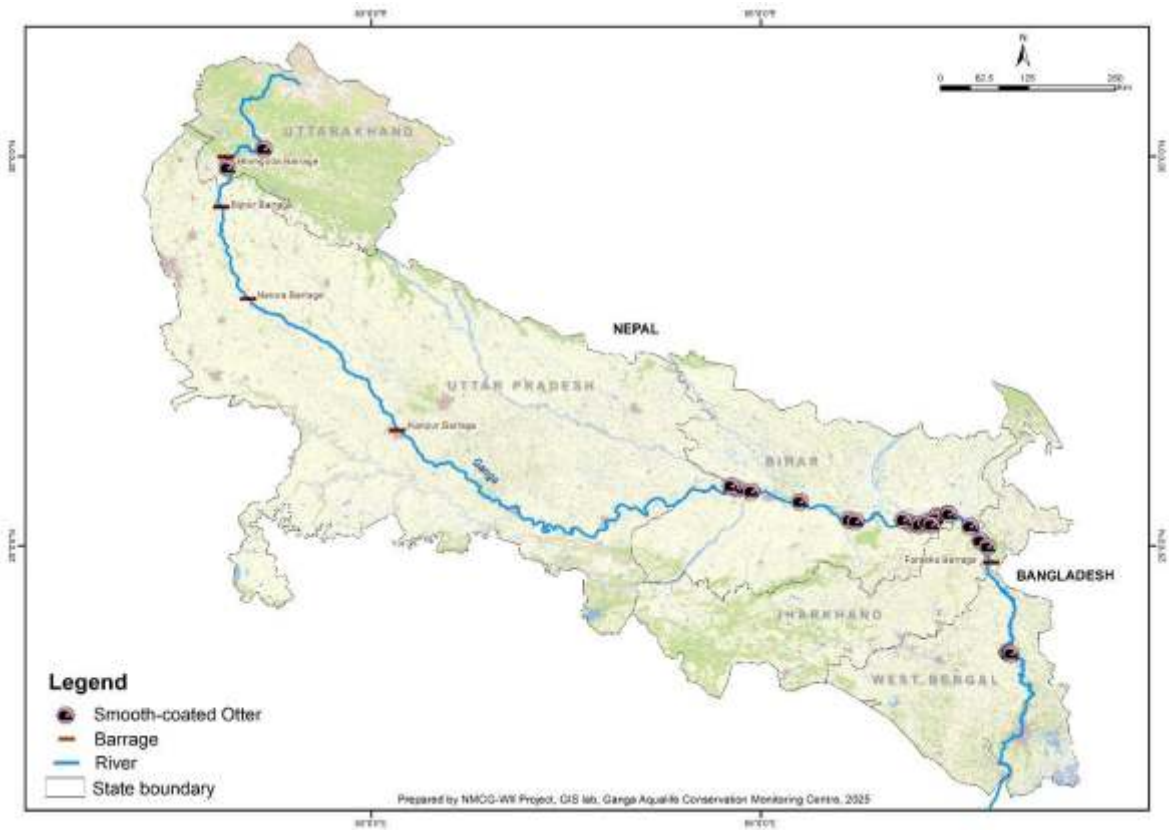


Figure 8.5 Distribution of smooth-coated otter in the Ganga River

I. Asian small-clawed otter (*Aonyx cinereus*)

The MaxEnt algorithm using presence only occurrence recorded predicted the sporadic potential distribution of the Asian small-clawed otter across the Ganga River. The results showed a high predictive performance, with an average test AUC value of 0.963 ± 0.083, indicating excellent model discrimination between suitable and unsuitable habitats (Figure 8.6).



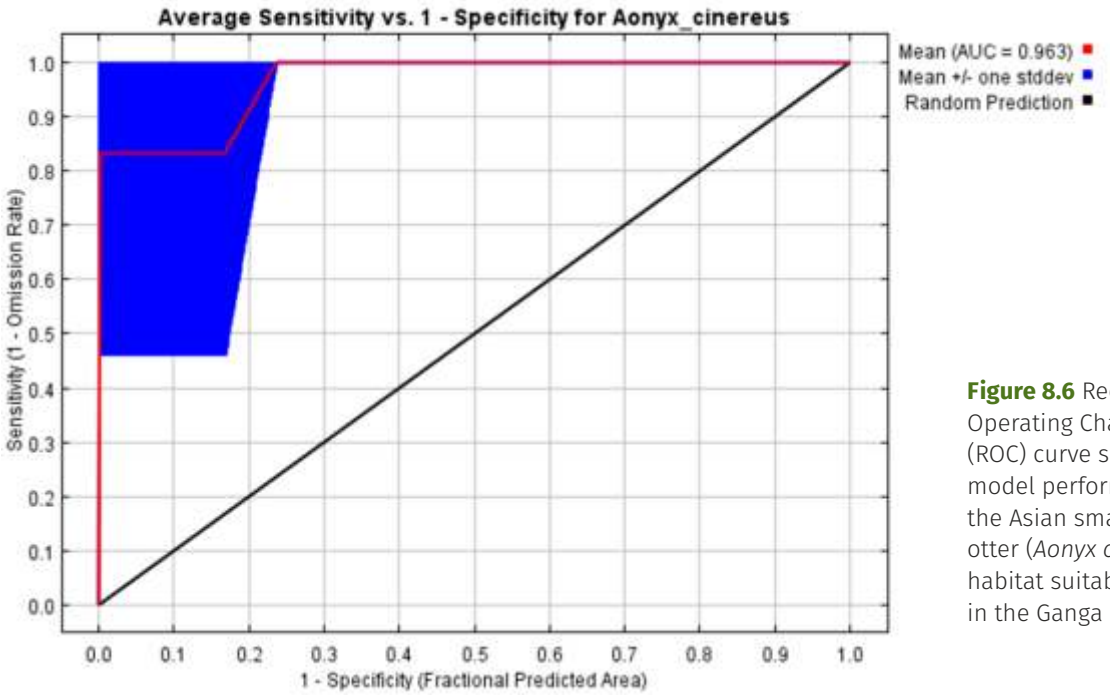


Figure 8.6 Receiver Operating Characteristic (ROC) curve showing model performance for the Asian small-clawed otter (*Aonyx cinereus*) habitat suitability model in the Ganga Riverscape.



Approximately 98.6% of the riverscape area was classified as low or unsuitable habitat for the Asian small-clawed otter, whereas only 0.56% of the riverscape was predicted to be moderately suitable, and 0.85% was identified as highly suitable habitat (Figure 8.7). The moderately suitable habitats were primarily concentrated in wetland-dominated floodplains and deltaic regions, particularly in the upper Ganga and close to the Sundarbans region of West Bengal, where extensive mangrove systems, tidal creeks, and marshy wetlands occur. These areas are characterized by low-gradient river channels, marshlands, and shallow wetlands, which support abundant crustaceans and aquatic invertebrates that constitute the primary prey base of the Asian small-clawed otter.



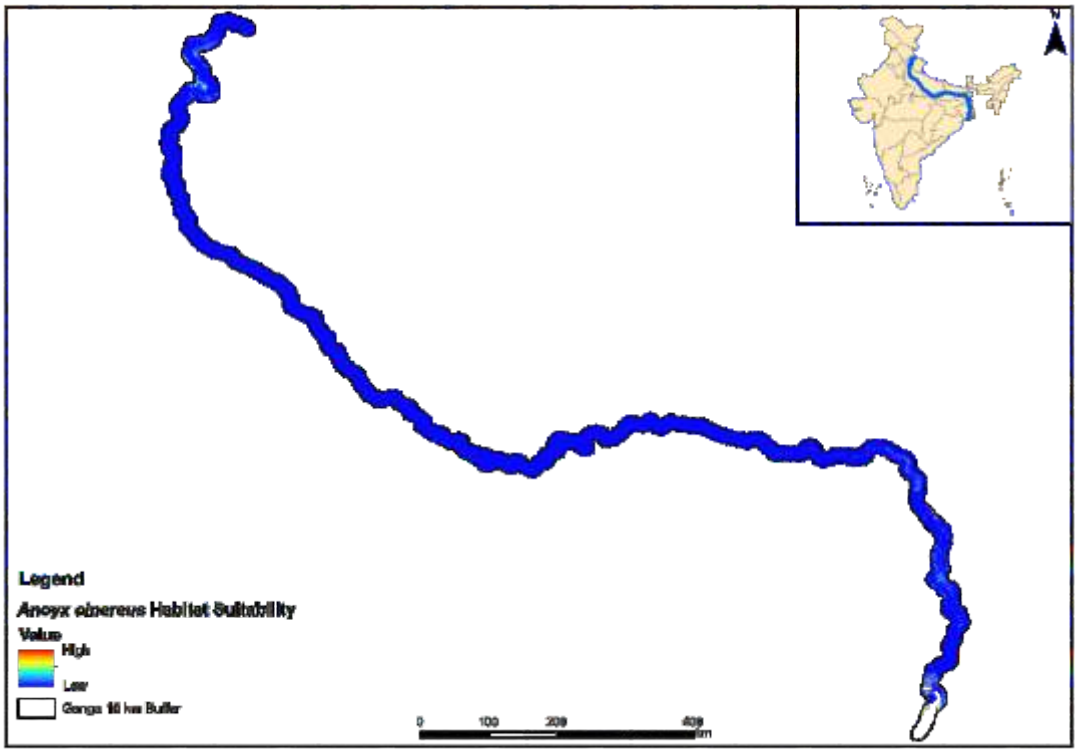


Figure 8.7 Predicted habitat suitability map for the Asian small-clawed otter (*Aonyx cinereus*) along the Ganga Riverscape

Among the various variables, temperature annual range (bio7) contributed the highest proportion to the model (38.9%), followed by human footprint index (24.8%), mean diurnal temperature range (bio2) (18.7%), and temperature seasonality (bio4) (10.9%). Other variables, such as the mean temperature of the coldest quarter (bio11) and precipitation of the coldest quarter (bio19), contributed smaller proportions to the model. The jackknife analysis further indicated that bio2 (mean diurnal range) provided the highest gain when used in isolation, suggesting that this variable contains strong independent explanatory power (Table 8.2). In contrast, the human footprint resulted in the largest decrease in model gain when omitted, indicating its strong influence on the predicted distribution of the species.

Table 8.2 Relative contribution and permutation importance of environmental variables influencing the habitat suitability model for *Aonyx cinereus*.

Variable	Percent contribution	Permutation importance
bio_7	38.9	0
Human footprint	24.8	13.5
bio_2	18.7	0
bio_4	10.9	69.4
bio_11	1.9	0
bio_19	1.7	0.3
bio_3	1.5	2.3
bio_13	1	0.8
Terrain ruggedness	0.3	9
bio_14	0.1	0
bio_17	0.1	0.2

II. Eurasian otter (*Lutra lutra*)

The habitat suitability model developed using the MaxEnt algorithm predicted the potential distribution of the Eurasian otter (*Lutra lutra*) across the Ganga River. The model demonstrated good predictive accuracy with an average test AUC value of 0.901 ± 0.118, indicating reliable discrimination between suitable and unsuitable habitats for the species (Figure 8.8). The ROC curve illustrates that the model performs substantially better than a random prediction and confirms the robustness of the environmental variables used in predicting the distribution of the Eurasian otter across the Ganga River.



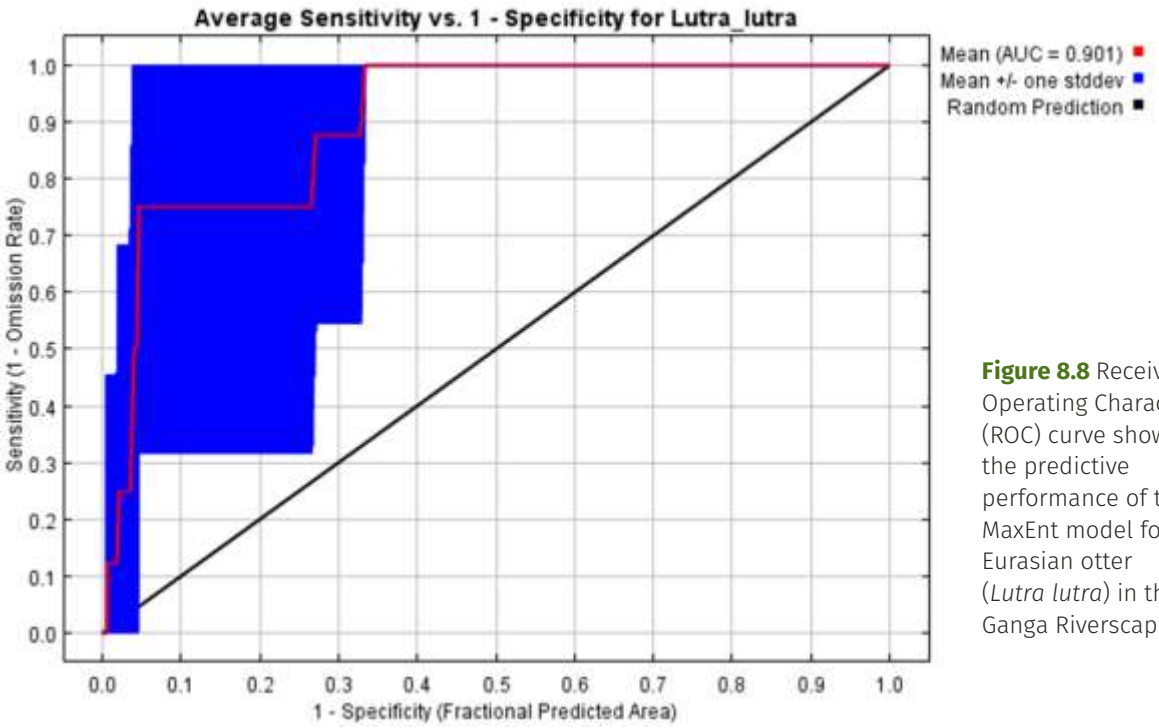


Figure 8.8 Receiver Operating Characteristic (ROC) curve showing the predictive performance of the MaxEnt model for the Eurasian otter (*Lutra lutra*) in the Ganga Riverscape

The classification of habitat suitability revealed that approximately 7.4% of the Ganga River represents highly suitable habitat for the Eurasian otter, while 21.6% of the riverscape area was classified as moderately suitable, and the remaining 71.0% was predicted to be low or unsuitable habitat. The predicted suitable habitats for the Eurasian otter are primarily concentrated in the upper Himalayan and sub-Himalayan regions of the Ganga River. These regions are characterized by cold, fast-flowing rivers, relatively intact riparian vegetation, and lower levels of anthropogenic disturbance, which correspond with the ecological requirements of the Eurasian otter. Moderate habitat suitability was predicted along the upper Ganga River system, whereas the middle and lower Gangetic plains exhibited very low habitat suitability due to high human population density, river regulation, and extensive habitat modification. The spatial distribution of predicted habitat suitability across the riverscape is illustrated in Figure 8.9, which highlights the concentration of highly suitable habitats in the Himalayan landscape and the gradual decline in suitability toward downstream floodplain regions.

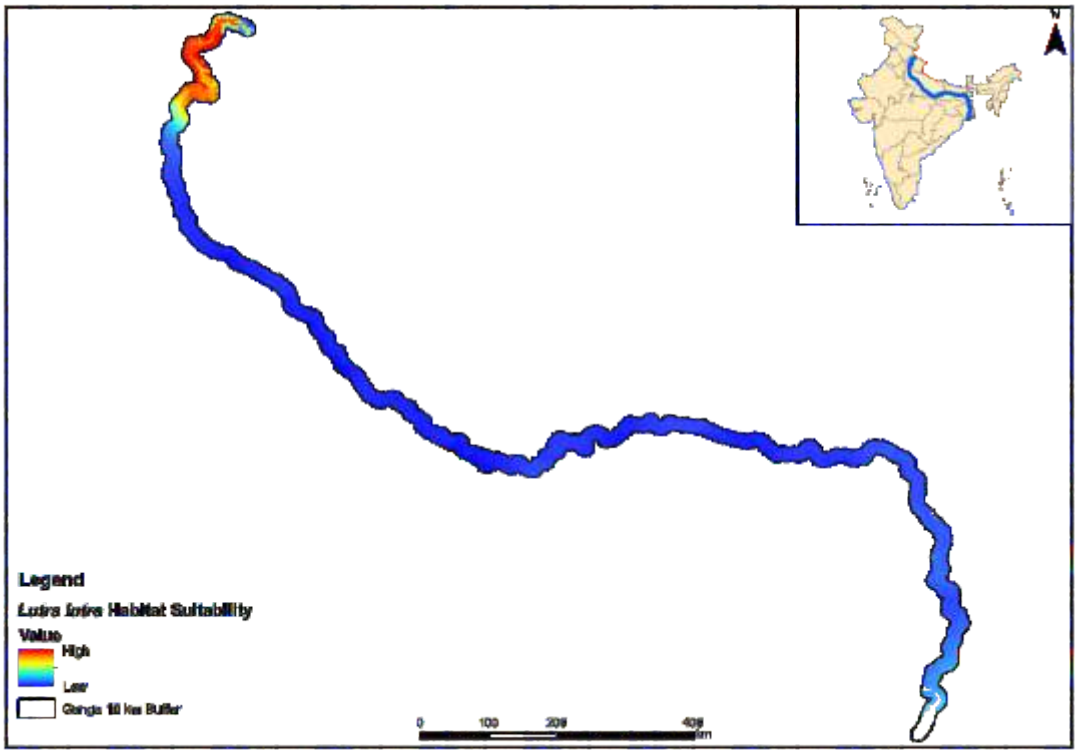


Figure 8.9 Predicted habitat suitability map for the Eurasian otter (*Lutra lutra*) along the Ganga Riverscape

The analysis of environmental variable contributions indicated that precipitation-related variables were the most important determinants influencing the predicted distribution of the Eurasian otter. Among the environmental predictors, precipitation of the driest quarter (bio17) contributed the largest proportion to the model (83.6%), followed by precipitation of the wettest month (bio13) contributing 10.6%, and precipitation of the wettest quarter (bio16) contributing 5.2%. Minor contributions were observed from mean temperature of the driest quarter (bio9) and the human footprint index, which together accounted for less than one percent of the total model contribution. The relative contribution and permutation importance of environmental variables influencing the habitat suitability model are presented in Table 8.3.

Table 8.3 Relative contribution and permutation importance of environmental variables influencing the habitat suitability model for the Eurasian otter (*Lutra lutra*) in the Ganga Riverscape

Variable	Percent contribution	Permutation importance
bio_17	83.6	63.4
bio_13	10.6	0
bio_16	5.2	33.8
bio_9	0.4	2.7
Human footprint	0.1	0

III. Smooth-coated otter (*Lutrogale perspicillata*)

The species distribution model predicted the potential distribution of the smooth-coated otter across the Ganga River. The model showed good predictive performance with an average test AUC value of 0.852 ± 0.185, indicating that the model performed substantially better than random prediction and reliably distinguished suitable habitats from unsuitable areas across the riverscape (Figure 8.10). The ROC curve illustrates the sensitivity and specificity of the model predictions and confirms the robustness of the environmental predictors used for modelling the distribution of the smooth-coated otter.



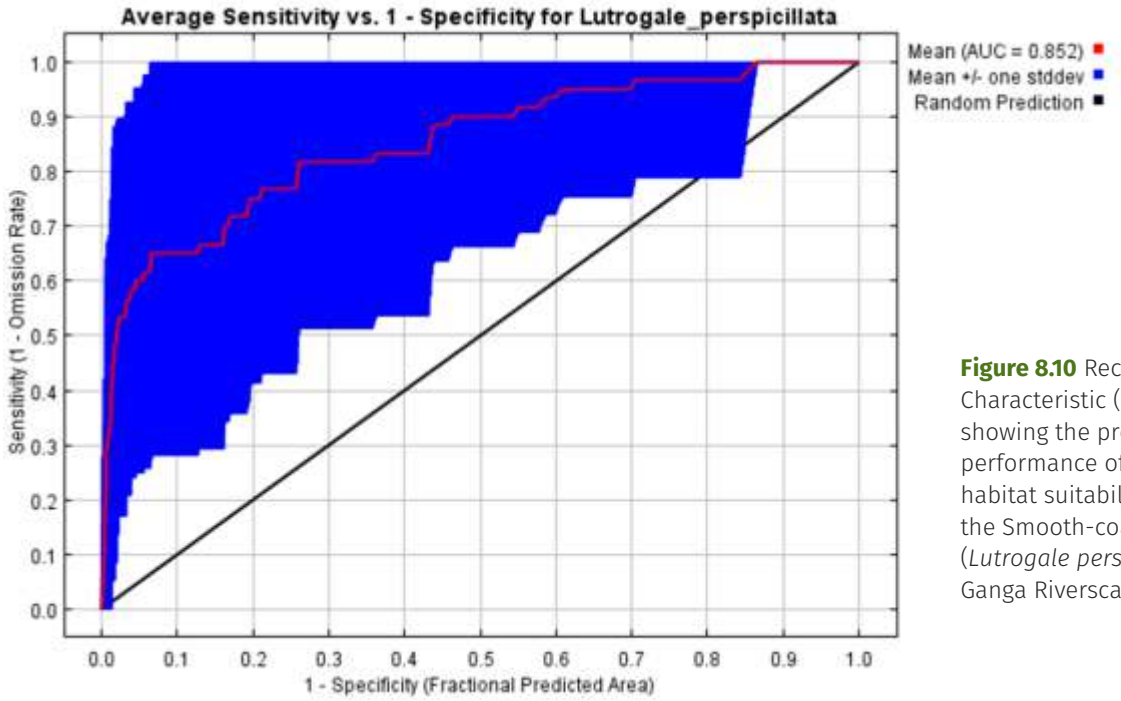
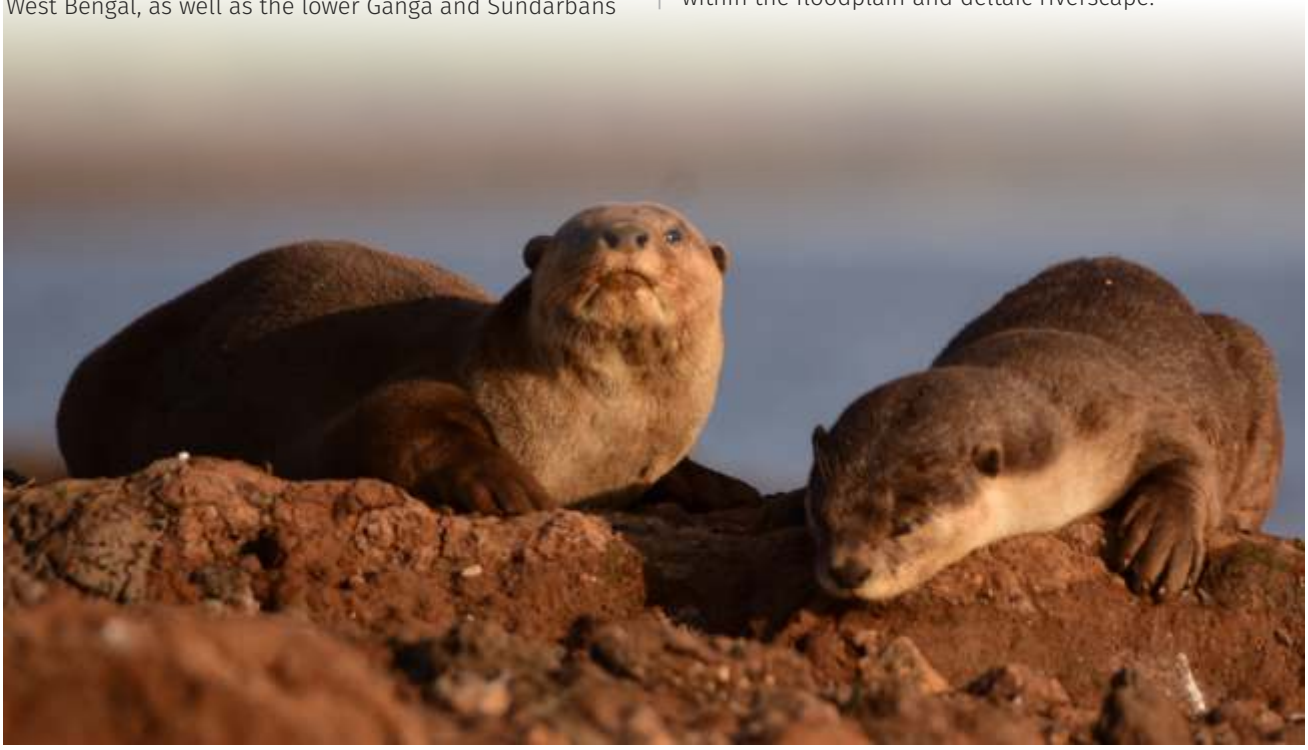


Figure 8.10 Receiver Operating Characteristic (ROC) curve showing the predictive performance of the MaxEnt habitat suitability model for the Smooth-coated otter (*Lutrogale perspicillata*) in the Ganga Riverscape

The classification of habitat suitability revealed that approximately 15.8% of the Ganga River represents highly suitable habitat for the smooth-coated otter, while 28.6% of the riverscape area was predicted to be moderately suitable, and the remaining 55.6% was classified as low or unsuitable habitat. The predicted habitat suitability map indicated that suitable habitats for the smooth-coated otter are widely distributed along the middle and lower stretches of the Ganga River, particularly in regions associated with large rivers, floodplains, wetlands and deltaic ecosystems. High suitability patches were predicted in eastern Uttar Pradesh, Bihar, Jharkhand and West Bengal, as well as the lower Ganga and Sundarbans delta region. These areas are characterised by extensive floodplain wetlands, marshes, oxbow lakes and slow-flowing river channels that provide suitable foraging habitats and denning sites for the species. Moderate suitability was predicted along several tributaries and floodplain river corridors across the middle Gangetic plains, whereas the upper Himalayan region showed relatively lower suitability due to steep terrain, colder climatic conditions and reduced wetland availability. The spatial distribution of predicted habitat suitability across the riverscape is illustrated in Figure 8.11, which highlights the concentration of highly suitable habitats within the floodplain and deltaic riverscape.



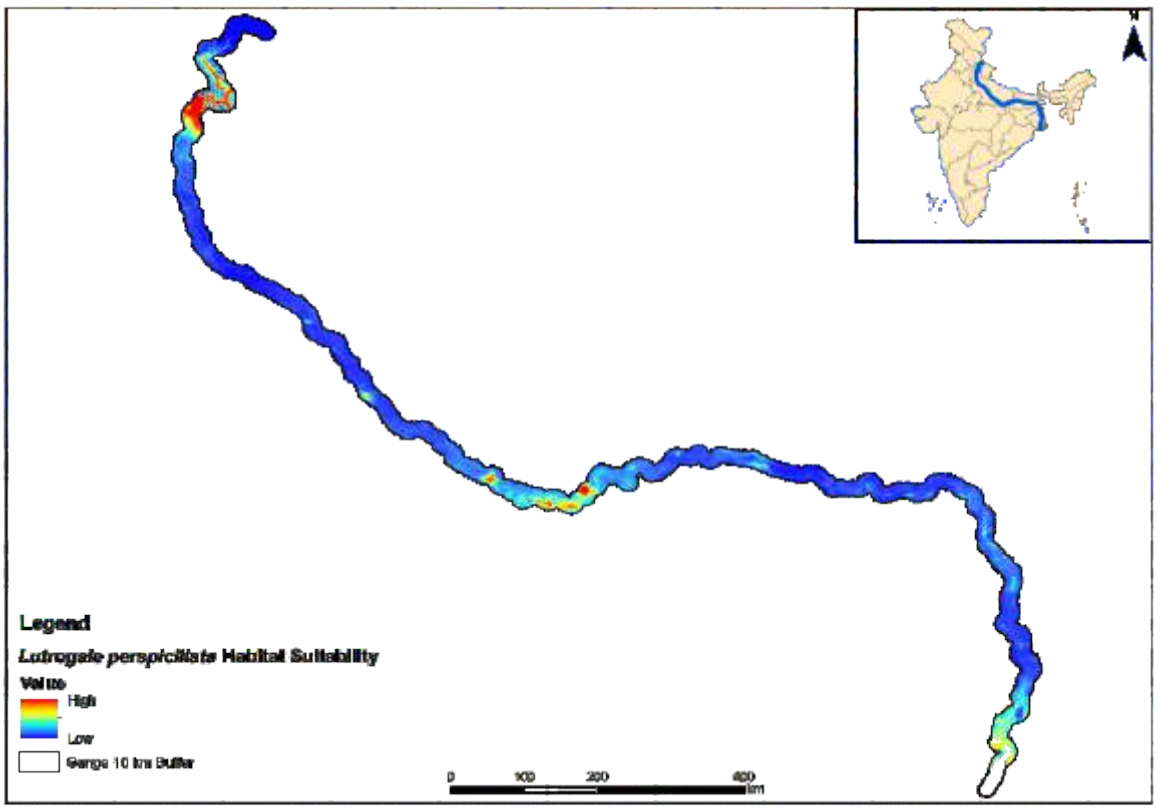


Figure 8.11 Predicted habitat suitability map for the Smooth-coated otter (*Lutrogale perspicillata*) across the Ganga Riverscape

Among the variables used in the model, precipitation of the driest quarter (bio17) contributed the highest proportion (28.6%) to the model, followed by isothermality (bio3) with 12.5% contribution, mean diurnal temperature range (bio2) with 10.4%, and mean temperature of the wettest quarter (bio8) contributing 9.7%. Additional influential variables included precipitation of the coldest quarter (bio19) contributing 7.6%, maximum temperature of the warmest month (bio5) contributing 4.8%, mean temperature of the warmest quarter (bio10) contributing 4.3%, and temperature seasonality (bio4) contributing 4.2%. Anthropogenic variables such as the human footprint index contributed 3.8%, suggesting that the species shows some tolerance to moderate levels of human disturbance compared with the other otter species. The relative contributions and permutation importance of environmental predictors used in the model are summarized in Table 8.4.

Table 8.4 Relative contribution and permutation importance of environmental variables influencing the MaxEnt habitat suitability model for the Smooth-coated otter (*Lutrogale perspicillata*) in the Ganga Riverscape

Variable	Percent contribution	Permutation importance
bio_17	28.6	43.3
bio_3	12.5	2.5
bio_2	10.4	14.8
bio_8	9.7	18.3
bio_19	7.6	6.7
bio_5	4.8	1
bio_10	4.3	4.3
bio_4	4.2	0
bio_15	4	0.1
Human footprint	3.8	0.6

Variable	Percent contribution	Permutation importance
bio_13	3.4	3.5
bio_14	2.7	0.2
Terrain ruggedness	1.8	4
bio_11	1.1	0.2
bio_18	0.5	0
bio_16	0.2	0.4
bio_7	0.1	0.2

8.3.3 Threats

I. Dams/Barrages

a. *Inadequate Water Flow and Reduced Depth*

Freshwater cetaceans require adequate water flow and quality to support their health, movement, and foraging behavior (Sinha & Kannan, 2014; Sonkar & Kumar, 2022). However, human interventions such as dam construction, water diversion, and the impacts of climate change have led to river fragmentation, diminished ecological flows, and reduced water depth-particularly during dry seasons (Braulik et al., 2021; Sinha et al., 2010). Low occurrence of Gangetic dolphins in the lower stretch of Ganga River can be attributed to physical barriers like Farakka barrage, which restricts movement and gene flow of the individuals (Sonkar & Gaurav, 2020). Water discharge and flow velocity are found to be the key factors influencing dolphin distribution (Qureshi et al., 2019). In the Chambal River, sustaining a flow of 289.67 m^3/sec and a minimum depth of 10 meters has been identified as critical for maintaining dolphin populations (Hussain et al., 2011). River regulation through dams, barrages, and diversion structures has modified the hydrological characteristics of many river stretches within the basin. Structures such as the Bhimgoda, Bijnor, Narora, and Farakka barrages alter natural flow regimes, disrupt longitudinal connectivity, and influence sediment transport and channel morphology (Swarnkar et al., 2021; Sonkar & Kumar, 2022; Sarkar & Mishra, 2022). These hydrological changes can affect fish movement and availability, which in turn may influence foraging opportunities for otters. Reduced ecological flows downstream of barrages during lean seasons may also result in the contraction of river channels, exposure of sandbars, and loss of deep pools that typically support fish aggregations.

b. *Alteration in Hydro-Physical Habitats*

Human-induced land transformation and population growth alters hydrophysical habitats, impacting silt, nutrients, and discharge cycles (Richards & Flint, 1994; Allan, 2021). Such transformation in the Ganga River basin has blocked or fragmented foraging grounds and migratory pathways for Gangetic dolphins (Dudgeon, 2000). Whereas, changes in floodplain landscapes represent an important factor influencing otter habitats. Floodplain wetlands, marshes, and side channels support high fish productivity and provide suitable resting and denning sites for otters. In many parts of the Ganga basin the otter habitats have undergone significant modification due to agricultural expansion, embankment construction, settlement growth, and infrastructure development. Habitat suitability modelling conducted in the present study indicates that several floodplain regions of eastern Uttar Pradesh, Bihar, Jharkhand, and West Bengal continue to provide relatively favourable habitat conditions for Smooth-coated otters. Similarly, suitable habitats for the Asian small-clawed otter were predicted primarily in wetland-rich landscapes of the lower Ganga basin and the Sundarbans delta. These findings highlight the importance of maintaining floodplain wetlands and associated riparian habitats for sustaining otter populations across the basin. Present findings revealed that very low habitat suitability of the Eurasian otters in the Gangetic plains could be attributed to high human population density, river regulation, and extensive habitat modification. Similarly, human presence appeared as a major limiting factor for the Asian small-clawed otters, while smooth-coated otters showed resilience against anthropogenic threats.

c. *Isolated Population*

Structural barriers like dams or barrages increase local extirpation, inbreeding depression, and genetic bottlenecks among Gangetic dolphin subpopulations (Sinha & Kannan, 2014; Paudel & Koprowski, 2020; Sonkar & Kumar, 2022). Local extirpations are evident in stretches such as downstream of the Bhimgoda Barrage and upstream of the Bijnor Barrage.

II. Bycatch Mortality

Gangetic dolphins are severely threatened by accidental entanglement in fishing nets and targeted poaching (Sinha et al., 2000; Smith & Braulik, 2008; Kolipakam et al., 2020; Badola et al. 2025). Dolphins are often killed through net entanglement, with 75% of dolphin mortality in the Brahmaputra over the past 12 years attributed to this issue (Wakid, 2009).

III. Poaching for Bait Fishing and Medicinal Use

Poaching remains a serious threat, particularly for dolphin oil, which is used for bait fishing and traditional medicine. High dolphin mortality has been reported in both the Ganges and Brahmaputra rivers due to these practices (Mohan & Kunhi, 1996; Bairagi, 1999; Wakid,

2005). Reducing gill nets and monitoring oil use are crucial for addressing these threats (Kolipakam et al., 2020).

IV. Pollution and Water Quality

Industrial waste, pesticides, and fertilizers contribute heavily to the pollution of the Ganges River Basin, significantly affecting dolphin health. High levels of toxins, including DDT, butyltins, and heavy metals, have been found in their tissues (Kannan et al., 1993,1994; Sinha et al., 2007). Recent studies have also reported elevated mercury and arsenic concentrations, further endangering the species (Singh et al., 2023; Sah et al., 2024a, 2024b).

V. Noise Pollution

Several projects have been proposed under the National Waterways initiative, as outlined in the Indian National Waterways Act, 2016. The stretch from Sagar and Haldia to Prayagraj has been designated as National Waterway 1, and the construction of two fixed jetties and 19 floating terminals is underway. These developments have raised significant concerns about their potential adverse effects, including increased vessel traffic, underwater noise pollution, dredging activities, and overall habitat disturbance. Preliminary studies have reported behavioral changes and elevated stress levels in Gangetic dolphins in areas with heavy boat traffic and heightened underwater acoustic disturbances (Dey et al., 2019).

VI. Climate Change Impacts

Climate change is reshaping dolphin habitats and disrupting their prey availability, with rising temperatures and extreme weather events intensifying these challenges. Notable instances include the 2008 mass die-off of Yangtze finless porpoises and increased dolphin strandings following the 2010 Indus River floods (Schelle, 2010). Over the long term, threats such as sea level rise and increasing salinity pose serious risks to dolphin populations, particularly in the lower stretches of the Ganga River. Future survival in the Himalayan region is at risk as a result of the combination of climate change and vulnerability related to land use change among all three otter species (Jamwal et al., 2022).

8.3.4 Trend Analysis

The trend analysis of the Gangetic dolphin population in the Ganga River, based on three assessment years (2018, 2020, and 2024), indicated a weak but significant positive trend (Figure 8.12). The estimated mean exponential rate of increase ($\bar{r}$) was 0.01, suggesting a marginal annual increase in population abundance. Further, the Gangetic dolphins were found to be occurring in the larger stretch of the Ganga River, indicating an expansion in the range of the Gangetic dolphin, by 245 km, which can be attributed to improved habitat conditions, particularly river depth. Encounter rate of Gangetic dolphin increased in 175 BEUs, decreased in 108 BEUs, remained unchanged in 54 BEUs, and no sightings were recorded in 77 BEUs (Figures 8.13 and 8.14). The increasing trend in the ER of the Gangetic dolphin indicates apparent positive changes in the overall habitat quality. In 2018, ER was recorded as 0.65 (SE 0.05) sightings/km, which increased in subsequent years of sampling to 0.77 (0.06) sightings/km in 2024. The Ganga River harbors a significant population of dolphins in the Ganga basin, with one of the highest ERs.

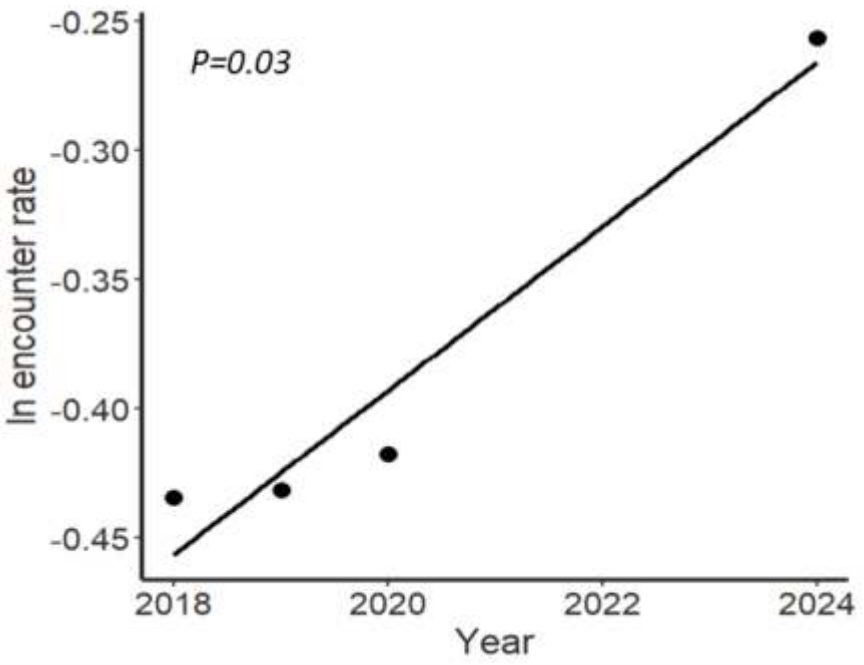


Figure 8.12 Temporal trend in encounter rate (ER) of the Gangetic dolphin (*Platanista gangetica*) in the Ganga River between 2018 and 2024.

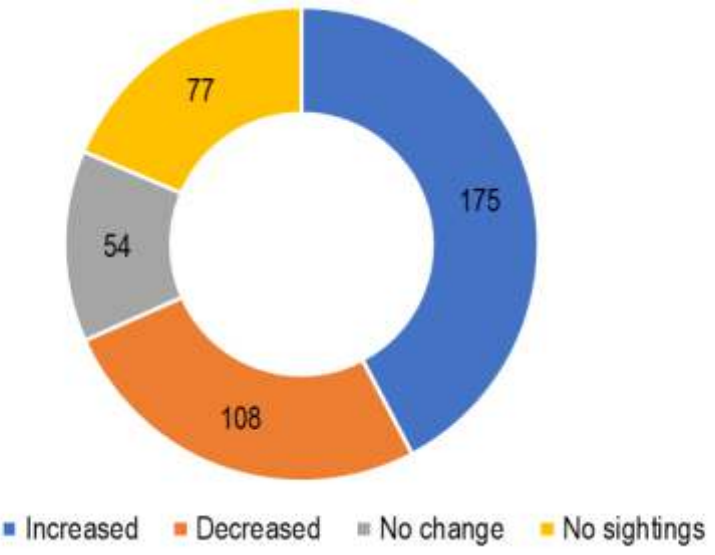


Figure 8.13 Number of BEUs in the Ganga River, exhibiting changes in encounter rate of the Gangetic dolphin (*Platanista gangetica*), between 2018 and 2024



Figure 8.14 Spatial depiction of the trend in encounter rate of Gangetic dolphin





CONCLUSION

River dolphins represent one of the most evolutionarily distinct and threatened groups of freshwater mammals worldwide, with their global decline reflecting escalating anthropogenic pressures on riverine ecosystems (Hamilton et al., 2001). Among them, the Gangetic dolphin serves as both a flagship and indicator species of ecological integrity in the Ganga River basin (Das et al., 2022). The present assessment demonstrates that Gangetic dolphins remain unevenly distributed along the Ganga River, with consistently higher encounter rates in the middle stretches of the Ganga River, particularly between Prayagraj and Kahalgaon, while several upstream and downstream reaches show persistently low or zero sightings. This spatial heterogeneity underscores the importance of deep pools, confluences, and relatively less-fragmented habitats in sustaining viable Gangetic dolphin populations (Choudhary et al., 2012; Sinha & Kannan, 2014).

Temporal analyses across post-monsoon surveys (2018-2024) indicate a marginal increase in total sightings and encounter rates in certain core stretches such as Bijnor and Brijghat, Kahalgaon and Sahibganj and between Bandel and Noorpur. However, the overall population trend remains statistically non-significant, suggesting a broadly stable but vulnerable population status rather than a clear recovery. The co-occurrence of otters, another group of top predators and ecological indicators, further highlights the ecological value of select river segments, particularly in the middle and lower reaches of the basin.

Despite the continued occurrence of Gangetic dolphins, the species faces persistent and interacting threats, including river fragmentation by dams and barrages, altered flow regimes, habitat degradation, bycatch mortality, poaching, pollution, noise disturbance from inland waterways development, and emerging climate change impacts. These pressures contribute to habitat isolation, reduced connectivity, and heightened risk of local extirpations in several stretches of the river (Sinha & Kannan, 2014; Das et al., 2022).

Overall, the findings emphasize that while the Gangetic dolphin population in the Ganga River has not shown a statistically significant decline during the study period, the lack of a strong positive trend, combined with pronounced spatial contraction and intensifying threats, signals an urgent need for targeted conservation action. Maintaining ecological flows, restoring longitudinal connectivity, mitigating bycatch and pollution, regulating vessel traffic, and prioritizing high-density stretches as conservation priority areas are essential to ensure the long-term persistence of Gangetic dolphins and the ecological health of the Ganga River.

The present study confirms the occurrence of three otter species within the Ganga River, with distinct spatial patterns of distribution associated with different habitat types. Smooth-coated otters were recorded more frequently in the middle and lower stretches of the basin, while Eurasian otters were primarily associated with upper Himalayan river systems and Asian small-clawed otters were linked to wetland-dominated landscapes in the lower basin.

Although otters continue to occur across several parts of the basin, their habitats are influenced by a combination of factors including river regulation, floodplain modification, fisheries interactions, sand mining, pollution, and increasing human activity along river corridors (Dettori et al., 2022; Nawab & Hussain, 2012; Sinha et al., 2014; Tolrà et al., 2024). While these pressures do not necessarily result in immediate population declines, they may gradually affect habitat quality and connectivity if not managed carefully. Maintaining ecological flows, protecting floodplain wetlands, and conserving riparian vegetation are therefore important for sustaining suitable habitats for otters.

From a management perspective, conservation efforts may benefit from prioritizing river stretches where suitable habitats and confirmed sightings overlap, particularly in parts of Bihar, eastern Uttar Pradesh, and the lower Ganga floodplains. Integrating otter conservation considerations into broader river basin management programmes, including initiatives under the *Namami Gange* Programme, may also contribute to the long-term conservation of these species. Strengthening wetland protection, promoting sustainable fishing practices, regulating sand extraction in ecologically sensitive stretches, and continuing efforts to improve water quality would collectively support the conservation of otters as well as other aquatic biodiversity in the Ganga River Basin.

Overall, the findings highlight the importance of maintaining healthy and connected river ecosystems across the basin. Conservation of otters not only supports the persistence of these species but also contributes to safeguarding the ecological integrity of the Ganga River and its associated floodplain landscapes.



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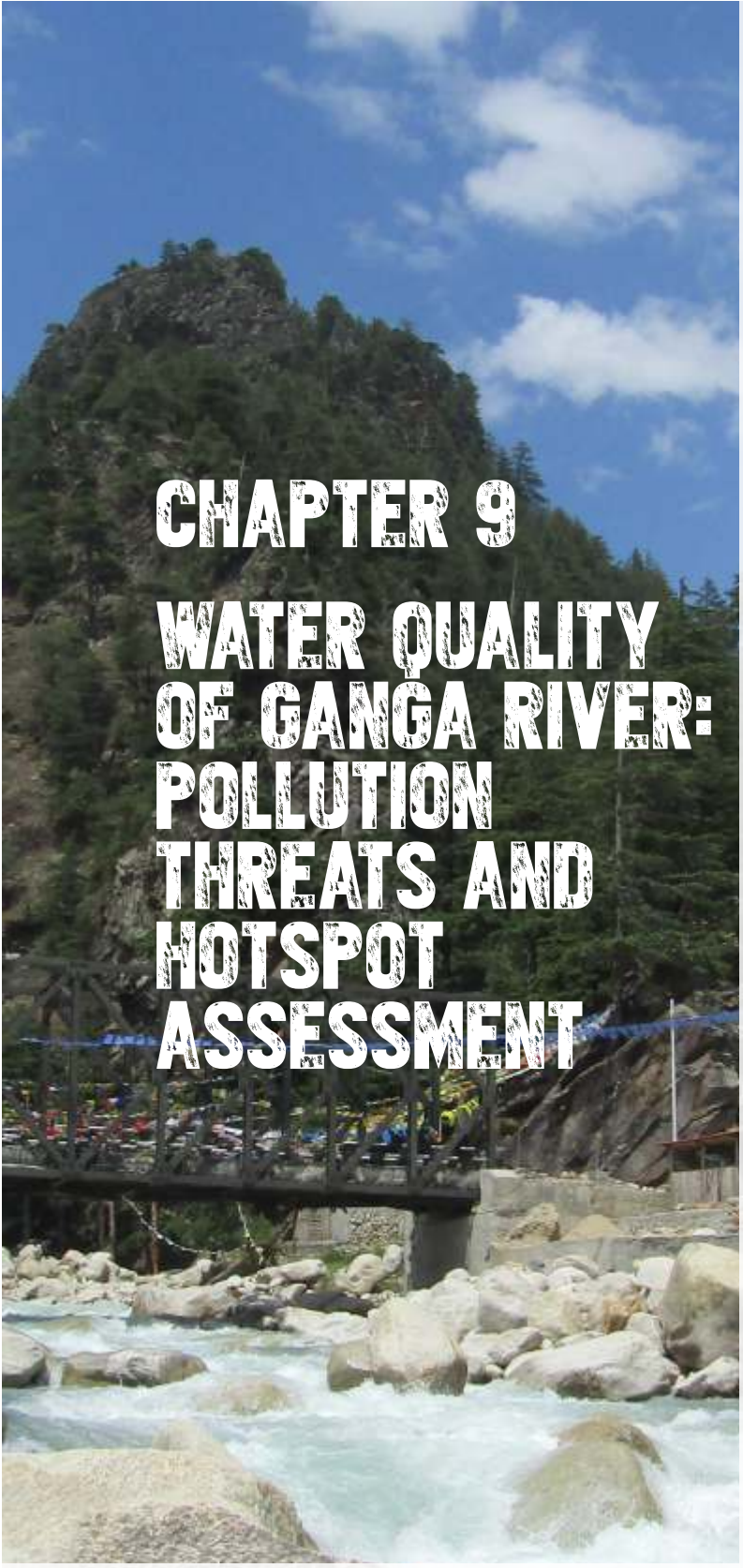
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CHAPTER 9

WATER QUALITY OF GANGA RIVER: POLLUTION THREATS AND HOTSPOT ASSESSMENT

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SUMMARY

The Ganga is statistically cleaner today on the parameters India monitors and ecologically compromised on the parameters it does not. This is the central finding of the 2018-2025 assessment. The pollutant classes that India has regulated for decades are in measurable retreat under the Namami Gange Mission's programme, while a new generation of unregulated contaminants is establishing itself in the same waterways. The two trends are independent and require independent responses: sustaining the first does not address the second, and addressing the second does not displace the first. This assessment, the first integrated profile of the Ganga across water, sediment, and biota, identifies what is working, what is emerging, and what the Mission's next phase will need to add to its existing toolkit.

Regulated pollutants show statistically significant declines between 2018 and 2025. Heavy metals ($p<0.05$), organochlorine ($p<0.001$), and organophosphate pesticides ($p<0.001$) have declined across the main stem from 2018 to 2025. The Ganga River is getting statistically cleaner by the parameters India monitors and ecologically more dangerous by the parameters it does not. The trend reflects the combined effect of industrial effluent standards, banned-substance enforcement, and sewage treatment capacity commissioned under Namami Gange.

Conventional water quality compliance stands at 69%. The mainstem meets prescribed standards at 69% of monitored stretches, with conductivity and pH accounting for most of the residual non-compliance. Dissolved oxygen achieves full annual compliance but falls below threshold at seven sites during lean flow, including Varanasi, indicating a seasonal rather than structural deficit.

Heavy metals remain the dominant contaminant class by mass across all environmental matrices. River-wide mean concentrations are highest among all analyte classes measured, exceeding the next-largest class by an order of magnitude in water and sediment matrices alike. While concentrations are declining, absolute loads continue to warrant sustained monitoring.

Emerging contaminants are detected river-wide and fall outside the existing regulatory framework. Phthalate esters, Bisphenol A, pharmaceuticals, personal care products, and steroids are present across the main stem at concentrations that

warrant ambient regulation. BPA has approximately quintupled since 2022, and DEHP exceeds internationally referenced ecological thresholds at two-thirds of monitored stations. India presently prescribes no discharge, ambient, or monitoring standards for any of these compound classes.

Bioaccumulation is confirmed across the contaminant spectrum. Organochlorine pesticide concentrations in fish muscle exceed sediment levels by more than thirtyfold, and every class of emerging contaminant, phthalates, personal care products, pharmaceuticals, and steroids, is detected in fish tissue. These findings confirm direct exposure of threatened species, including the gharial, smooth-coated otter, and Gangetic dolphin, to regulated and unregulated contaminants through prey-base bioaccumulation.

Contamination patterns invert by season. Emerging contaminants peak post-monsoon under sewage overflow and plastic leachate mobilisation, while legacy contaminants peak pre-monsoon under reduced dilution during lean flows. Three pathways dominate the residual contamination signal: untreated and partially treated sewage from urban and peri-urban catchments, agricultural runoff from diara and intensive cropping systems via tributary confluences, and plastic and ritual waste from floodplain settlements and ghats. No single sampling window captures the full burden, and no single source-control instrument is sufficient on its own.

As the Ganga flows from source to sea, ecological risk increases along a clear longitudinal gradient, with Critical + High risk coverage rising to 54% in the Middle Ganga Zone (*Bijnor-Varanasi; 930 km*) and 74% in the Lower Ganga Zone (*D/S Varanasi-Ganga Sagar; 1,155 km*). This downstream intensification reflects cumulative basin-scale pollution loading, with the Critical Conservation Corridor (Prayagraj-Bhagalpur), supporting the densest Gangetic dolphin population, falling entirely within the Lower Ganga Zone, the stretch of maximum ecological stress. Six High Biodiversity Zones (HBZ-I-HBZ-VI; 1,240 km) occur along the Ganga mainstem. HBZ-III (*Bithoor-Ghazipur*) and HBZ-IV (*Gandak Confluence-Kosi Confluence*) show the highest clustering of Critical-High pollution hotspots, identifying them as priority intervention zones requiring integrated, source-pathway-specific pollution abatement.

The Mission's existing instruments cover capacity gaps, with limited scope for addressing performance or coverage gaps. The assessment identifies 15 intervention deficits grouped into three categories. Capacity gaps (STP construction, drain interception) are the current Mission focus and have driven the regulated-pollutant gains. Performance gaps (O&M, contract compliance, treatment technology at commissioned infrastructure) affect the conversion of installed capacity into compliant effluent quality, and account for a measurable share of the residual contamination signal. Coverage gaps (agricultural runoff, emerging contaminants, atmospheric deposition, rural sewage, tributary pollution, environmental flows) are not comprehensively covered within the Mission's current instrument set and account for the contaminant classes and pathways. Closing each category requires a different instrument: capacity gaps require continued execution, performance gaps require contractual and fiscal reform, and coverage gaps require new policy instruments.

The identified critical stretches across HBZ are proposed as the first-priority implementation zone across all tiers, building on the Mission's existing geographic focus. The four priority tiers below address the three gap categories identified in Finding 8 in sequence: Priority 1 closes urgent capacity and enforcement gaps, Priority 2 closes performance gaps, Priority 3 closes coverage gaps, and Priority 4 addresses structural and hydrological reform.

Priority 1- Immediate (0 to 6 months): Enforcement action at critical stations. Issue an emergency compliance order under EP Act Section 5 to Sultanganj STP (10 MLD, MBBR), currently non-compliant on COD, TSS, TN, and TP, with 90-day mandatory remediation and financial penalty for non-compliance; deploy an interim constructed wetland or aerated lagoon downstream during the remediation window. Commission the completed 9 MLD Naugachia STP within 60 days, with O&M contract awarded immediately. Commission a structured technical assessment for Patna, Sultanganj, and Bhagalpur STPs covering EDC effluent characterisation, assimilative capacity of the Sultanganj-Kosi Confluence reach, and retrofit feasibility for tertiary treatment. Finalize drain-wise action plans for the 55 untapped drains between Prayagraj and Ballia in Uttar Pradesh along with 63 untapped drains between Buxar and Kahalgaon in Bihar. The first tranche should prioritize Permiya Nala (Kanpur), City Jail Drain (Unnao), Rasoolabad (Prayagraj), Nagwa and Varuna River (Varanasi), Railway Drain (Mughal Sarai). Operationalise the River Regulation Zone notification (2002) on diara and riverbed cultivation across Ganga-front

districts in UP and Bihar. Mandate pre-monsoon floodplain plastic cleanup under MGNREGA. Initiate restoration of the Chunar-Varanasi reach to reconnect fragmented Gangetic dolphin habitat.

Priority 2-Near-term (6 to 24 months): Close performance gaps, build rural abatement. Convert all CRITICAL-stretch STP contracts to performance-based agreements with effluent-linked payment and CPCB/SPCB dashboard integration. Retrofit disinfection at STPs failing faecal coliform standards. Ring-fence O&M financing and flood-proof Bihar STPs. Deploy the tiered rural abatement framework along the Buxar-Kosi corridor and at the Middle Zone CRITICAL stations of Brijghat and Kannauj. Establish agri-runoff monitoring at major tributary confluences and canal return-flow tail-ends. Pilot Soil Health Card linkage to fertiliser subsidy. Operationalise nylon fishing net buy-back at fish landing sites.

Priority 3 -Medium-term (2 to 4 years): New instruments for coverage gaps. Notify ambient water quality criteria for priority emerging contaminants under the Water Act. Mandate tertiary treatment retrofit at all CCC STPs. Scale the organic corridor to sub-basin coverage with a 2028 chemical-free village target. Operationalise the Ganga Ecosystem Services Payment scheme and the "Organic Ganga" procurement mechanism. Amend PWM Rules 2024 for Extended Producer Responsibility on agrochemical packaging. Institute plastic-free ghat zones and deploy the four-stage pesticide interception chain basin-wide.

Priority 4- Long-term (4 to 10 years): Structural and hydrological reform. Operationalise environmental flows through dam operating rules. Scale groundwater recharge across the upper and middle basin. Establish tributary load budgets as the basis for cap-and-trade instruments. Expand decentralised wastewater and faecal sludge treatment across rural Ganga settlements. Institutionalise the contaminant and agri-runoff monitoring networks as a permanent CPCB programme.



9.1 INTRODUCTION

Chemical pollution, climate change, species invasions, and habitat degradation threaten about 27% of all freshwater species catalogued in the IUCN Red List, with the risk of extinction (Tickner et al., 2020). The Ganga River, supports 438.2 million people (36.1% of the national population). Despite its immense religious, economic, and ecological significance, the river is increasingly burdened by chemical pollution from unregulated sewage discharge, industrial effluents, agricultural runoff, and diminished environmental flows, particularly across the middle and lower reaches in Uttar Pradesh, Bihar, and West Bengal (CPCB, 2021). Several of these degraded stretches coincide with critical habitats for threatened aquatic species, including the endangered Gangetic dolphin. Yet, monitoring and regulation of emerging and legacy contaminants in the Ganga River Basin remain fragmented and inadequate, posing a direct challenge to the effectiveness of ongoing conservation efforts for endangered species. Thus, study was conducted to:

i. Investigate the contamination status and spatiotemporal distribution of legacy and emerging contaminants, particularly endocrine-disrupting compounds (EDCs), in biotic and abiotic matrices across the Ganga River.

ii. Assess the ecotoxicological risks posed by priority emerging contaminants to aquatic organisms and their food webs in the Ganga River.

iii. Integrate contaminant exposure profiles to inform spatial prioritization of pollution abatement interventions for aquatic species conservation in the Ganga River.

This evidence-based analysis is intended to inform policy, restoration strategies, and conservation efforts for improving the health and sustainability of the Ganga River ecosystem.

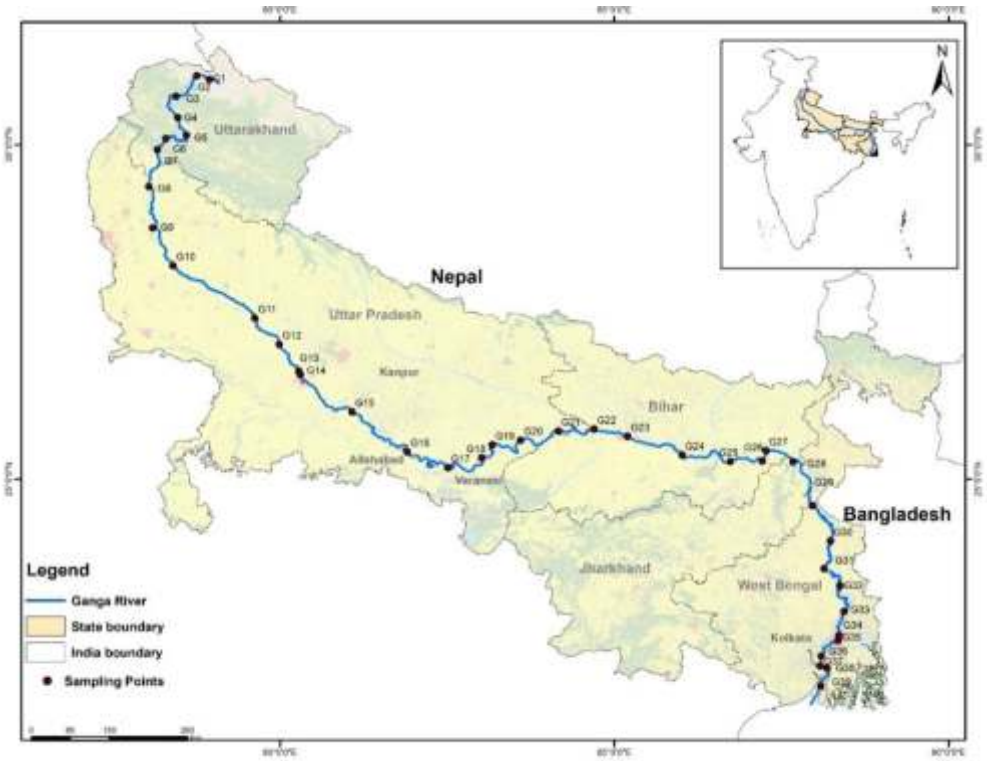


Figure 9.1 Spatial Distribution of Sampling Sites along the Ganga River

9.2 METHODOLOGY

Surface water, sediment, and fish samples were collected from 39 designated sampling (Figure 9.1 and Table 9.1) sites along the Ganga River in accordance with standard sampling protocols and established guidelines. Sampling campaigns were conducted during the pre-monsoon (April-June) and post-monsoon (October-December) periods in 2021, 2022, 2024, and 2025. The report provides assessment of current contamination (based on 2025 surveys) across water, sediment, and biota, analyses temporal trends to evaluate intervention effectiveness and emerging risks, identifies pollution hotspots based on contamination intensity and ecological vulnerability, and outlines targeted, tiered interventions at zone-wide aligned with pollution types, institutional responsibilities, and implementation timelines.

Results are presented at three scales: river-wide, zone-wise, and state-wise (Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal). State-wise reporting is retained for administrative relevance.

Table 9.1: Details of Sampling locations in Ganga River

Site Code	Site	State	District	Latitude	Longitude
GR1	Gangotri	Uttarakhand	Uttarkashi	30.9799	78.94061
GR2	Harsil	Uttarakhand	Uttarkashi	31.0351	78.75319
GR3	Uttarkashi	Uttarakhand	Uttarkashi	30.72666	78.4402
GR4	Tehri	Uttarakhand	Uttarkashi	30.40842	78.46733
GR5	Devparyag	Uttarakhand	Uttarkashi	30.1447	78.59741
GR6	Rishikesh	Uttarakhand	Dehradun	30.09217	78.28955
GR7	Haridwar	Uttarakhand	Haridwar	29.92861	78.16212
GR8	Bijnor	Uttar Pradesh	Bijnor	29.37403	78.0362
GR9	Brij Ghat	Uttar Pradesh	Bijnor	28.75848	78.09301
GR10	Narora	Uttar Pradesh	Bulandshahr	28.19191	78.3955
GR11	Farrukhabad	Uttar Pradesh	Farrukhabad	27.40619	79.62175
GR12	Kannauj	Uttar Pradesh	Kannauj	27.01394	79.98709
GR13	Bithoor	Uttar Pradesh	Kanpur	26.61346	80.27675
GR14	Kanpur	Uttar Pradesh	Kanpur	26.56128	80.30086
GR15	Dalmau	Uttar Pradesh	Raebareilly	26.00331	81.07542
GR16	Prayagraj	Uttar Pradesh	Prayagraj	25.40232	81.90232
GR17	Mirzapur	Uttar Pradesh	Mirzapur	25.16496	82.51038
GR18	Varanasi	Uttar Pradesh	Varanasi	25.31217	83.0177
GR19	Gomti Confluence	Uttar Pradesh	Varanasi	25.50776	83.17369
GR20	Ghazipur	Uttar Pradesh	Ghazipur	25.57792	83.59529
GR21	Ballia	Uttar Pradesh	Ballia	25.71323	84.16225
GR22	Ghaghara Confluence	Bihar	Saran	25.74578	84.69401
GR23	Gandak Confluence	Bihar	Patna	25.63542	85.19568
GR24	Simariya	Bihar	Begusarai	25.35527	86.01341
GR25	Sultanganj	Bihar	Bhagalpur	25.25929	86.73567
GR26	Kahalgoan	Bihar	Bhagalpur	25.26458	87.21153
GR27	Kosi Confluence	Bihar	Bhagalpur	25.42139	87.26365
GR28	Sahibganj	Jharkhand	Sahibganj	25.25323	87.67288
GR29	Farakka	West Bengal	Murshidabad	24.59832	87.96523
GR30	Behrampore	West Bengal	Murshidabad	24.0691	88.2321
GR31	Ajay Confluence	West Bengal	Purba Bardhaman	23.65568	88.13416
GR32	Nabdwip	West Bengal	Nadia	23.40165	88.37672
GR33	Kalyani	West Bengal	Nadia	23.01325	88.4363
GR34	Kolkata	West Bengal	Kolkata	22.57731	88.34384
GR35	Dakshineshwar	West Bengal	North 24 Parganas	22.65488	88.35769
GR36	Damodar Confluence	West Bengal	Howrah	22.34637	88.095
GR37	Rupnarayan Confluence	West Bengal	East Midnapore	22.1986	88.07613
GR38	Diamond Harbour	West Bengal	South 24 Parganas	22.16356	88.17935
GR39	Ganga Sagar	West Bengal	South 24 Parganas	21.89699	88.08448

9.2.1 Sampling Strategy

The physical and chemical properties of the surface water were assessed online using a ProDSS Multiparameter Digital Water Quality Meter (YSI, USA). At each site, 4-5 grab samples were collected, at an average depth of 0-15 cm below surface water, bulked together to form a composite sample. At confluence sites, water and sediment was sampled at mixing of tributary and river water. The samples were collected in pre-cleaned amber glass bottles (water) and aluminium zip-locks(sediment), labelled, and preserved. Samples were stored at 4°C during transport and processed within 48-72 hours. A total of 72 fish species (600 Individuals) were sampled (2023-2024) from local fishermen's routine catches at available sites, with total length and weight recorded in the field. The species were identified on-site, packed in a sealed bag, and kept in an ice-box for transportation to the laboratory, where they were stored in a deep freezer at -20°C until further processing.

9.2.2 Sample treatment and instrument analysis

The sample analysis was done as per the established and validated in-house methods for different contaminant classes in diverse matrices (Sah et al, 2024a; Sah et al, 2024b). The extracts were identified and quantified by Ultra-High Performance Liquid Chromatography-Tandem Mass Spectrometry (UHPLC-MS/MS), Gas Chromatography-Tandem Mass Spectrometry (GC-MS/MS), and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The analytical data quality was guaranteed through the implementation of laboratory quality assurance and quality control methods, including the use of in-house standard operating procedures, calibration with standards, analysis of reagent blanks, recovery of Standard Reference materials (SRM) and analysis of replicates. The target chemicals monitored in this study are presented in Table 9.2

Table 9.2 Target chemicals monitored

Category	Number of analytes (Total No: 61)
Plastics Additives	7 Phthalates (PAEs) and BPA
Polychlronited Biphenyls (PCBs)	7 (Priority Congeners)
Pesticides	26 : Organochlorine Pesticides (OCP): 20 compounds Organophosphate Pesticides (OPP): 6 compounds
Hormones	Natural (3) and Synthetic (2: Pharmaceutics)
Personal care products (PCPs)	Anti-microbial (2)
Pharmaceuticals (Pharma)	5 (Analgesic / Antipyretic, Central Nervous System Stimulant, Non-Steroidal Anti-Inflammatory Drug (NSAID), Anti-inflammatory and pain relief, Antibiotic)
Heavy Metals (HMs)	9 Mercury, Cadmium, Lead, arsenic, Chromium, Cobalt, Zinc, Nickel, Copper



9.3 RESULTS AND DISCUSSION

9.3.1. Annual and Seasonal Water Quality Assessment of the Ganga River (2025)

Water Quality Status of the Ganga River

This section presents the water quality of the Ganga River based on pre-monsoon and post-monsoon surveys conducted in 2025. Six principal pollution parameters were assessed: dissolved oxygen (DO), pH, total dissolved solids (TDS), conductivity, nitrate, and salinity. For each parameter, results are presented at three spatial scales: river-wide, zone-wide, and state-wide (Figures 9.2 to 9.7; Tables 9.3 to 9.5). Based on the 2025 annual mean, 69% of the Ganga River stretch met good water quality criteria, while 31% was classified as poor (Table 9.3). Conductivity is the dominant driver of non-compliance (31% poor), followed by pH (18%), TDS (10%), salinity (8%), and nitrate (3%). Dissolved oxygen was the only parameter to achieve 100% annual compliance, though this is seasonally conditional. Two broadly distinct drivers underlie exceedances across the river: anthropogenic loading (industrial, municipal, agricultural) concentrated in the Middle Ganga Zone and Uttar Pradesh, and geophysical estuarine dynamics at the deltaic terminus in Lower Zone across the state of West Bengal.

Table 9.3 Current River-wide Water Quality Status of the Ganga River Based on 2025 Annual Mean

Parameter	Threshold	River-wide Mean±SEM	Good %	Poor %	Priority Pollution Zones
DO (mg/L)	≥5	7.99 ± 0.19	100%	0%	Pre-monsoon: 7 sites (UK, UP, WB)
pH	6.5-8.5	8.20 ± 0.10	82%	18%	MGZ (36%), LGZ (26%),
TDS (mg/L)	≤500	312 ± 1025	90%	10%	MGZ (7%), LGZ (27%)
Conductivity (µS/cm)	≤500	445 ± 1960	69%	31%	MGZ (36%), LGZ (38%)
Nitrate (mg/L)	<10	1.42 ± 0.65	97%	3%	UGZ (28%), MGZ (7%)
Salinity (ppt)	<0.5	0.25 ± 20.12	92%	8%	MGZ (9%), LGZ (18%)

**SEM: Standard Error Mean; MGZ: Middle Ganga Zone (Origin-Haridwar); UGZ: Upper Ganga Zone (D/S Haridwar-Varanasi); LGZ: Lower Ganga Zone (D/S Varanasi-Ganga Sagar)*



Dissolved oxygen (DO; ≥5 mg/L)

River-wide: DO, a primary indicator of aquatic habitat viability (threshold ≥5 mg/L), shows 100% compliance at the annual mean of 7.99 ± 0.19 mg/L (Table 9.3). However, the pre-monsoon period recorded only 82% good (18% poor), while post-monsoon showed full compliance (Table 9.5).

Zone-wide: The UGZ recorded the highest DO (8.27 to 10.12 mg/L), reflecting well-oxygenated headwater conditions with no compliance concern. The MGZ (6.00 to 9.58 mg/L) showed pre-monsoon stress at Varanasi. The LGZ (5.90 to 9.62 mg/L) recorded the lowest minimum, with four pre-monsoon exceedance sites (Kolkata, Dakshineswar, Damodar Confluence, Rupnarayan Confluence) implicating upstream tributary pollution and urban sewage discharge as concurrent drivers (Table 9.5; Figure 9.2a and 9.3a). These seven pre-monsoon priority pollution sites were distributed across the MGZ in Uttar Pradesh and the LGZ in West Bengal.

Recommended action: Pre-monsoon sewage interception at the seven seasonal exceedance sites, with particular attention to the LGZ cluster in West Bengal.

Table 9.4 Zone-wide assessment of physical-chemical parameters based on 2025 Annual Mean

Category	Zone-wide			River Wide
	Upper Ganga Zone	Middle Ganga Zone	Lower Ganga Zone	(Annual Mean±SEM)
DO (mg/L)	8.27-10.12	6.00-9.58	5.90-9.62	7.99 ± 0.19
pH	7.57-8.29	7.82-9.03	7.34-8.88	8.20 ± 0.10
TDS (mg/L)	94.92-129	138.17-745	138-30001	312 ± 1025
Cond (µS/cm)	87.75-145	208-1193	226-61118	445 ± 1960
Nitrate (mg/L)	0.46-9.17	0.19-22.54	0.10-7.85	1.42 ± 0.65
Salinity (ppt)	0.05-0.10	0.10-0.57	0.25-8.63	0.25 ± 20.12

MGZ: Middle Ganga Zone (Origin-Haridwar); UGZ: Upper Ganga Zone (D/S Haridwar-Varanasi); LGZ: Lower Ganga Zone (D/S Varanasi-Ganga Sagar)

pH (6.5-805)

River-wide:

The annual mean pH was 8.20 ± 0.10, with 82% good and 18% poor, all driven by upper-threshold breaches (>8.5) (Table 9.3). Pre-monsoon was more stressed (74% good) than post-monsoon (87% good), consistent with reduced dilution during lean flow (Table 9.5).

Zone-wide:

The UGZ (7.57 to 8.29) across Uttarakhand was largely compliant, with the exception of Tehri, which recorded pre-monsoon exceedance. The MGZ (7.82 to 9.03) across Uttar Pradesh displayed the widest pH fluctuation across the river and contributed the largest share of poor readings (36%), indicative of elevated alkalinity from point-source industrial and municipal effluent loading, with priority pollution sites at Bijnor, Kannauj, Kanpur, Dalmau, and Prayagraj. The LGZ (7.34 to 8.88) contributed 26% of poor readings, with exceedances distributed across Uttar Pradesh (Ballia), Bihar (Ghaghara Confluence, Gandak Confluence, Simariya, Kahalgaon), and West Bengal (Behrampore, Ganga Sagar). Several sites across the MGZ and LGZ showed dual-season exceedance, indicating chronic alkalinity stress that persists independent of seasonal flow variation (Tables 9.3 and 9.4; Figure 9.2b & 9.3b).

Recommended action: Targeted regulation of industrial and municipal effluent alkalinity along the MGZ corridor in Uttar Pradesh, with tributary-level monitoring at the Ghaghara and Gandak confluences (LMZ, Bihar).



Table 9.5 Seasonal Fluctuations in Water Quality Condition across Ganga River

Season (2025)	Category	Water Quality Condition (%)					
		DO (mg/L)	pH	TDS (mg/L)	Cond (µS/m)	Nitrate (mg/L)	Salinity
Pre-Monsoon	Good	82	74	87	72	97	90
	Poor	18	26	13	28	3	10
Post-Monsoon	Good	100	87	90	69	95	92
	Poor	0	13	10	31	5	8
Priority Pollution Sites		Brij Ghat, Varanasi, Kolkata, Dakshineshwar, Damodar Confluence, Rupnarayan Confluence, Diamond Harbour	Tehri, Bijnor, Kannauj, Kanpur, Dalmau, Prayagraj, Ballia, Ghaghara Confluence, Gandak Confluence, Simariya, Kahalgoan, Behrampore, Ganga Sagar	Brij Ghat, Varanasi, Prayagraj, Rupnarayan Confluence, Kolkata, Damodar Confluence, Diamond Harbour, Ganga Sagar	Brij Ghat, Kannauj, Prayagraj, Mirzapur, Varanasi, Gomti Confluence, Ghazipur, Ballia, Ghaghara Confluence, Simariya, Sultanganj, Kolkata, Dakshineshwar, Damodar Confluence, Rupnarayan Confluence, Diamond Harbour, Ganga Sagar	Gangotri, Bithoor	Brij Ghat, Varanasi, Rupnarayan Confluence, Diamond Harbour, Ganga Sagar

Note *Priority pollution sites are color-coded based on seasonal exceedance patterns: sites marked in green indicate exceedance during the pre-monsoon season, blue indicate exceedance during the post-monsoon season, and orange represent sites showing exceedance in both seasons.*



TDS (≤500 mg/L)

River-wide:

The annual mean TDS was 312 ± 1025 mg/L, with 90% good and 10% poor (Table 9.3). The disproportionately large standard error confirms that the river-wide mean masks site-specific extremes. Pre-monsoon showed 87% good and post-monsoon 90% good (Table 9.5).

Zone-wide: The UGZ (94.92 to 129 mg/L) was well within compliance. The MGZ (138.17 to 745 mg/L) contributed 7% poor, with exceedances at Brijghat and Varanasi driven by industrial and municipal loading. The LGZ (138 to 30,001 mg/L) contributed 27% poor with West Bengal accounted for the entire LGZ exceedance, with extreme values at Kolkata, Damodar Confluence, Rupnarayan Confluence, Diamond Harbour, and Ganga Sagar (peaks up to 54,000 mg/L) largely attributable to estuarine tidal influx. Diamond Harbour and Ganga Sagar showed dual-season exceedance, confirming persistent tidal influence independent of flow regime (Table 9.5; Figure 9.4a and 9.5a).

Recommended action: Catchment-level runoff controls at Brijghat and Varanasi in the MGZ; separate estuarine TDS benchmarks for the LGZ deltaic stations in West Bengal.

Conductivity (≤500 µS/cm)

River-wide:

Conductivity, reflecting overall ionic concentration and dissolved pollutant load, is the most pervasive compliance failure parameter across the Ganga mainstem, with only 69% good and 31% poor (annual mean: 445 ± 1960 µS/cm) (Table 9.3). Unlike other parameters, exceedances persisted across both seasons (pre-monsoon: 28% poor; post-monsoon: 31% poor), indicating sustained ionic loading independent of hydrological dilution (Table 9.5).

Zone-wide:

The UGZ (87.75 to 145 µS/cm) across Uttarakhand was fully compliant. The MGZ (208 to 1,193 µS/cm) across Uttar Pradesh contributed 36% poor, with exceedances at Brijghat, Kannauj, Prayagraj, Mirzapur, and Varanasi; tributary confluences of the Gomti, Ghaghara, and Gandak showed pre-monsoon-only exceedances, implicating seasonal mobilization of ionic loads from sub-basin sources. The LGZ (226 to 61,118 µS/cm) contributed 38% poor, the largest zonal share across Uttar Pradesh (Gomti Confluence, Ghazipur, and Ballia), Bihar (Ghaghara Confluence, Simariya, and Sultanganj), and West Bengal (Kolkata, Dakshineswar, Damodar Confluence, Rupnarayan Confluence, Diamond Harbour, and Ganga Sagar).

Diamond Harbour, and Ganga Sagar recorded extreme values up to ~95,000 µS/cm attributable to tidal influx. Multiple sites across both MGZ and LGZ showed dual-season exceedance, confirming that conductivity is the only parameter where the pollution burden spans the entire middle-to-lower Ganga continuously (Table 9.4; Figure 9.4b and 9.5b).

Recommended action: Conductivity warrants the most urgent regulatory attention. In the MGZ, interventions should target industrial effluent discharge, municipal outfalls, and diffuse agrochemical inputs across the Uttar Pradesh corridor, with tributary-level ionic load reduction for the Gomti, Ghaghara, and Gandak sub-basins. In the LGZ, Bihar requires tributary confluence interventions, while the West Bengal estuarine stations require a separate conductivity framework distinct from freshwater thresholds.

Nitrate (<10 mg/L)

River-wide:

Nitrate, a principal indicator of nutrient loading that drives eutrophication and algal proliferation, recorded an annual mean of 1.42 ± 0.65 mg/L, well below the threshold, with 97% good and 3% poor (Table 9.3). Pre-monsoon and post-monsoon compliance were comparable (97% and 95% good, respectively) (Table 9.5).

Two priority pollution sites were identified: Gangotri and Bithoor (Table 9.5). A pronounced pre-monsoon spike at Bithoor (~35 mg/L) exceeded the threshold by over threefold, attributable to fertilizer-laden agricultural runoff during lean flows. Elevated pre-monsoon values at Gangotri (~12 mg/L) are likely linked to snowmelt-mobilized organic nitrogen from the headwater catchment.

Zone-wide:

The UGZ (0.46 to 9.17 mg/L) across Uttarakhand contributed 28% of poor readings, driven by a pre-monsoon spike at Gangotri (~12 mg/L) likely linked to snowmelt-mobilized organic nitrogen from the headwater catchment. The MGZ (0.19 to 22.54 mg/L) across Uttar Pradesh contributed 7% poor, driven entirely by a pronounced pre-monsoon spike at Bithoor (~35 mg/L), exceeding the threshold by over threefold, attributable to fertilizer-laden agricultural runoff during lean flows. The LGZ (0.10 to 7.85 mg/L) nitrate values were all individually compliant. Both priority sites (Gangotri and Bithoor) showed pre-monsoon-only exceedance, confirming that nitrate stress is site-specific and seasonally confined to localized sources within the UGZ and MGZ (Table 9.4 and 9.5; Figure 9.6a and 9.7a).

Recommended action: Non-point-source nutrient management plans targeting agricultural watersheds in the Bithoor belt in Uttar Pradesh and headwater nutrient dynamics monitoring in the Gangotri catchment in Uttarakhand.

Salinity (<0.5 parts per thousand)

River-wide: Salinity, indicating dissolved salt loading that induces osmotic stress in sensitive freshwater taxa, recorded an annual mean of 0.25 ± 20.12 ppt, with 92% good and 8% poor (Table 9.3). The large standard error is driven almost entirely by estuarine stations in the LGZ. Pre-monsoon showed 90% good and post-monsoon 92% good (Table 9.5).

Zone-wide:

The UGZ (0.05 to 0.10 ppt) across Uttarakhand was well within the freshwater threshold. The MGZ (0.10 to 0.57 ppt) across Uttar Pradesh contributed 9% poor, with localized pre-monsoon exceedances at Brijghat (~0.59 ppt) and Varanasi (~0.79 ppt). The LGZ (0.25 to 8.63 ppt) contributed 18% poor; Bihar (0.10 to 0.27 ppt) and Jharkhand (0.19 ppt) were fully compliant within the zone, while West Bengal (0.18 to 785 ppt) accounted for the entire LGZ exceedance at Rupnarayan Confluence, Diamond Harbour, and Ganga Sagar, driven by tidal ingress that pushes salinity orders of magnitude above the freshwater threshold. Diamond Harbour and Ganga Sagar showed dual-season exceedance, confirming persistent tidal influence, while MGZ exceedances at Brijghat and Varanasi were pre-monsoon-only, indicating that inland salinity stress is seasonally reversible (Table 9.5; Figure 9.6b and 9.7b).

Recommended action: Seasonal discharge controls at Brijghat and Varanasi in the MGZ; tidal salinity intrusion monitoring in the LGZ under a dedicated estuarine management framework for West Bengal.

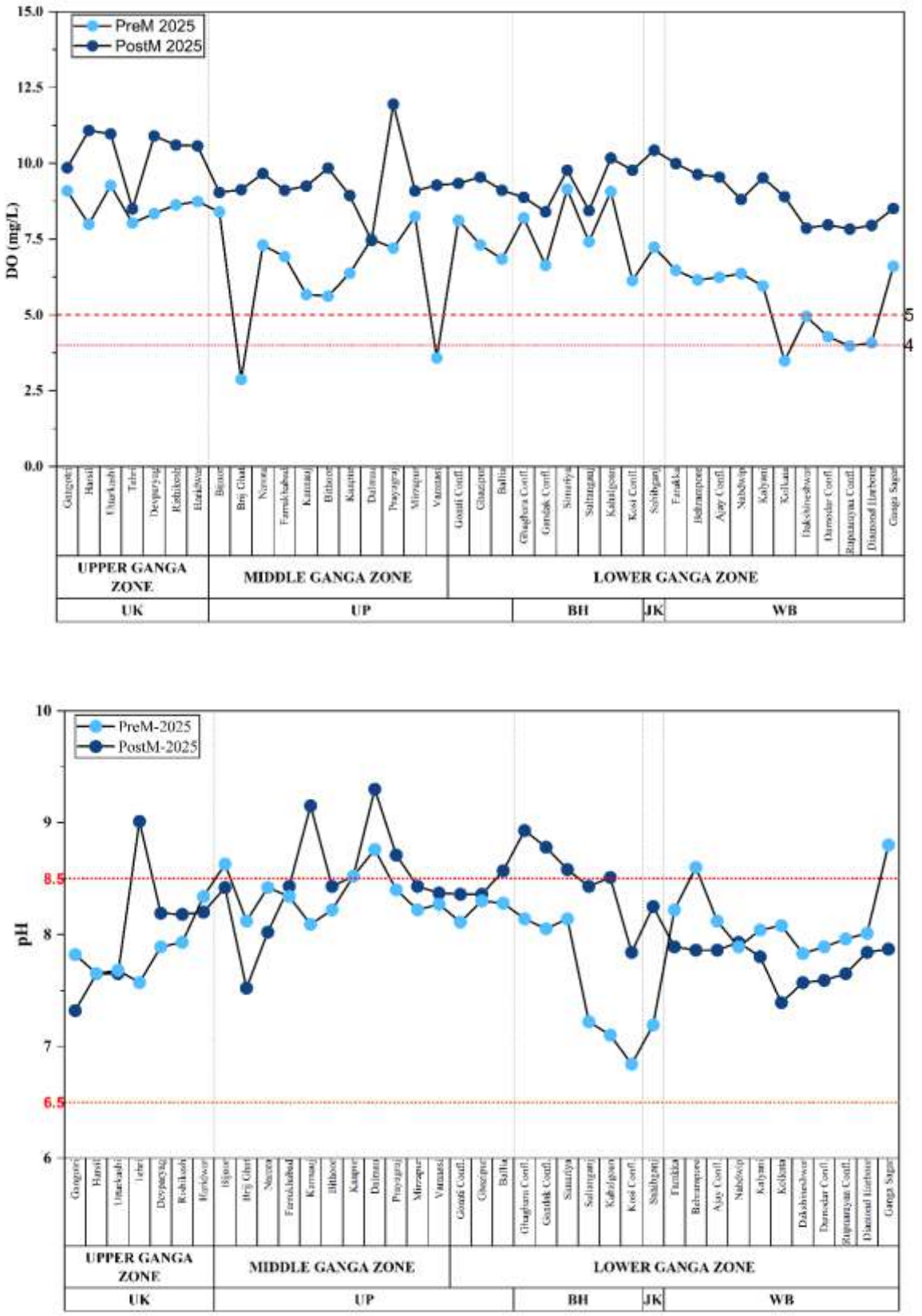


Figure 9.2 Spatiotemporal variation in (a) Dissolved Oxygen (DO, mg/L) and (b) pH along the Ganga mainstem in 2025. Dashed line denotes the regulatory threshold.

Note: *UK: Uttarakhand; UP: Uttar Pradesh; BH: Bihar; Jharkhand: JK; WB: West Bengal*

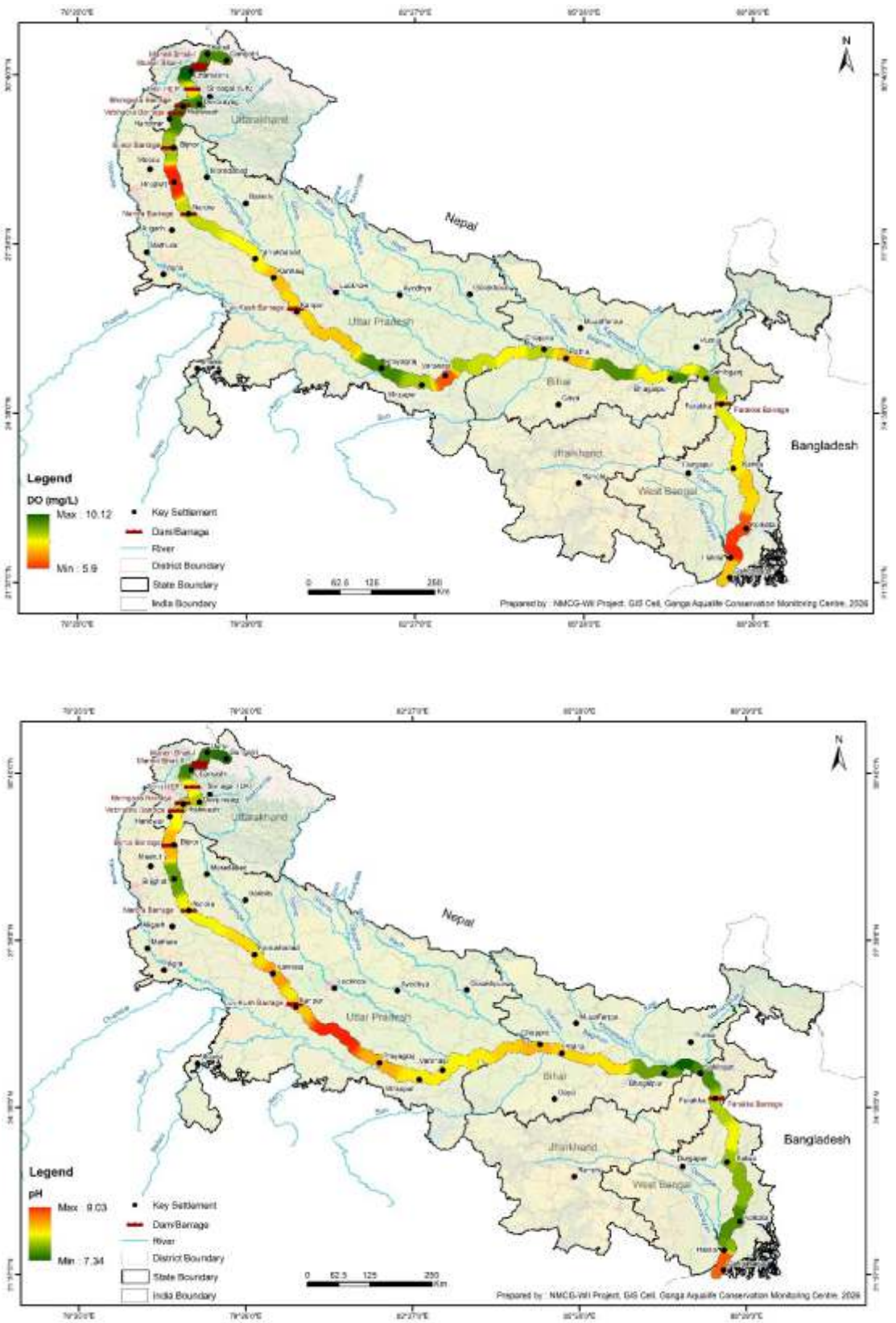


Figure 9.3 Annual variation in (a) Dissolved Oxygen (DO, mg/L) and (b) pH along the Ganga mainstem in 2025.

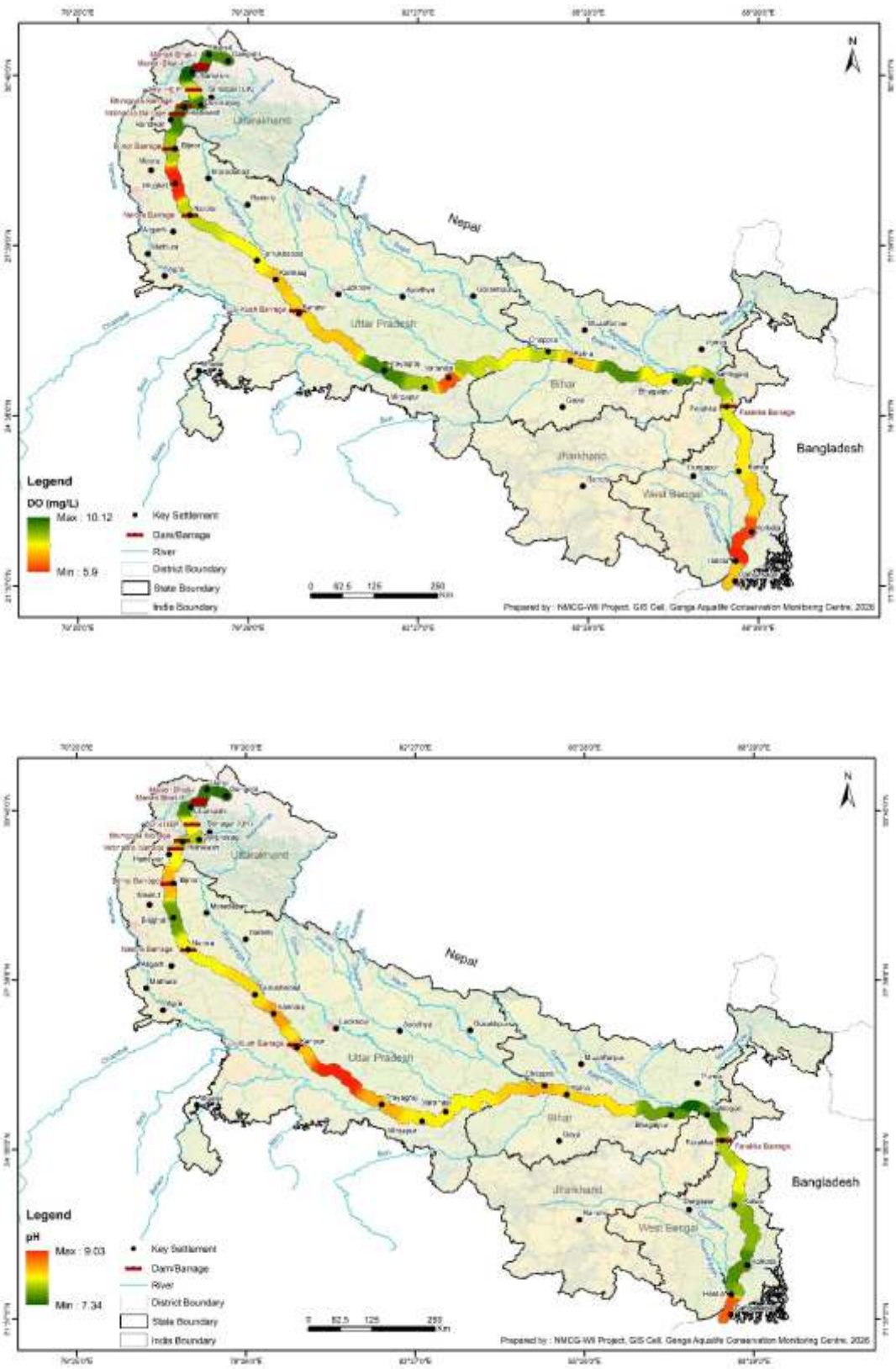


Figure 9.3 Annual variation in (a) Dissolved Oxygen (DO, mg/L) and (b) pH along the Ganga mainstem in 2025.

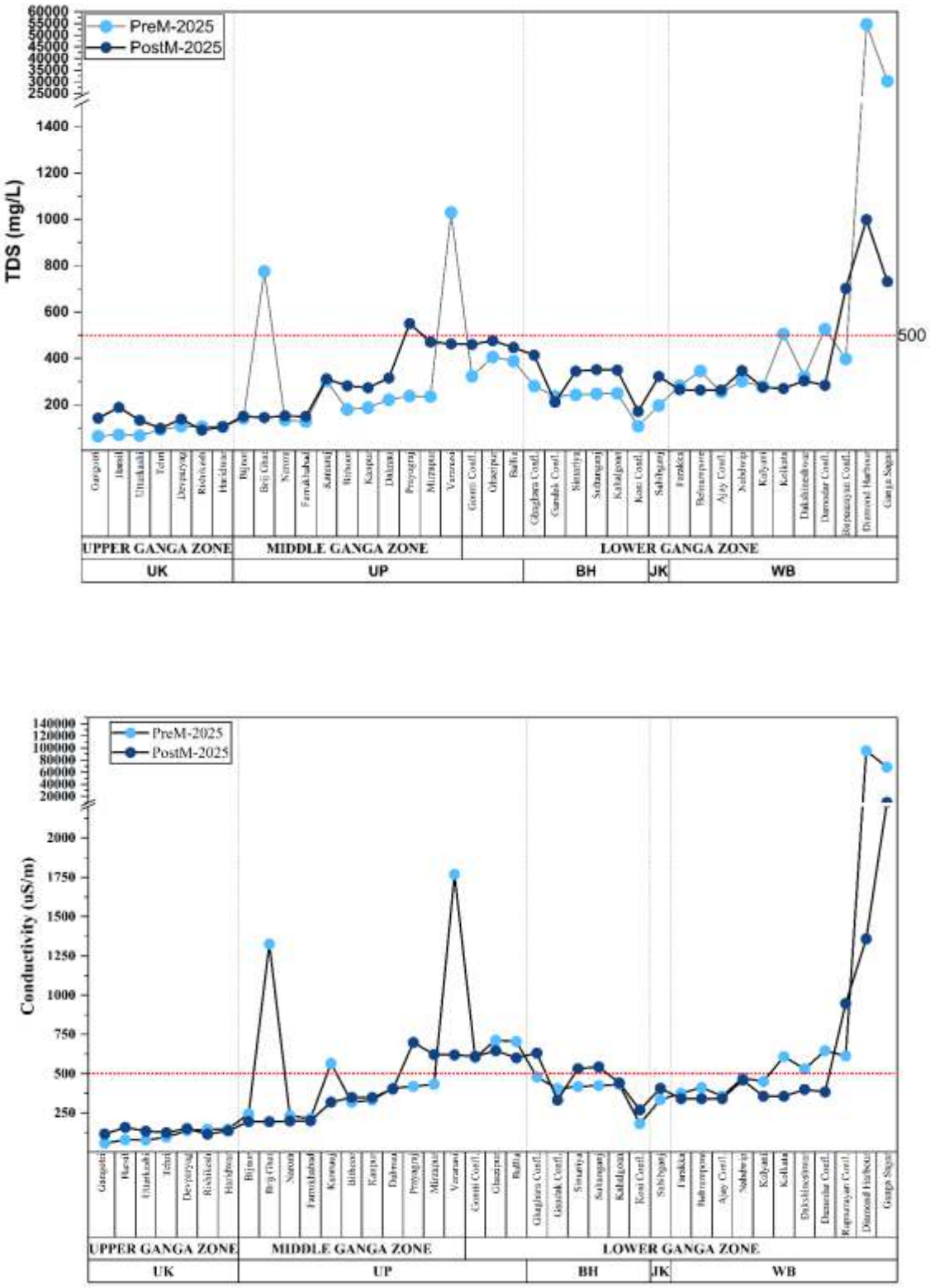


Figure 9.4 Spatiotemporal variation in (a) Total Dissolved Solids (TDS, mg/L) and (b) Conductivity (µS/cm) along the Ganga mainstem in 2025. Dashed line denotes the regulatory threshold.

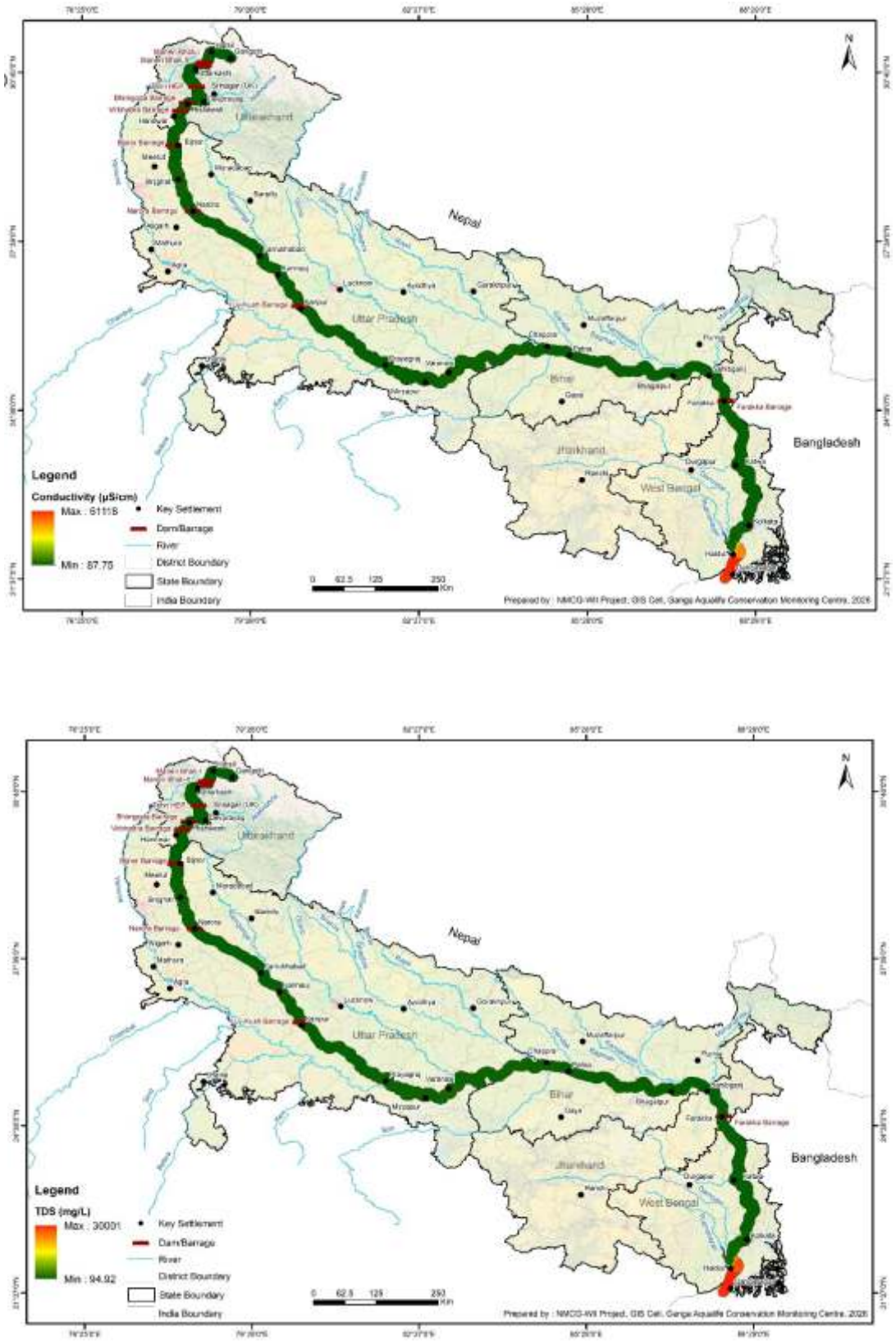


Figure 9.5 in (a) Total Dissolved Solids (TDS, mg/L) and (b) Conductivity (µS/cm) along the Ganga mainstem in 2025

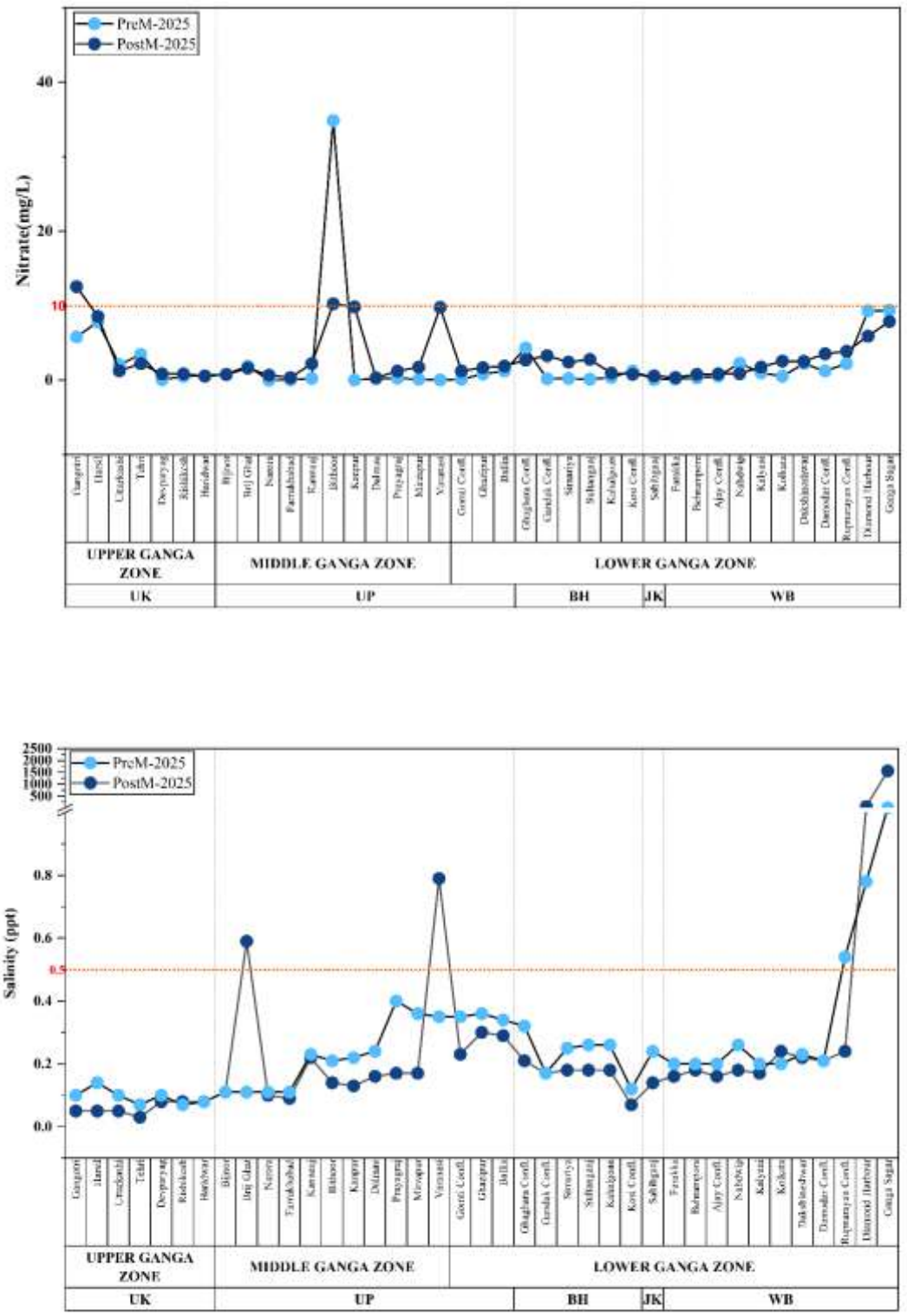


Figure 9.6 Spatiotemporal variation in (a) Nitrate (mg/L) and (b) Salinity (ppt) along the Ganga mainstem in 2025. Dashed line denotes the regulatory threshold.

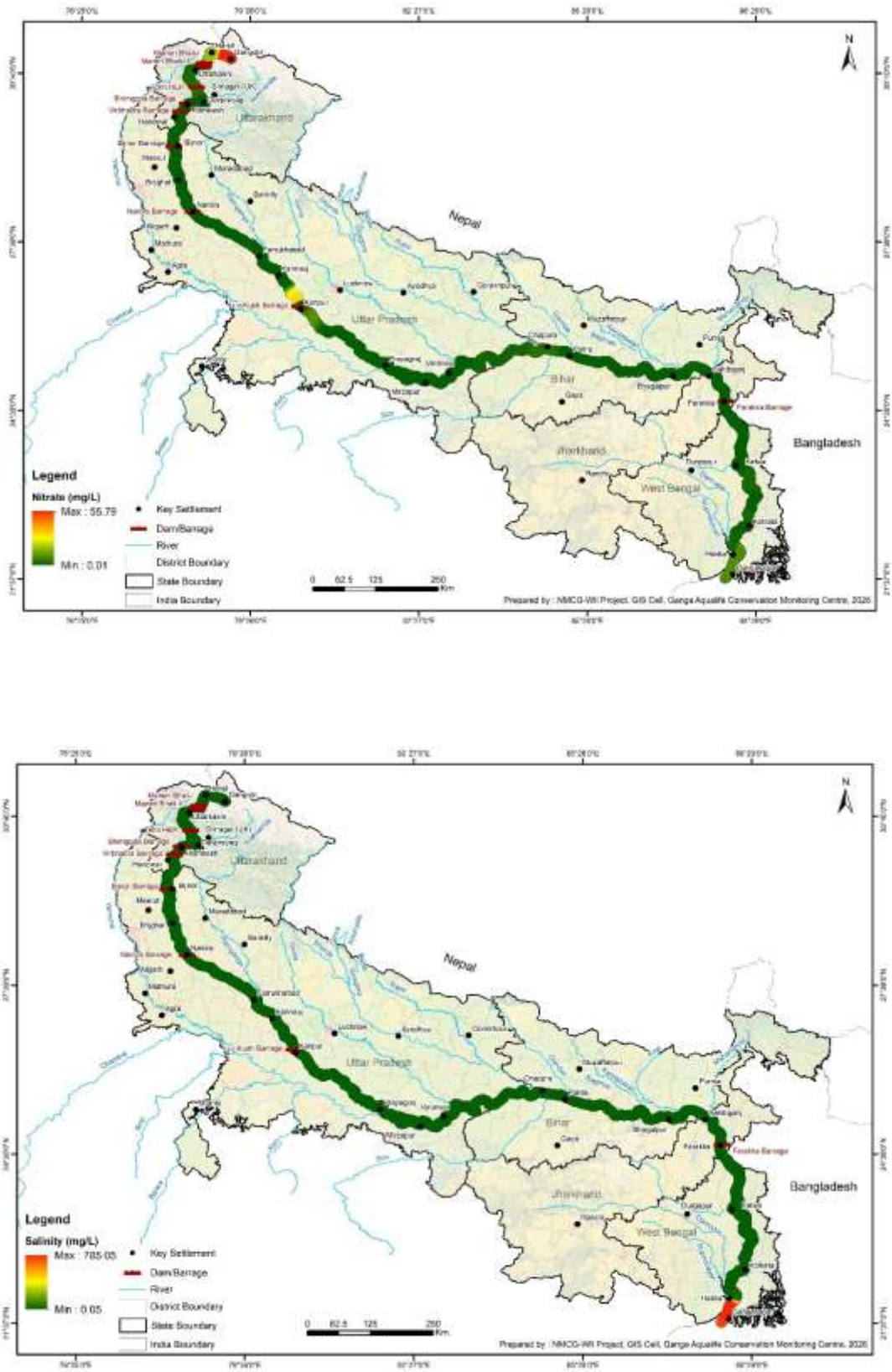


Figure 9.7 Annual variation in (a) Nitrate (mg/L) and (b) Salinity (ppt) along the Ganga mainstem in 2025.

9.3.2 CONTAMINATION PROFILE OF ENDOCRINE DISRUPTING CHEMICALS (EDCS) AND HEAVY METALS (HMS) IN GANGA RIVER

Endocrine-disrupting chemicals (EDCs) and heavy metals (HMs) are among the most ecologically consequential pollutants due to their persistence, bioaccumulation, mobility, and toxicity. These contaminants adversely affect a wide range of taxa, from primary producers to aquatic mammals, and are continuously released into freshwater systems through agriculture, healthcare, industry, and domestic activities via pathways such as runoff, sewage discharge, landfill leachate, and wastewater effluents. Stormwater events and aging sewer infrastructure further intensify their diffuse loading in urban river reaches.

A detailed analyte-wise assessment is presented below at river-wide and zone-wide scales covering the Upper Ganga Zone (UGZ: Source-Haridwar), Middle Ganga Zone (MGZ: D/S Haridwar-Varanasi), and Lower Ganga Zone (LGZ: D/S Varanasi-Ganga Sagar).

Endocrine Disrupting Chemicals (EDCs) In Surface Water Of Ganga River

River-wide:

The river-wide contamination profile of emerging EDCs followed the order ΣPAEs (2,174 ± 123 ng/L) > BPA (138.5 ± 47.27 ng/L) > ΣPharma (26.46 ± 3.82 ng/L) > ΣPCPs (6.08 ± 0.79 ng/L) > ΣSteroids (1.46 ± 0.26 ng/L), while legacy EDCs followed ΣOCPs (13.71 ± 8.39 ng/L) > ΣOPPs (10.27 ± 4.41 ng/L) > ΣPCBs (0.71 ± 0.44 ng/L).

Phthalate esters dominated the emerging EDC profile, reflecting ubiquitous municipal sewage (domestic PVC, medical waste, cosmetics), solid waste/landfill leachate, and plastic waste contamination with minimal inter-zone variation (Table 9.6; Figures 9.8, 9.9a, 9.10a, 9.11).

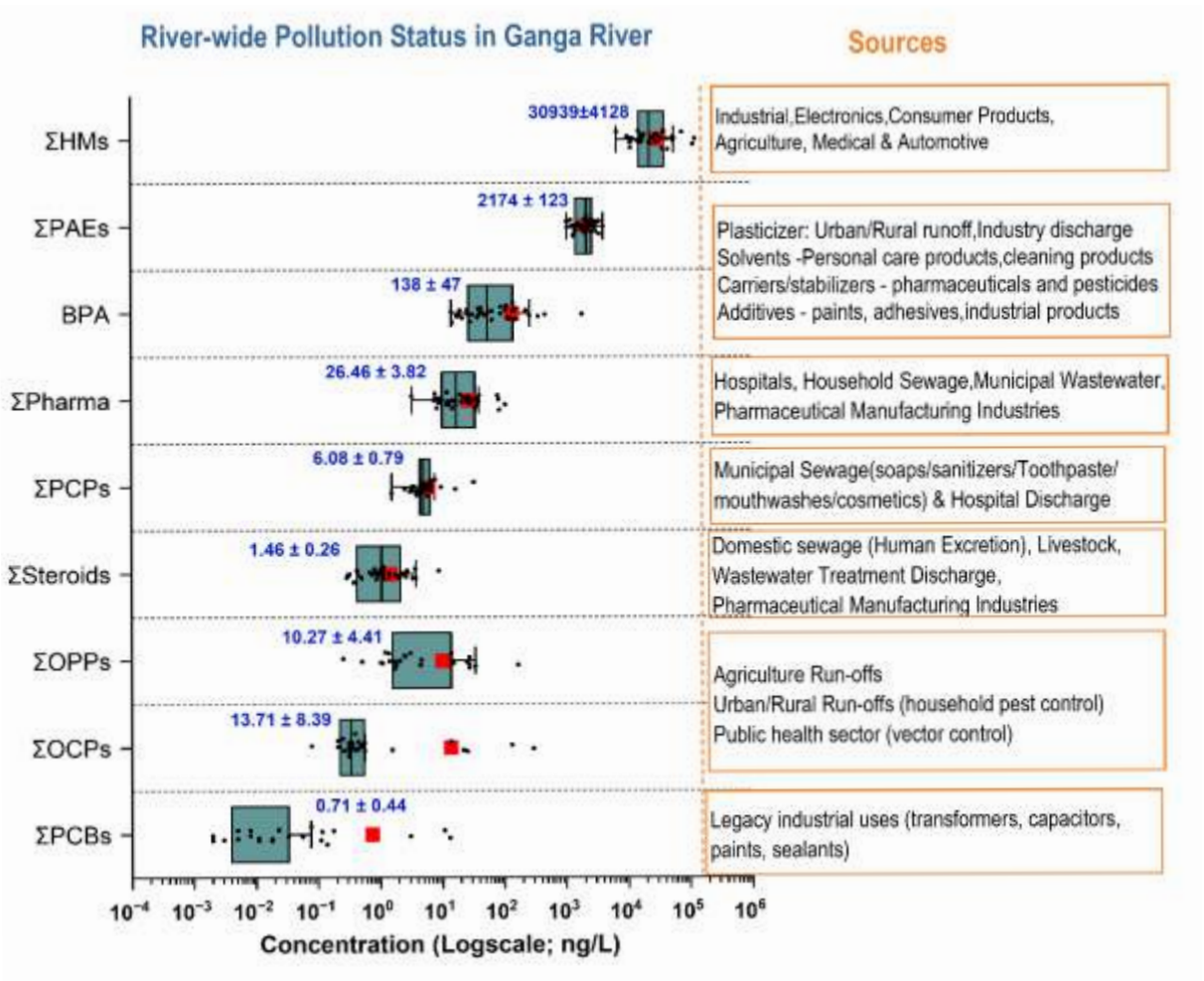


Figure 9.8 Endocrine-Disrupting Chemicals (EDCs) contamination profile in Surface Water of the Ganga River based on 2025 Annual Mean Concentrations. EDCs levels (ng/L) presented on a log scale (to account for the wide range of observed values for different EDCs group) with Mean?±?SEM (labels); black dots indicate distribution along Ganga River

Zone-wide:

he UGZ (Source to Haridwar) across Uttarakhand recorded the lowest EDC burden, with near-negligible legacy pesticides and PCBs, though elevated PCPs (mean 7.46 ± 1.60 ng/L) at pilgrimage towns and moderate phthalates (1,789 ± 169 ng/L) confirm emerging contaminant inputs even in the headwater stretch (Table 9.6).

The MGZ (D/S Haridwar to Varanasi) across Uttar Pradesh recorded the highest pharmaceutical residues (mean 34.04 ± 8.12 ng/L), PCPs (up to 32.51 ng/L), and PCBs (mean 1.01 ± 0.98 ng/L) among all zones, with sharp escalation in legacy pesticides relative to the UGZ (?OCPs: up to 25.32 ng/L; ΣOPPs: up to 27.7 ng/L), driven by the urban-industrial corridor and agricultural belt. Priority sites include Brij Ghat (BPA, PCPs, OCPs), Mirzapur, Kannauj, Bithoor, and Narora (pharmaceuticals, OPPs, PCBs) (Table 9.6).

The LGZ (D/S Varanasi to Ganga Sagar) recorded the highest zonal means for BPA (mean 196 ± 84.04 ng/L), steroids (mean 1.75 ± 0.43 ng/L), phthalates (2,391 ± 183 ng/L), and legacy pesticides (ΣOCPs: mean 23.33 ± 14.96 ng/L; ΣOPPs: mean 14.16 ± 7.96 ng/L). Within the LGZ, downstream Uttar Pradesh carries the heaviest burden, with Ghazipur emerging as the single most multi-contaminated site on the river (priority site for five of eight EDC groups) and Ballia recurring across three groups. Bihar contributed hotspots for BPA (Kosi Confluence) and OPPs (Kahalgaon); Jharkhand through Sahibganj across three groups; and West Bengal dominated steroid and PCB priorities (Behrampore, Dakshineshwar, Rupnarayan Confluence) and contributed to BPA and pharmaceutical loading (Kolkata, Ganga Sagar) (Table 9.6; Figure 9.6a). The recurrence of the same sites across multiple EDC classes confirms co-contamination from common source pathways, and the absence of ambient water quality criteria for emerging contaminants in Indian regulatory frameworks represents a critical governance gap.

Table 9.6 Current River & Zone-wide Contamination Status (ng/L) of the Ganga River (2025 Annual Mean)

Analyte	Zone-wide			River-wide Mean±SEM
	Upper Ganga Zone	Middle Ganga Zone	Lower Ganga Zone	
ΣHMs	1160 – 21280 (5791 ± 1631)	6690 – 56400 (2711 ± 47?)	10000 – 76040 (23960 – 3570)	30939 ± 4127
ΣPAFs	1056 – 2400 (1765 ± 169)	1051 – 3088 (2007 – 210)	1069 – 4030 (2291 – 183)	2174 ± 123
BPA	19.31 – 1282.63 (64.87 – 21.63)	14.40 – 466 (75.14 – 39.63)	1760 – 1834 (196 ± 84.04)	138.5 ± 47.27
ΣPharma	7.76 – 34.63 (15.58 ± 4.12)	8.42 – 85.33 (34.04 ± 8.12)	3.3 – 105 (26.?? ± 5.36)	26.46 ± 3.82
ΣPCPs	3.18 – 16.48 (7.46 ± 1.60)	2.52 – 32.51 (7.43 – 2.53)	1.56 – 9.68 (4.90 ± 0.37)	6.08 ± 0.79
ΣSteroids	<DL – 2.22 (0.89 ± 0.37)	<DL – 2.74 (1.28 ± 0.78)	<DL – 8.84 (1.75 ± 0.43)	1.46 ± 0.26
ΣOCPs	0.21 – 0.36 (0.27 ± 0.07)	<D_ – 25.32 (7.93 ± 2.49)	<D_ – 294 (23.33 ± 14.96)	13.?? ± 8.39
ΣOPPs	<D_ – 1.59 (0.86 – 0.23)	<DL – 27.7 (8.83 – 3.26)	<DL – 166.9 (?4.?6 ± 7.96)	10.27 ± 4.4?
ΣPCBs	<DL – 0.01	<DL – 10.78 (1.01 – 0.98)	<DL – 13.23 (0.80 ± 0.54)	0.71 ± 0.44

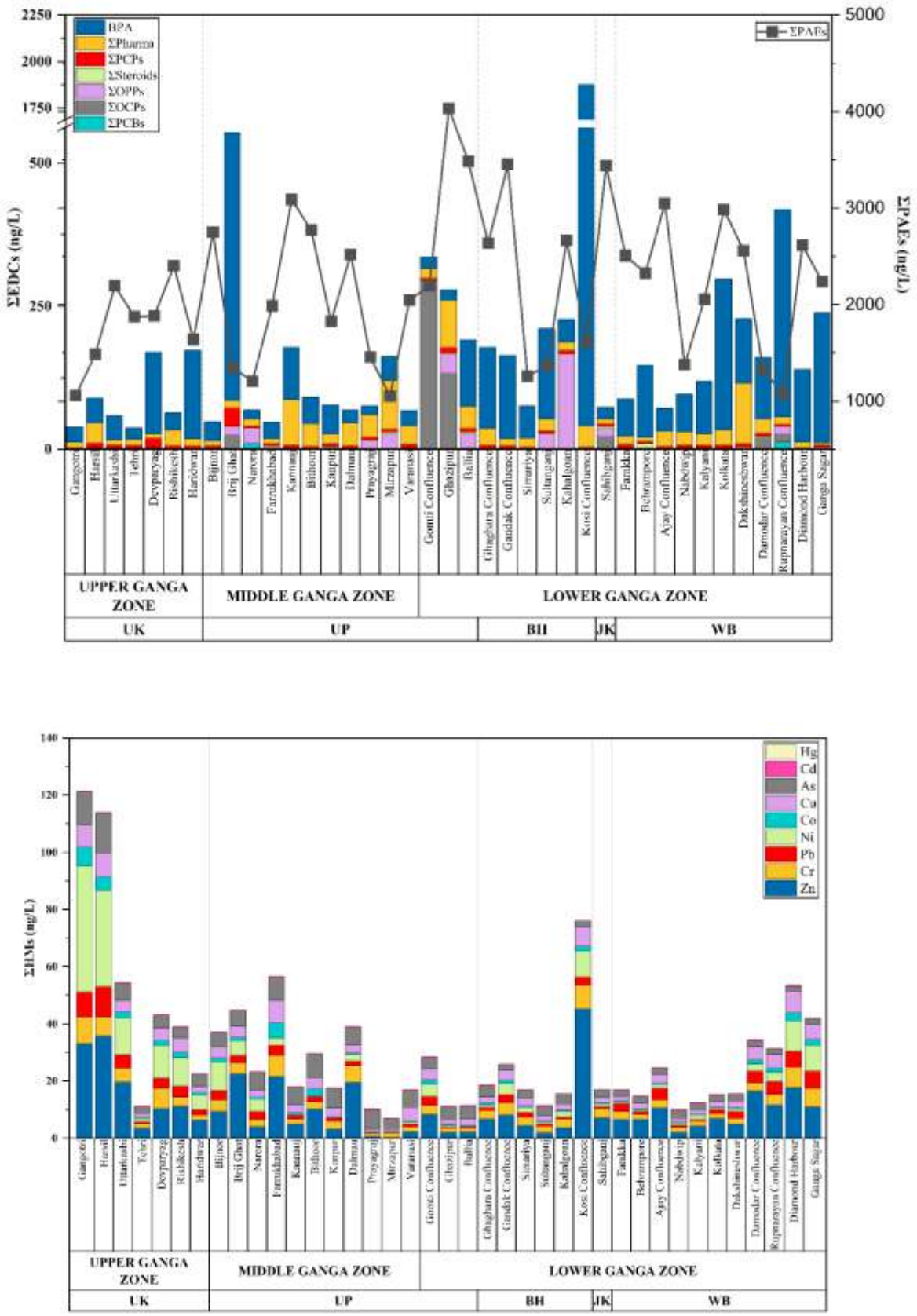


Figure 9.9 Site-wide, zone-wide, and state-wide spatial distribution of (a) legacy and emerging endocrine-disrupting chemicals (EDCs) and (b) heavy metals (HMs) in the surface water of the Ganga River.

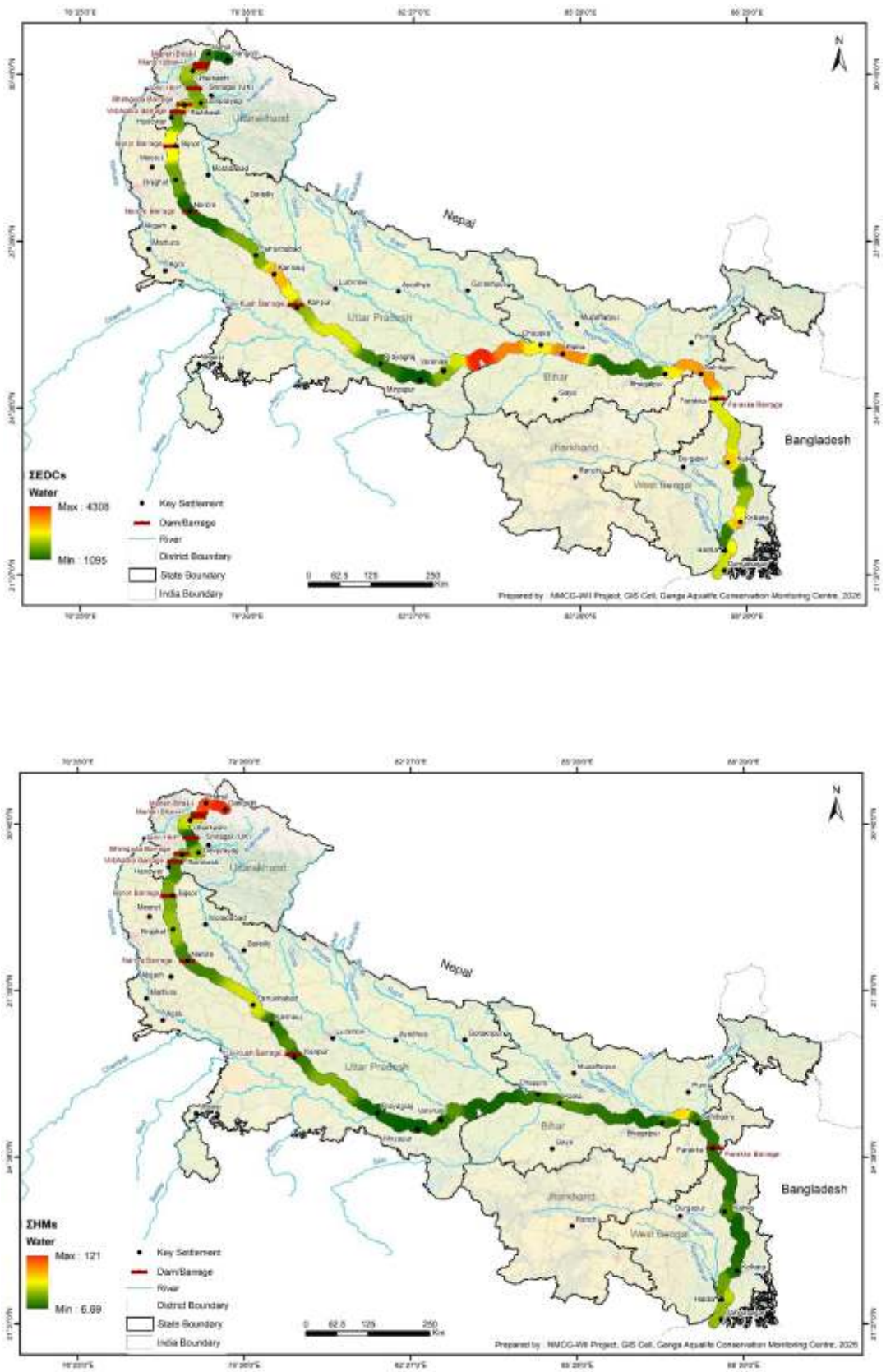


Figure 9.10 Spatial distribution of (a) legacy and emerging endocrine-disrupting chemicals (EDCs) and (b) heavy metals (HMs) in the surface water of the Ganga River in 2025.



Heavy Metals In Surface Water Of Ganga River

River-wide:

Heavy metals constitute the dominant contamination class across the Ganga mainstem, with a river-wide mean of 30,939 ± 4,127 ng/L, exceeding all other analyte classes by an order of magnitude across both seasons. Concentrations spanned three orders of magnitude (6,686 to 121,281 ng/L), reflecting extreme spatial heterogeneity in source loading (Table 9.6; Figure 9.6b).

Zone-wide:

The UGZ (Source to Haridwar) across Uttarakhand recorded the highest zonal mean (57,910 ± 16,310 ng/L), nearly double the river-wide average, with Gangotri, Harsil, and Uttarkashi as the top three priority sites. Zinc dominated the metal profile across UGZ sites, with substantial contributions from chromium, cobalt, and nickel. Notably, mercury showed visibly elevated levels at Gangotri and Harsil relative to all other sites on the river, suggesting localized geogenic or glacial sources in the headwater reaches. Concentrations declined sharply downstream from Devprayag through Haridwar (Table 9.6; Figures 9.8, 9.9b, 9.10b, 9.12).

The MGZ (D/S Haridwar to Varanasi) across Uttar Pradesh recorded a zonal mean of 27,110 ± 4,710 ng/L. Zinc remained the dominant metal, but chromium contributions increased notably at sites such as Farrukhabad and Kanpur, consistent with tannery and electroplating effluent loading. Lead showed elevated contributions at Brij Ghat and Narora. The metal profile in the MGZ reflects a shift from geogenic to anthropogenic-industrial sources relative to the UGZ (Table 9.6).

The LGZ (D/S Varanasi to Ganga Sagar) recorded the lowest zonal mean (23,960 ± 3,570 ng/L), with zinc dominating across all sites. Kosi Confluence in Bihar was a clear outlier (~76,000 ng/L), the third highest site on the river, with substantial zinc, chromium, and nickel loading. The West Bengal stretch showed a resurgence at Ganga Sagar and Diamond Harbour, with arsenic, lead, and chromium contributions becoming more prominent in the estuarine reach. The remaining LGZ sites across Bihar, Jharkhand, and upstream West Bengal showed comparatively lower and more uniform concentrations (Table 9.6; Figure 9.6b). Unlike EDCs, heavy metal contamination is highest in the headwater zone and progressively declines downstream, confirming that geogenic and extractive-industry sources in Uttarakhand are the primary drivers rather than the urban-industrial and sewage pathways that dominate EDC loading in the MGZ and LGZ.

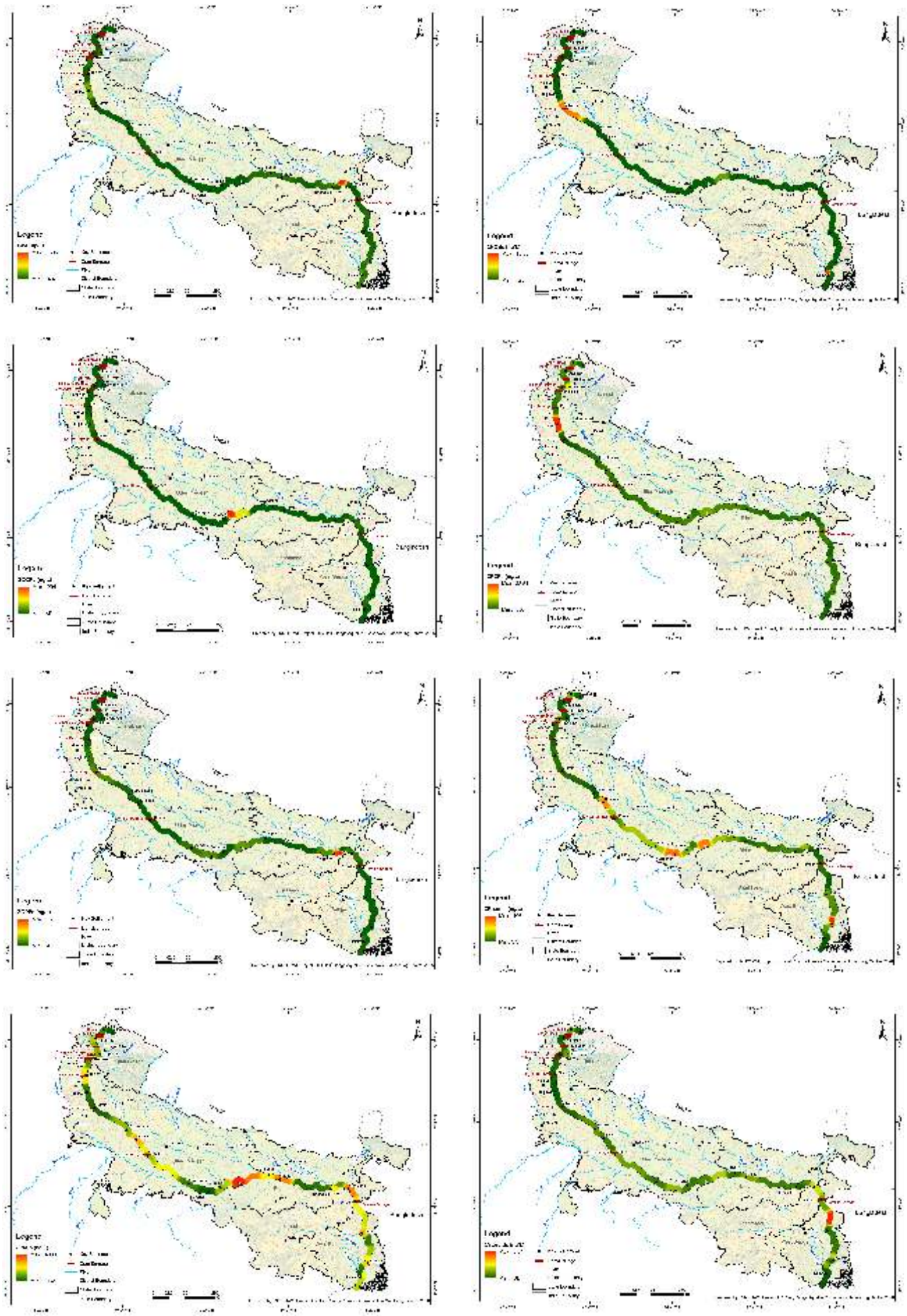


Figure 9.11 Spatial distribution of legacy and emerging endocrine-disrupting chemicals (EDCs) groups in the surface water of the Ganga River in 2025.

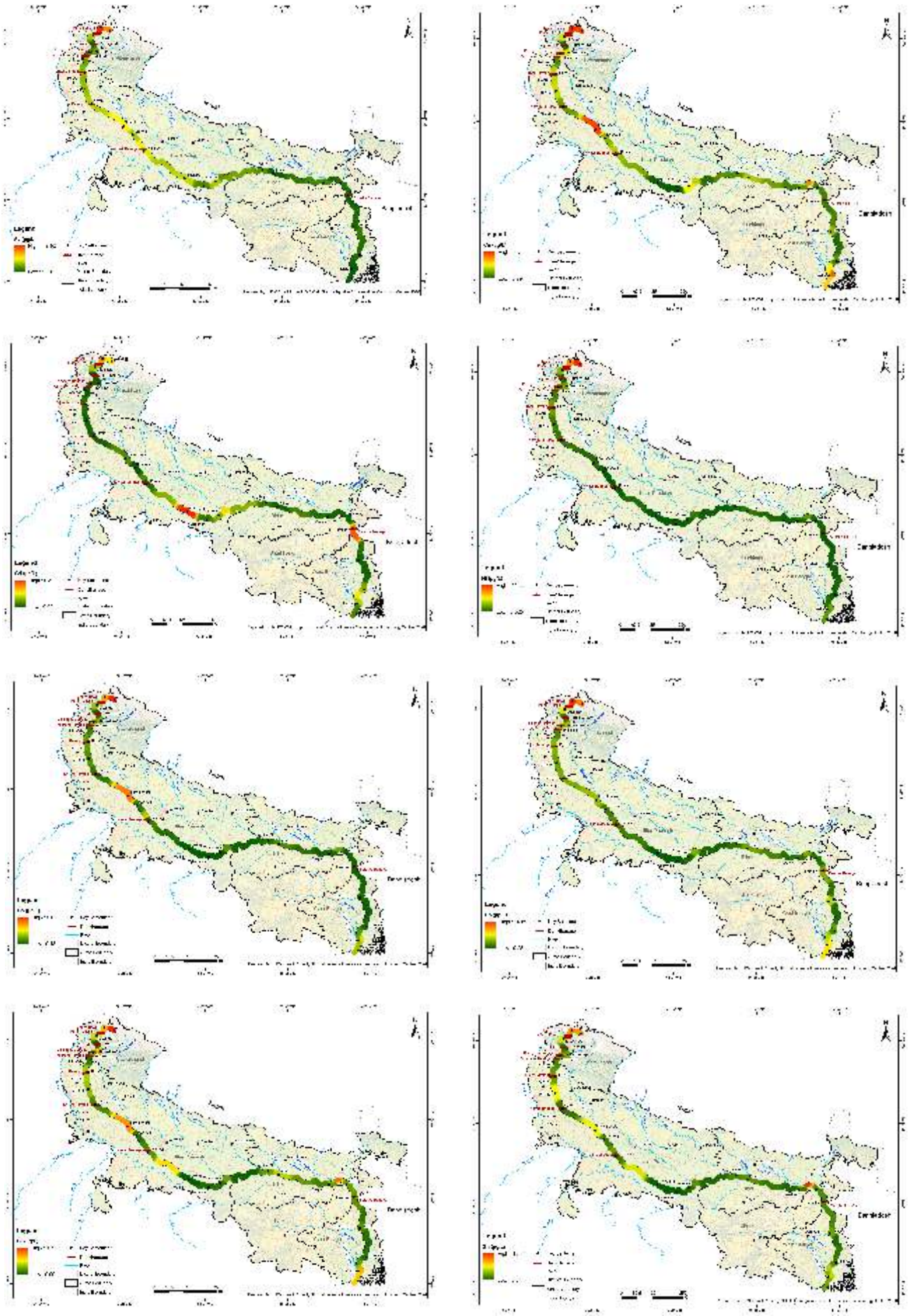


Figure 9.12 Spatial distribution of Heavy Meatls (HMs) groups in the surface water of the Ganga River in 2025.

Seasonal Dynamics Of Legacy And Emerging EDCs In Surface Water Of Ganga River

Emerging contaminants (ΣPAEs > BPA > ΣPharma > ΣPCPs > ΣSteroids) peaked post-monsoon due to monsoon-driven sewage overflow and plastic leachate mobilisation, while legacy contaminants (ΣOPPs > ΣOCPs > ΣPCBs) peaked pre-monsoon due to reduced dilution capacity during lean flows, with ΣHMs dominating both seasons. This seasonal inversion in contaminant dominance confirms that no single monitoring window captures the full contamination burden, necessitating year-round surveillance, season-specific intervention design (STP capacity and solid waste management before monsoon onset; discharge regulation and flow augmentation during lean flows), and sustained budgetary commitment to continuous monitoring rather than periodic campaigns (Figure 9.13).

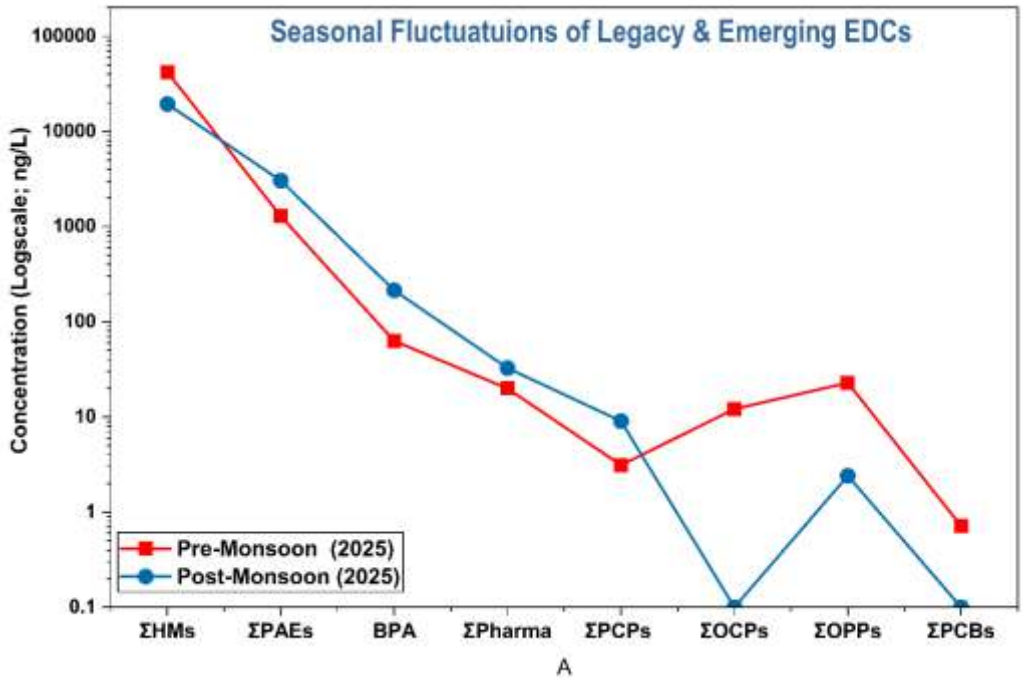


Figure 9.13 Seasonal fluctuations of Legacy and Emerging Endocrine-Disrupting Chemicals (EDCs)



Endocrine Disrupting Chemicals (EDCs) In Surface Sediments Of Ganga River

Sediment-bound contaminants represent cumulative, long-term deposition that persists across hydrological cycles, unlike surface water where concentrations fluctuate seasonally. Results are presented at river-wide and zone-wide scales covering the Upper Ganga Zone (UGZ: Source to Haridwar), Middle Ganga Zone (MGZ: D/S Haridwar to Varanasi), and Lower Ganga Zone (LGZ: D/S Varanasi to Ganga Sagar) (Table 9.7; Figures 9.14a, 9.15a, 9.16).

River-wide:

The sediment contamination profile of emerging EDCs followed the order ΣPAEs (3,513 ± 511 µg/kg) > BPA (102.18 ± 14.89 µg/kg) > ΣPharma (12.08 ± 3.13 µg/kg) > ΣPCPs (3.44 ± 1.35 µg/kg) > ΣSteroids (0.36 ± 0.08 µg/kg), confirming that plastic-derived contaminants have permeated the entire sediment matrix. Legacy contaminants followed ΣOCPs (2.87 ± 1.94 µg/kg) > ΣOPPs (1.84 ± 0.20 µg/kg) > ΣPCBs (0.16 ± 0.08 µg/kg) (Table 9.7; Figure 9.8).

Zone-wide:

The UGZ (Source to Haridwar) across Uttarakhand recorded low legacy pesticide and PCB levels (ΣOCPs: 1.82 ± 1.24 µg/kg; ΣPCBs: <DL to 0.75 µg/kg), but notably elevated BPA (7.1 to 454 µg/kg; mean 131 ± 59.74 µg/kg), the highest zonal mean for BPA across the river, and substantial phthalate levels (mean 3,446 ± 1,104 µg/kg), indicating that plastic contamination in sediment is not confined to urban stretches (Table 9.7).

The MGZ (D/S Haridwar to Varanasi) across Uttar Pradesh recorded the highest pharmaceutical residues (mean 19.63 ± 7.57 µg/kg, with sites reaching 110.43 µg/kg), the highest steroid levels (mean 0.49 ± 0.15 µg/kg), the highest PCB concentrations (mean 0.29 ± 0.18 µg/kg), and the highest phthalate levels (627 to 19,002 µg/kg; mean 3,923 ± 1,155 µg/kg) among all zones, driven by dense urban-industrial discharge. Pharmaceutical residues confirm that these compounds partition into and persist within the sediment phase, creating chronic low-dose exposure pathways for benthic invertebrates that are consumed by small fish and crustaceans, the primary prey of the Gangetic dolphin, thereby enabling stepwise trophic biomagnification of pharmaceutically active compounds to an apex predator already under conservation stress. OPP loading was also highest in the MGZ (mean 2.06 ± 0.36 µg/kg) (Table 9.7).

The LGZ (D/S Varanasi to Ganga Sagar) recorded the highest legacy pesticide burden (ΣOCPs: up to 83.4 µg/kg, mean 4.67 ± 4.15 µg/kg), over 3x the river-wide mean, and the highest PCP levels (up to 53.56 µg/kg; mean 5.69 ± 2.85 µg/kg). Within the LGZ, West Bengal emerged as the primary sediment contamination hotspot for phthalates (3272± 483 µg/kg), PCPs (5.69 ± 2.85 µg/kg), and legacy pesticides (?OCPs: 4.67 ± 4.15 µg/kg). Jharkhand recorded the highest individual BPA value (168 µg/kg). Bihar showed elevated BPA (126 ± 28.91 µg/kg), confirming widespread plastic contamination across the sediment matrix independent of urbanization intensity (Table 9.7; Figure 9.8a).

The sediment EDC profile diverges from surface water in one important respect: BPA contamination is highest in the UGZ sediments rather than the LGZ, suggesting long-term accumulation and retention of plastic degradation products in headwater sediments despite lower surface water concentrations. This decoupling between water and sediment compartments underscores the need for matrix-specific monitoring and confirms that sediments serve as a long-term contaminant reservoir with chronic exposure implications for benthic biota.



Heavy Metals In Surface Sediments Of Ganga River

River-wide:

Heavy metals constitute the dominant sediment contaminant class at

31769 ± 2592 µg/kg, exceeding all other analytes by an order of magnitude. Sediment-bound heavy metals represent cumulative, long-term deposition that persists across hydrological cycles, unlike surface water where concentrations fluctuate seasonally.

Zone-wide:

The UGZ (Source to Haridwar) across Uttarakhand recorded the highest zonal mean (53286 ± 8513 µg/kg),, nearly double the river-wide average, with Gangotri, Harsil, and Uttarkashi as the top three priority sites. Zinc dominated the metal profile across UGZ sites, with substantial contributions from chromium, cobalt, and nickel. Notably, mercury showed visibly elevated levels at Gangotri and Harsil relative to all other sites on the river, suggesting localized geogenic or glacial sources in the headwater reaches. Concentrations declined sharply downstream from Devprayag through Haridwar (Table 9.7; Figures 9.14b, 9.15b, 9.17).

The MGZ (D/S Haridwar to Varanasi) across Uttar Pradesh recorded a zonal mean of 23496± 2615 µg/kg.. Zinc remained the dominant metal, but chromium contributions increased notably at sites such as Farrukhabad and Kanpur, consistent with tannery and electroplating effluent loading. Lead showed elevated contributions at Brij Ghat and Narora. The metal profile in the MGZ reflects a shift from geogenic to anthropogenic-industrial sources relative to the UGZ (Table 9.7).

The LGZ (D/S Varanasi to Ganga Sagar) recorded the lowest zonal mean (30857± 2858 µg/kg), with zinc dominating across all sites. Kosi Confluence in Bihar was a clear outlier (~60,000 µg/kg), the third highest site on the river, with substantial zinc, chromium, and nickel loading. The West Bengal stretch showed a resurgence at Ganga Sagar and Diamond Harbour, with arsenic, lead, and chromium contributions becoming more prominent in the estuarine reach. The remaining LGZ sites across Bihar, Jharkhand, and upstream West Bengal showed comparatively lower and more uniform concentrations (Table 9.6; Figure 9.8b).

Unlike EDCs, heavy metal contamination is highest in the headwater zone and progressively declines downstream, confirming that geogenic and extractive-industry sources in Uttarakhand are the primary drivers rather than the urban-industrial and sewage pathways that dominate EDC loading in the MGZ and LGZ.

Table 9.7 Zone-wide Contamination Status of surface sediments (µg/Kg) of the Ganga River (2025 Annual Mean)

Analyte	Zone-wide			River-wide Mean±SEM
	Upper Ganga Zone	Middle Ganga Zone	Lower Ganga Zone	
THMs	20147 – 91818 (53286 ± 8513)	12561 – 44729 (23496 ± 2615)	24409 – 60379 (30857 ± 2858)	31769 ± 2592
ΣPAHs	0.82 – 8712 (3446± 1104)	627 – 19002 (3923± 1155)	828 – 8401 (3272± 483)	3613± 511
BPA	7 – 484 (131± 59.7)	12.24 – 302 (93.42 – 23.91)	6.48 – 243 (94.87 ± 16.67)	102.3 – 14.36
ΣPharma	<DL – 35.64 (6.59 ± 4.09)	<DL – 110.42 (19.63 ± 7.57)	<DL – 26.5 (7.97 ± 1.98)	12.05 ± 3.03
ΣPCPs	< DL – 2.53 (0.89 – 0.40)	0.75 – 7.06 (1.74 ± 0.26)	<DL – 58.56 (5.69 ± 2.85)	3.47 ± 1.33
ΣSterols	<DL – 1.45 (0.32 ± 0.20)	<DL – 1.81 (0.49 ± 0.15)	<DL – 1.37 (0.28 ± 0.12)	0.36 ± 0.08
ΣOCPs	0.07 – 9.16 (1.82 ± 1.24)	0.37 – 10.89 (1.08 ± 0.66)	<DL – 83.6 (7.67 ± 4.15)	2.67 ± 1.97
ΣOPPs	0.24 – 3.2 (1.08 ± 0.38)	0.32 – 5.69 (2.06 ± 0.36)	<DL – 4.43 (1.93 ± 0.26)	1.84 ± 0.2
ΣPCBs	<DL – 0.75 (0.1 ± 0.11)	<DL – 2.29 (0.29 ± 0.12)	<DL – 1.42 (0.07 ± 0.07)	0.16 ± 0.08

<DL: Below instrument detection limit



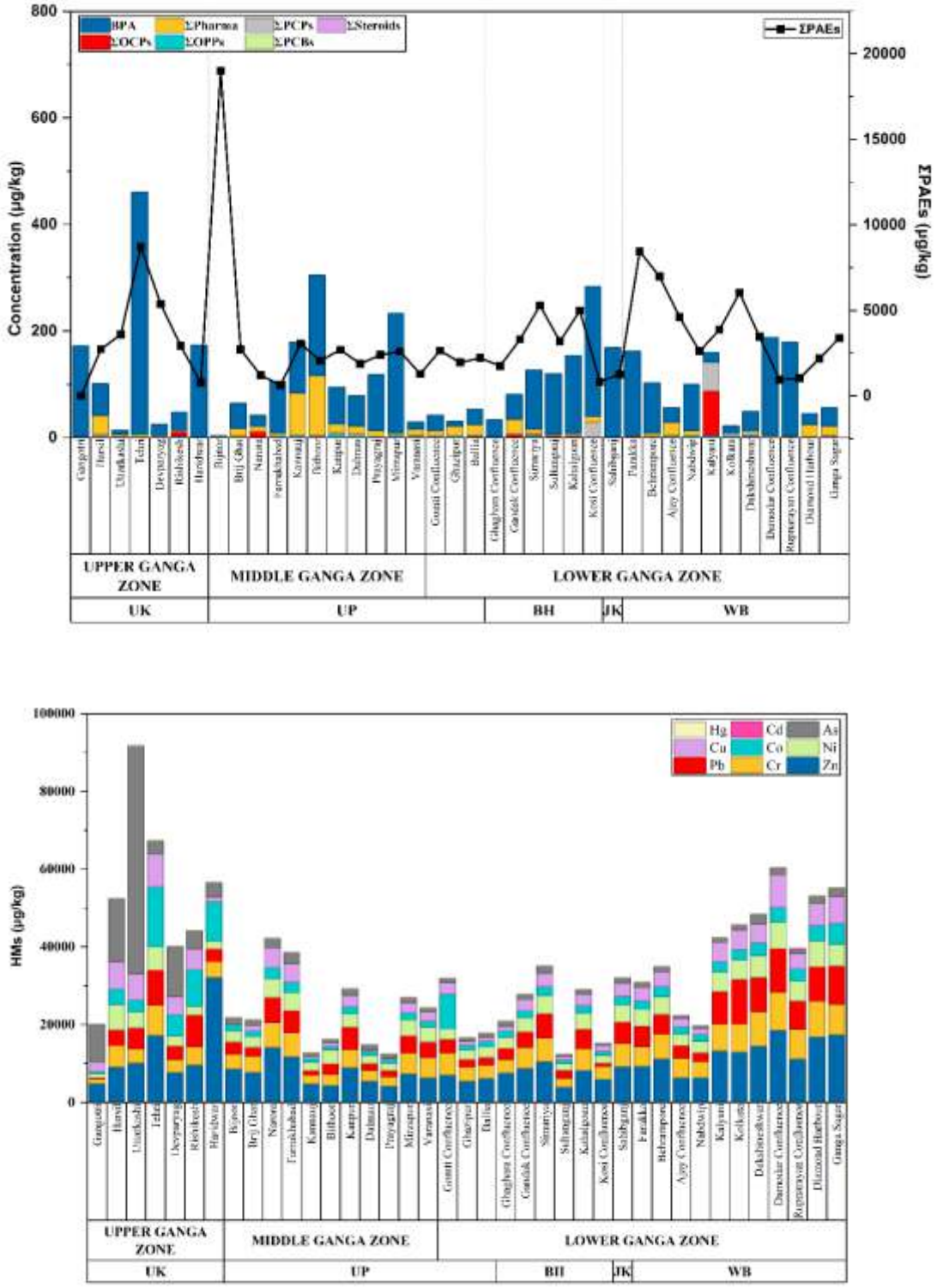


Figure 9.14 Site-wide, zone-wide, and state-wide spatial distribution of (a) legacy and emerging endocrine-disrupting chemicals (EDCs) and (b) heavy metals (HMs) in the surface sediment of the Ganga River.

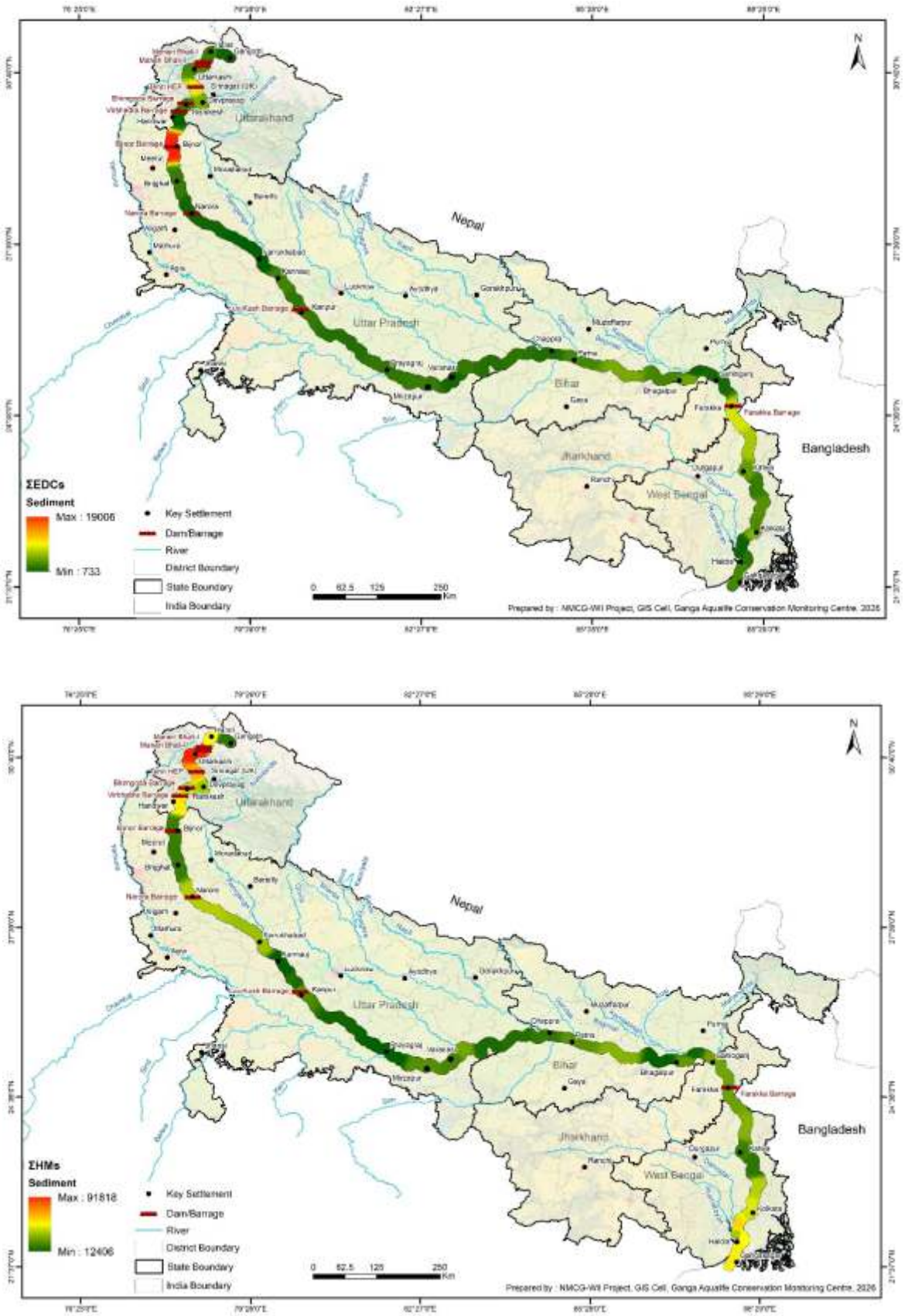


Figure 9.15 Spatial distribution of (a) legacy and emerging endocrine-disrupting chemicals (EDCs) and (b) heavy metals (HMs) in the surface sediment of the Ganga River in 2025.

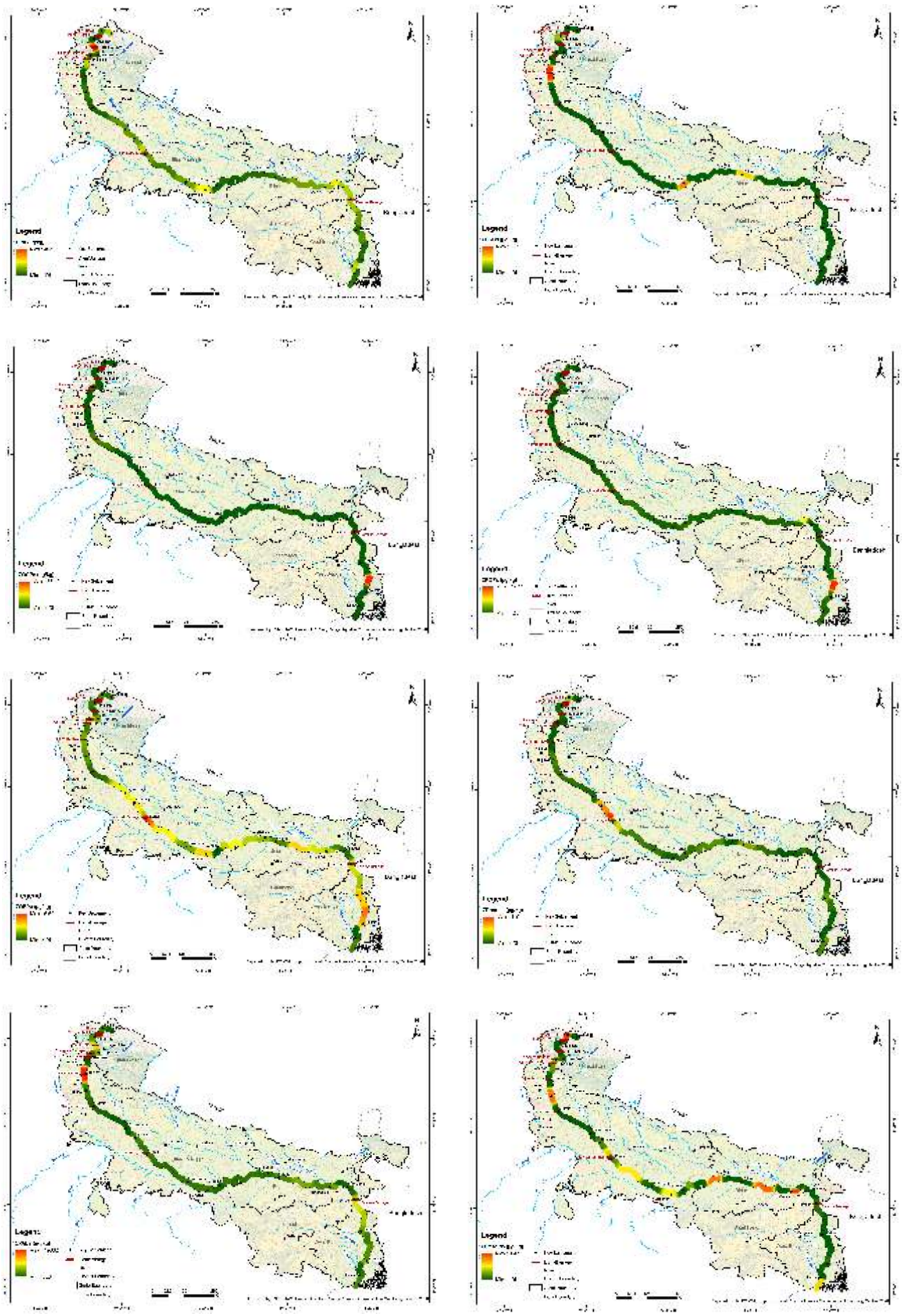


Figure 9.16 Spatial distribution of (a) legacy and emerging endocrine-disrupting chemicals (EDCs) groups in the surface sediment of the Ganga River in 2025.

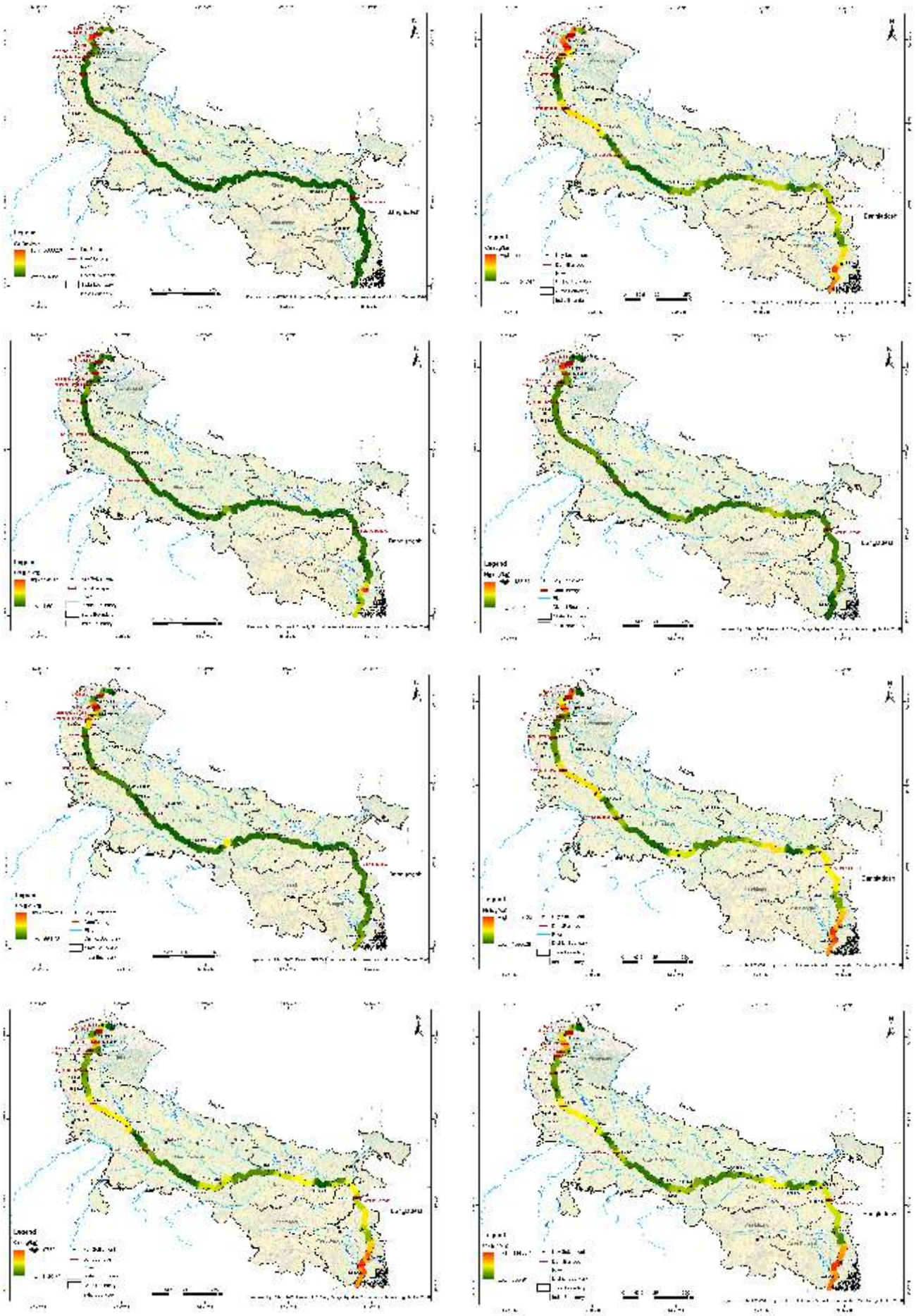


Figure 9.17 Spatial distribution of Heavy Metals HMs) groups in the surface sediment of the Ganga River in 2025.

Bioaccumulation Profiles Of EDCs And Heavy Metals In Fish Biota From Ganga River

Endocrine Disrupting Chemicals (EDCs) In Fish Biota

River-wide:

The fish tissue bioaccumulation profile of emerging EDCs followed the order ΣPAEs (55.03 ± 5.23 µg/kg) > ΣPCPs (19.53 ± 1.77 µg/kg) > ΣPharma (1.67 ± 0.33 µg/kg) > ΣSteroids (0.76 ± 0.15 µg/kg) > BPA (0.19 ± 0.08 µg/kg), confirming active transfer of emerging contaminants from the water column and sediment into the aquatic food chain. Legacy contaminants in fish tissue followed ΣOCPs (15.60 ± 1.73 µg/kg) > ΣOPPs (1.19 ± 0.56 µg/kg) >ΣPCBs (0.26 ± 0.04 µg/kg), with OCPs demonstrating classical biomagnification as fish tissue concentrations substantially exceed corresponding sediment levels (Table 9.8 & Figure 9.18). The species-level EDC profile reveals substantial variation in both total burden and contaminant composition across fish taxa (Figure 9.18a and 9.19a).

Zone-wide:

The UGZ (Source to Haridwar) across Uttarakhand had limited fish sampling (single composite), recording moderate phthalate (9.00 µg/kg) and PCP (8.57 µg/kg) levels. BPA in fish tissue was notably highest in the UGZ (5.42 µg/kg), suggesting localized plastic leachate exposure in headwater species. Legacy pesticides and steroids were negligible to below detection (Table 9.8).

The MGZ (D/S Haridwar to Varanasi) across Uttar Pradesh recorded the highest fish tissue burdens for phthalates (mean 63.08 ± 8.32 µg/kg; up to 368 µg/kg), PCPs (mean 22.56 ± 2.61 µg/kg; up to 106.54 µg/kg), OCPs (mean 17.81 ± 2.75 µg/kg; up to 142.61 µg/kg), and OPPs (mean 1.62 ± 1.15 µg/kg; up to 112.18 µg/kg), driven by its dense urban-industrial corridor and intensive agricultural belt. The OCP upper bound of 142.61 µg/kg is the highest individual fish tissue OCP value on the river, confirming active biomagnification of banned legacy pesticides within this zone (Table 9.8).

The LGZ (D/S Varanasi to Ganga Sagar) recorded the highest fish tissue steroids (mean 0.85 ± 0.24 µg/kg; up to 13.21 µg/kg) and pharmaceuticals (mean 1.87 ± 0.43 µg/kg; up to 20.4 µg/kg), attributable to cumulative sewage exposure in the lower basin. Within the LGZ, Bihar recorded the highest PCP bioaccumulation (38.43 ± 5 µg/kg) and elevated pharmaceuticals (3.08 ± 0.88 µg/kg). West Bengal led in steroid accumulation (1.28 ± 0.59 µg/kg), driven by sewage-derived hormonal residues. Jharkhand recorded the highest PCB levels in fish (0.85 ± 0.38 µg/kg), indicating legacy industrial contamination. OCP levels in the LGZ (mean 13.71 ± 2.17 µg/kg; up to 104.08 µg/kg) remained high, confirming that legacy pesticide biomagnification extends across the entire middle-to-lower Ganga (Table 9.8; Figure 9.18a and 9.19a).

The fish tissue EDC profile reveals a critical pattern: while the MGZ dominates for lipophilic legacy contaminants (OCPs, OPPs) and plastic-derived compounds (PAEs), the LGZ dominates for sewage-derived contaminants (steroids, pharmaceuticals, PCPs), reflecting the distinct pollution source signatures of the two zones being actively transferred into and concentrated within the aquatic food chain.

Table 9.8 River & Zone-wide Contamination Status (µg/Kg) in fishes of the Ganga River

Analyte	Zone-wide			River-wide Mean±SEM
	Upper Ganga Zone	Middle Ganga Zone	Lower Ganga Zone	
Σ-Ms	949*	<DL 71491 (10257 – 1474)	<D 57909 (17658 + 1314)	3769 + 2592
> Ms	9.00	<DL 368 (63.08 + 8.32)	<D 330 (46.70 + 6.54)	3573+ 511
B M	5.42	<DL 11.95 (0.17 – 3.12)	<DL 5.76 (0.18 + 0.09)	102+ 14.89
> Pharma	2.56	<DL 38.44 (1.44 – 0.31)	<DL 20.4 (1.87 + 0.43)	12.06 – 3.73
> P. S	8.57	<DL – 106.54 (22.56 – 2.61)	<DL – 106.69 (16.87 + 2.39)	3.44 – 1.3
ΣSteroids	<D	<DL – 10.83 (0.87 – 0.19)	<D – 13.21 (0.85 + 0.24)	0.36 + 0.08
ΣOCPs	1.79	<DL – 142.61 (17.81 + 2.75)	<DL – 104.08 (13.71 + 2.17)	2.87 + 1.94
ΣOPPs	<D	<DL – 112.18 (1.62 + 1.15)	<DL – 17.27 (0.81 + 0.27)	1.37 + 0.2
ΣPCBs	0.52	<DL – 5.22 (0.25 + 0.06)	<D – 1.87 (0.26 + 0.04)	0.16 + 0.08

<DL: Below instrument detection limit



Heavy Metals in Fish Biota

River-wide:

Heavy metals constitute the dominant fish tissue contaminant at 18,803 ± 862 µg/kg, exceeding all other analytes by two orders of magnitude and confirming active trophic transfer from water and sediment into biota.

Zone-wide:

The UGZ (Source to Haridwar) across Uttarakhand recorded 9,491 µg/kg, the lowest among all zones, despite having the highest sediment and surface water heavy metal concentrations. The MGZ (D/S Haridwar to Varanasi) across Uttar Pradesh recorded the highest zonal mean (20,257 ± 1,424 µg/kg; range: <DL to 71,491 µg/kg), with the upper bound representing the single highest fish tissue heavy metal burden on the river, driven by tannery clusters, electroplating units, and municipal effluent along the industrial corridor. The LGZ (D/S Varanasi to Ganga Sagar) recorded a comparable zonal mean (17,558 ± 1,014 µg/kg; range: <DL to 52,909 µg/kg); within the LGZ, Bihar recorded the highest fish tissue burden (25,682 ± 1,768 µg/kg), followed by Jharkhand (19,316 ± 4,292 µg/kg), while West Bengal (12,122 ± 1,412 µg/kg) recorded comparatively lower levels (Table 9.8; Figure 9.18b and 9.19b).

The zone-wise ranking in fish tissue (MGZ > LGZ > UGZ) diverges from sediment (UGZ > LGZ > MGZ), confirming that bioaccumulation is governed by trophic exposure duration and food web structure rather than ambient concentration alone. Bihar's position as the highest fish tissue burden state, despite moderate sediment and water concentrations, underscores the role of cumulative downstream exposure and species-specific feeding ecology.

Feeding Guild And Habitat-linked Bioaccumulation Patterns:

Contaminant accumulation in Ganga fish follows predictable patterns linked to feeding behaviour and habitat (Table 9.9 and Figure 9.18b and 9.19b). Carnivorous fish accumulate the highest levels of banned pesticides, mercury, and PCBs through the food chain. Omnivorous fish carry the highest heavy metal loads due to feeding on both contaminated sediments and prey. Herbivorous fish show the highest steroid levels from sewage-contaminated water. Bottom-dwelling species retain more legacy pesticides from prolonged sediment contact, while mid-water species carry the highest combined contamination across both EDCs and heavy metals.

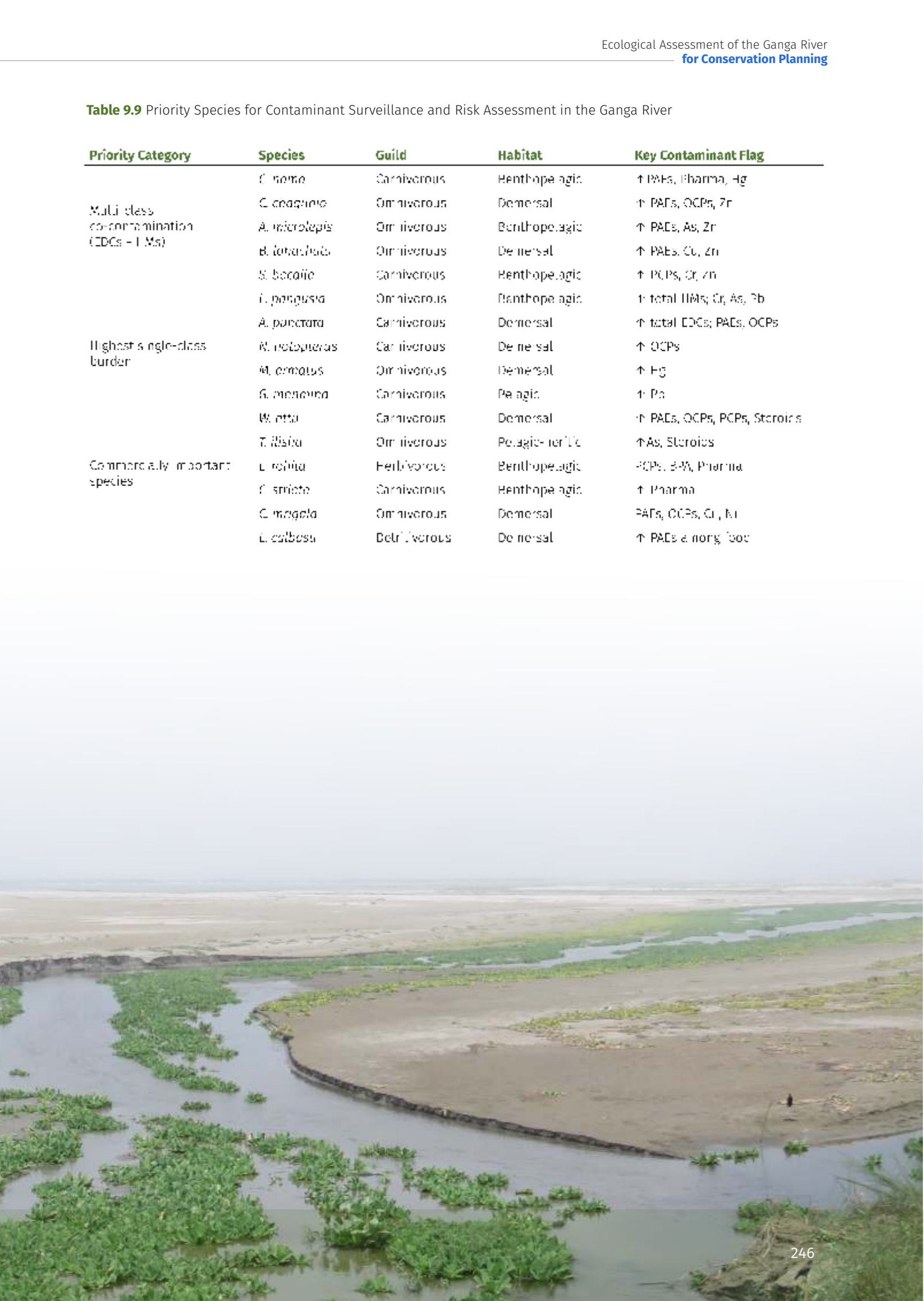
These patterns flag two management priorities. For dolphin conservation, the primary prey species of the Gangetic dolphin, including *C. nama*, *C. chagunio, A. microlepis*, *B. lohachata*, and *S. bacaila*, are among the most co-contaminated fish on the river, carrying elevated EDCs and heavy metals simultaneously (Table 9.9). Contaminant transfer through this prey base represents a chronic exposure pathway to the apex predator that cannot be addressed through habitat protection alone.

Several widely consumed commercial species carry species-specific contaminant risks: *W. attu* and *L. calbasu* for phthalates, *T. ilisha* for arsenic, *C. striata* for pharmaceuticals, *L. rohita* for PCPs and BPA, and M. armatus for mercury. A single river-wide fish consumption advisory would not capture these differences. Guild-specific and species-informed advisories, differentiated by contaminant type and consumption pattern, are recommended for the Ganga Basin (Table 9.9). These findings indicate that contaminant risk in Ganga fish is mediated by species ecology rather than ambient concentration alone.



Table 9.9 Priority Species for Contaminant Surveillance and Risk Assessment in the Ganga River

Priority Category	Species	Guild	Habitat	Key Contaminant Flag
	C. nama	Carnivorous	Benthopelagic	↑ PAHs, Pharma, Hg
	C. reagnievi	Omnivorous	Demersal	↑ PAHs, OCPs, Zn
Multi-class co-contamination (EDCs + HMs)	A. microlepis	Omnivorous	Benthopelagic	↑ PAHs, As, Zn
	B. bendelisis	Omnivorous	Demersal	↑ PAHs, Cu, Zn
	S. boaalis	Carnivorous	Benthopelagic	↑ PCPs, Cr, Zn
	L. pangusia	Omnivorous	Benthopelagic	↑ total HMs; Cr, As, Pb
	A. punctata	Carnivorous	Demersal	↑ total EDCs; PAHs, OCPs
Highest single-class burden	W. notopterus	Carnivorous	Demersal	↑ OCPs
	M. armatus	Omnivorous	Demersal	↑ Hg
	G. monoceros	Carnivorous	Pelagic	↑ Pb
	W. attu	Carnivorous	Demersal	↑ PAHs, OCPs, PCPs, Steroids
	T. ilisha	Omnivorous	Pelagic-benthic	↑ As, Steroids
Commercially important species	L. rohita	Herbivorous	Benthopelagic	PCPs, EDCs, Pharma
	C. striata	Carnivorous	Benthopelagic	↑ Pharma
	C. mrigala	Omnivorous	Demersal	PAHs, OCPs, Cr, Ni
	L. calbasu	Detritivorous	Demersal	↑ PAHs, organochlorines



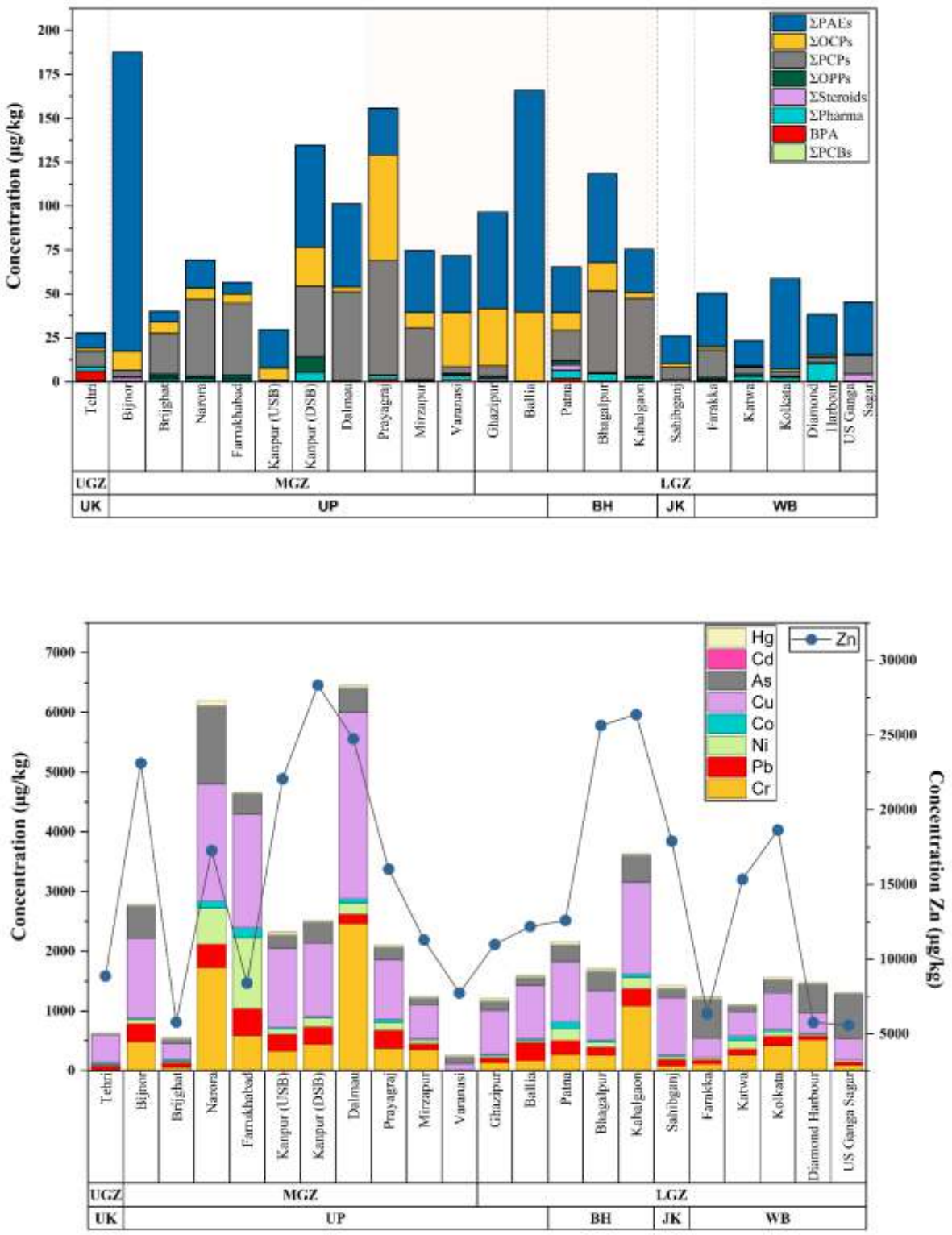


Figure 9.18 Bioaccumulation profiles (µg/kg, wet weight) of (a) Endocrine Disrupting Chemicals (EDCs) and (b) Heavy metals in fish biota across Ganga mainstem.

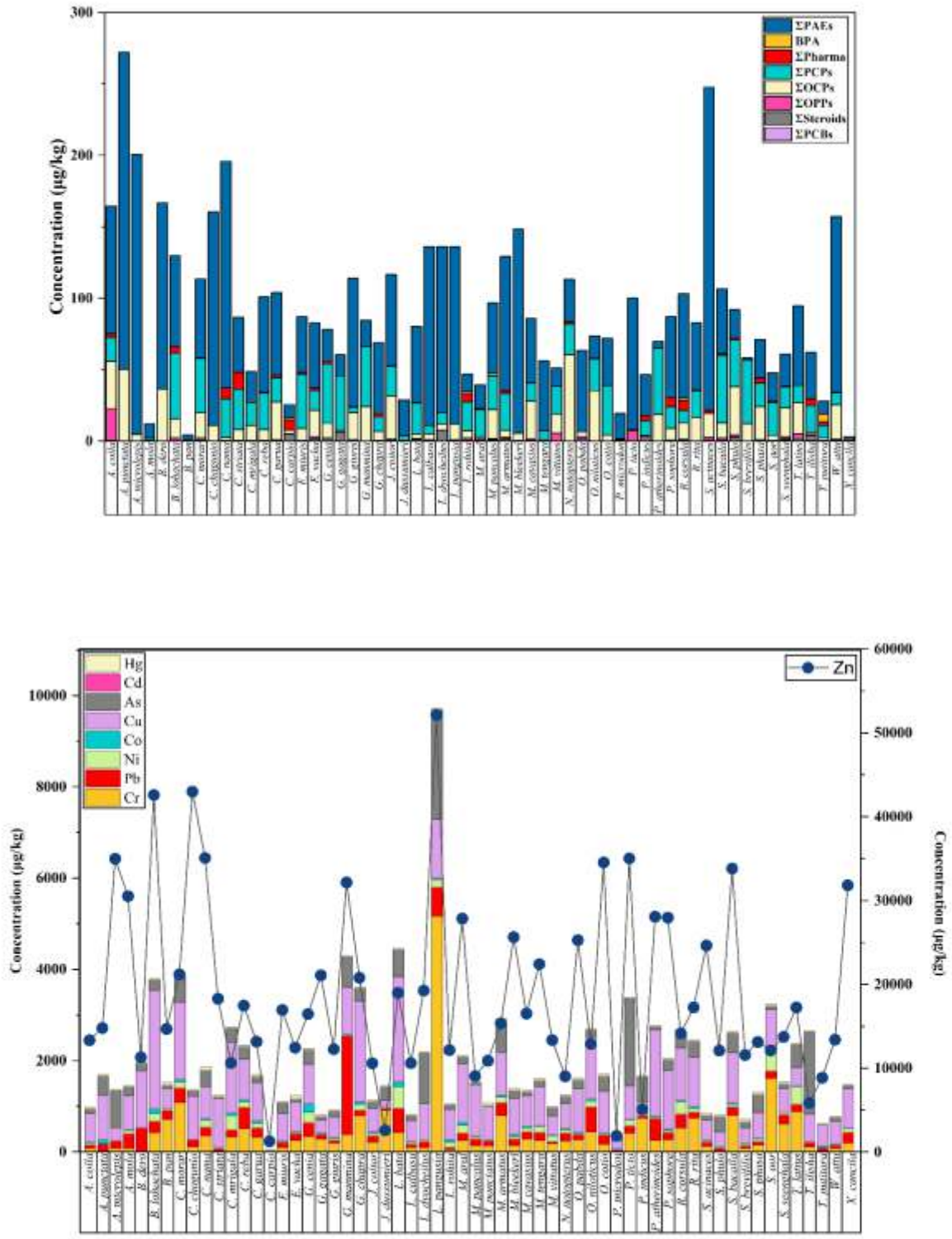


Figure 9.19 Species-specific bioaccumulation profiles (µg/kg, wet weight) of (a) Endocrine Disrupting Chemicals (EDCs) and (b) Heavy metals in fish biota across Ganga mainstem.

9.4 IDENTIFICATION OF THREATS AND POLLUTION HOTSPOT ASSESSMENT

Conventional river monitoring in India relies on single-parameter compliance assessment (BOD, DO, faecal coliform), which fails to capture the cumulative ecological burden at sites exposed to multiple contaminant classes simultaneously. The Ganga Ecological Risk Index (GERI) addresses this limitation by integrating multi-contaminant ecological risk into a single, site-specific, conservation-weighted priority score. Each monitoring station is evaluated across four dimensions: Pollution Severity (GERI score), quantifying the breadth of multi-contaminant ecological risk through weighted ecological Risk Quotient (RQ) > 1 exceedances across eight contaminant groups; Ecological Severity, which amplifies pollution severity by dolphin conservation tier to prioritise locations where contamination intersects with the highest conservation value; Pollutant Signature, identifying the dominant contaminant classes driving risk at each site based on persistence, bioaccumulation, and estrogenic potential; and Toxicity Threshold Diagnostics, which specify the individual analytes responsible, their RQ magnitudes, and their mechanisms of toxicological action (neurotoxicity, estrogenic disruption, chronic organ toxicity), translating each site's GERI score into targeted, actionable intervention prescriptions. Integrating these dimensions, each monitoring site is stratified into four threshold-defined priority categories:

1. CRITICAL: Multiple high-weight contaminant groups at ecological risk within conservation-sensitive habitat. Immediate intervention required.

2. HIGH: Two or more contaminant groups at ecological risk, or single high-weight exceedances amplified by conservation tier. Targeted remediation priority required.

3. MODERATE: Typically, single-compound exceedance. Enhanced monitoring and source control required.

4. MONITORING: No current RQ > 1 exceedances. Routine baseline surveillance required.

Using this classification framework, pollution hotspots are delineated across Ganga River (Figure 9.20).

As the Ganga flows from source to sea, ecological risk escalates progressively along a measurable gradient with 54% Critical+High coverage in the Middle Ganga Zone (Bijnor-Varanasi; 930 km), and 74% in the Lower Ganga Zone (D/S Varanasi-Ganga Sagar; 1,155 km). The downstream half of the river bears the cumulative pollution burden of the entire upstream basin, with the Critical Conservation Corridor (Prayagraj to Bhagalpur), which hosts densest Gangetic dolphin population, falling entirely within the Lower Ganga Zone, the zone of highest ecological stress (Figure 9.21 and Table 9.10).

Six High Biodiversity Zones (HBZ-I to HBZ-VI; 1240 Km) span the river length; HBZ-III (Bithoor to Ghazipur), HBZ-IV (Gandak Confluence to Kosi Confluence record the greatest density of Critical-High pollution hotspots, demanding integrated source-pathway-specific intervention (Figure 9.22 and Table 9.11).

Table 9.11 below translates these findings into a gap-intervention framework for the critically polluted stretches in HBZ, structured by pollution pathway and identifying, for each documented gap, the current intervention status, its point of failure, and the corrective action required with designated institutional accountability. As the implementing authority for pollution abatement across theses stretches rests with State Pollution Control Boards and state-level Programme Management Groups under NMCG, the gap assessment and targeted interventions below are structured by state, with Uttar Pradesh and Bihar addressed separately to enable direct administrative accountability.



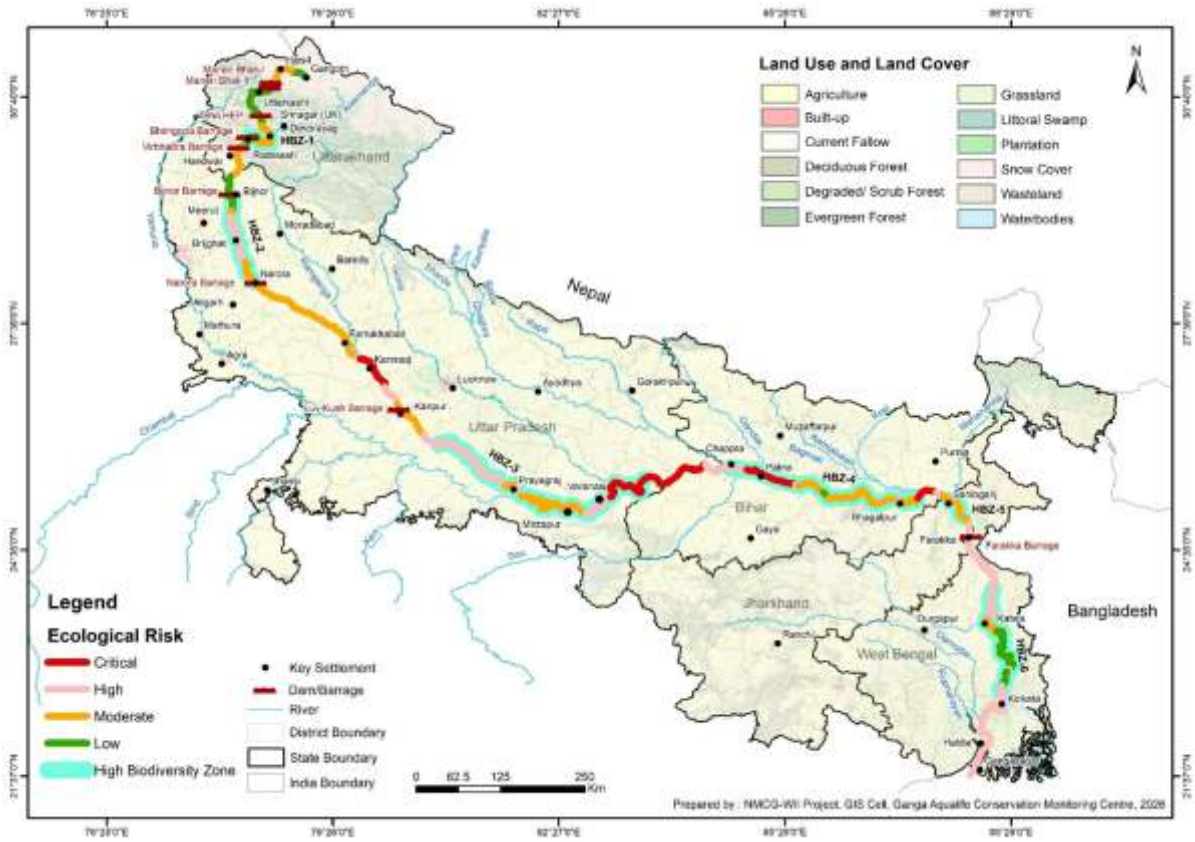


Figure 9.20 Pollution hotspots delineated across Ganga River based on annual mean concentration observed in 2025

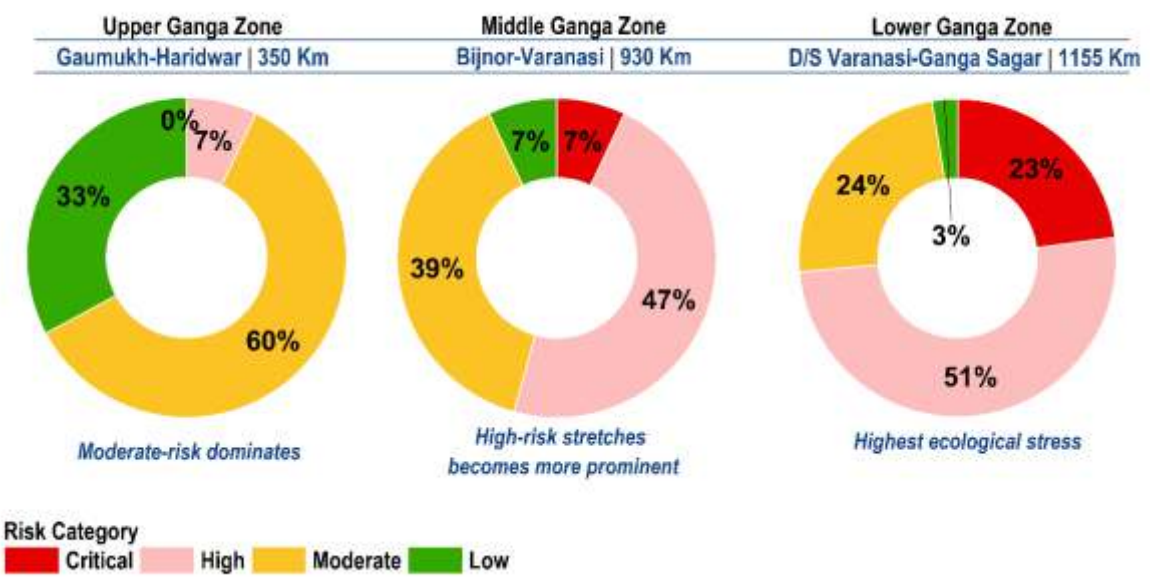


Figure 9.21 Ecological risk distribution across Upper, Middle, and Lower Ganga zones.

Table 9.10 Pollution hotspots and threats across zones along the Ganga.

	Upper Ganga Zone	Middle Ganga Zone	Lower Ganga Zone
Priority Sites	Devprayag, Haridwar	Brighat, Kannauj, Bithoor, Dalmau-Prayagraj, Varanasi	Ganga Confl. (Kaithi) -Gandak Confl. (Patna), Kos Confl (Bhagalpur), Farakka-Ajay Confl (Katwa), Kalyani Ganga Sagar
District	U. Tankashi, Haridwar	Bijnor, Kannauj, Kanpur, Raebareli, Prayagraj, Varanasi	Ghazipur, Ballia, Saran, Patna, Bhagalpur, Murshidabad, Purba Bardhaman, Nadia Kolkata, North 24 Parganas, Howrah East Midnapore, South 24 Parganas
State	U.K	U.P	U.P, BR, W.B
Threats	Hydropower-related sediment mobilisation, Pilgrimage town sewage plastic waste from tourist influx religious offerings	Legacy pesticide, agricultural runoff, perfumery/distillery effluent, Municipal sewage (domestic PVC, medical waste, cosmetics) Pilgrimage town sewage+plastic waste from tourist influx-religious offerings	Tributary-delivered legacy pesticides; Unregulated emerging contaminants (BPA, DEHP, PFI); estuarine tidal remobilisation; port activities/shipping (Diamond Harbour). Copper-based agrochemicals, Livestock and dairy waste, Municipal sewage (domestic PVC, medical waste, cosmetics) - solid waste/landfill leachate - plastic waste

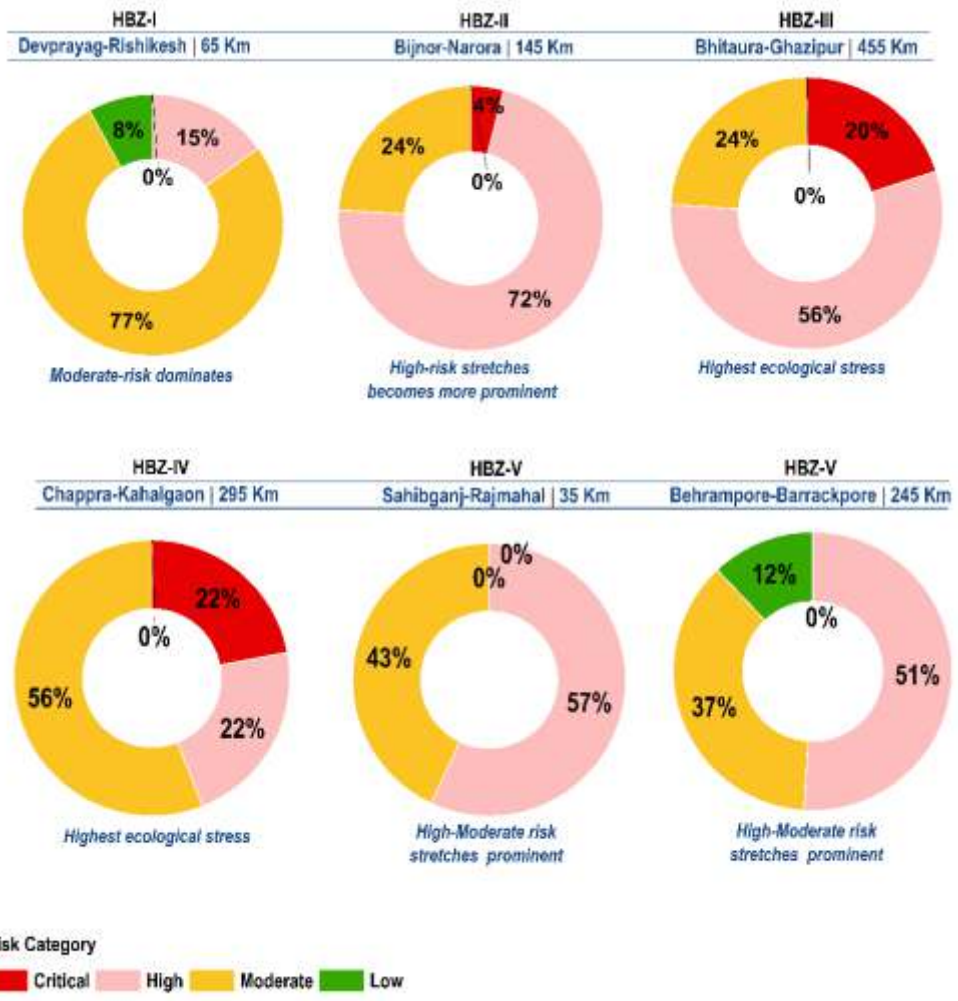


Figure 9.22 Ecological risk distribution across High Biodiversity Zones (HBZ)

Table 9.11 Pollution hotspots across High Biodiversity Zones (HBZ) along the Ganga River

High Biodiversity Zones (HBZ)	Priority Sites	District	State	Threats
BZ-I	Devprayag	Uttarkashi	UK	Site-specific threats are presented in Table 9.12
BZ-II	Brijghat	Bijnor	UP	
BZ-III	Bithoor, Dalmau, Prayagraj, Varanasi, Ghazipur	Kanpur, Raebareli, Prayagraj, Varanasi, Ghazipur	UP	
BZ-IV	Gandak Conf. (Patna), Kosi Confl. (Bhagalpur)	Saran, Patna, Bhagalpur	BH	
BZ-V	Kolaghat		JK	
BZ-VI	Behrampore, Ajay Confl. (Kenwe), Kalyani	Murshidabad, Purba Bardhaman, Nadia	WB	



Table 9.12 Site-specific threats and dominant source categories

Zone	State	District	Station
Upper Ganga Zone	UK	Uttarkashi	Gangotri
Upper Ganga Zone	UK	Uttarkashi	Harsil
Upper Ganga Zone	UK	Uttarkashi	Uttarkashi
Upper Ganga Zone	UK	Uttarkashi	Tehri
Upper Ganga Zone	UK	Uttarkashi	Devprayag
Upper Ganga Zone	UK	Dehradun	Rishikesh
Upper Ganga Zone	UK	Haridwar	Haridwar
Middle Ganga Zone	UP	Bijnor	Bijnor
Middle Ganga Zone	UP	Bijnor	Brij Ghat
Middle Ganga Zone	UP	Bulandshahr	Narora
Middle Ganga Zone	UP	Farrukhabad	Farrukhabad
Middle Ganga Zone	UP	Kannauj	Kannauj
Middle Ganga Zone	UP	Kanpur	Bithoor
Middle Ganga Zone	UP	Kanpur	Kanpur
Middle Ganga Zone	UP	Raebareilly	Dalmau
Middle Ganga Zone	UP	Prayagraj	Prayagraj
Middle Ganga Zone	UP	Mirzapur	Mirzapur
Middle Ganga Zone	UP	Varanasi	Varanasi
Lower Ganga Zone	UP	Varanasi	Gomti Confluence
Lower Ganga Zone	UP	Ghazipur	Ghazipur
Lower Ganga Zone	UP	Ballia	Ballia
Lower Ganga Zone	BH	Saran	Ghaghara Confluence
Lower Ganga Zone	BH	Patna	Gandak Confluence
Lower Ganga Zone	BH	Begusarai	Simariya
Lower Ganga Zone	BH	Bhagalpur	Sultanganj
Lower Ganga Zone	BH	Bhagalpur	Kahalgoan
Lower Ganga Zone	BH	Bhagalpur	Kosi Confluence
Lower Ganga Zone	JK	Sahibganj	Sahibganj
Lower Ganga Zone	WB	Murshidabad	Farakka
Lower Ganga Zone	WB	Murshidabad	Behrampore
Lower Ganga Zone	WB	Purba Bardhaman	Ajay Confluence
Lower Ganga Zone	WB	Nadia	Nabdwip
Lower Ganga Zone	WB	Nadia	Kalyani
Lower Ganga Zone	WB	Kolkata	Kolkata
Lower Ganga Zone	BH	Saran	Ghaghara Confluence

Dominant Source Categories
Geogenic mineralisation from Himalayan headwater geology (Cu-Cr bearing formations in the Greater Himalayan Sequence); glacial meltwater leaching of trace metals from exposed rock faces; minor contribution
Hydropower/mining-related metallic contamination, plastic waste from pilgrimage infrastructure
Hydropower-related sediment mobilisation, pilgrimage town sewage
Pilgrimage town sewage
Pilgrimage town sewage+plastic waste from tourist influx+religious offerings+Industrial settlements
Agricultural runoff
Industrial effluent (Ghaziabad-Meerut corridor), legacy pesticide, plastic waste, agricultural runoff
Thermal/industrial effluent (D/S Narora Atomic Power Station), agricultural runoff
Agricultural runoff
Legacy pesticide, agricultural runoff, pharmaceutical sewage discharge, perfumery/distillery effluent, Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Industrial effluent, Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Industrial effluent, Municipal sewage + solid waste/landfill leachate + plastic waste
Municipal sewage, pharmaceutical discharge, agricultural runoff
Municipal sewage (Kumbh/Magh Mela episodic load), agricultural runoff
Pharmaceutical/sewage discharge, agricultural runoff, carpet industry effluent
Industrial effluent, plastic waste, pharmaceutical/sewage discharge, cremation ghat runoff, Anti-fouling paints on fishing boats
Legacy pesticide (illegal use/vector control), agricultural runoff, industrial effluent, Municipal sewage
Untreated municipal sewage (E2 + Caffeine as sewage markers + domestic PVC, medical waste, cosmetics + solid waste/landfill leachate + plastic waste), pharmaceutical discharge, agricultural runoff, plastic waste
Municipal sewage, plastic waste, agricultural runoff
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Agricultural runoff, Copper-based agrochemicals, Livestock and dairy waste, Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate, agricultural runoff
Plastic waste
Plastic waste, agricultural runoff (extreme Chlorpyrifos RQ = 98.46)
Municipal sewage, plastic waste, industrial effluent
Legacy pesticide, agricultural runoff
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Municipal sewage+ solid waste/landfill leachate + plastic waste
Agricultural runoff, Copper-based agrochemicals, Livestock and dairy waste, Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate, agricultural runoff
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Urban plastic waste, Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachateLower Ganga ZoneUPBalliaBalliaMunicipal sewage, plastic waste, agricultural runoff
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste

Zone	State	District	Station
Lower Ganga Zone	BH	Patna	Gandak Confluence
Lower Ganga Zone	BH	Begusarai	Simariya
Lower Ganga Zone	BH	Bhagalpur	Sultanganj
Lower Ganga Zone	BH	Bhagalpur	Kahalgoan
Lower Ganga Zone	BH	Bhagalpur	Kosi Confluence
Lower Ganga Zone	JK	Sahibganj	Sahibganj
Lower Ganga Zone	WB	Murshidabad	Farakka
Lower Ganga Zone	WB	Murshidabad	Behrampore
Lower Ganga Zone	WB	Purba Bardhaman	Ajay Confluence
Lower Ganga Zone	WB	Nadia	Nabdwip
Lower Ganga Zone	WB	Nadia	Kalyani
Lower Ganga Zone	WB	Kolkata	Kolkata
Lower Ganga Zone	WB	North 24 Parganas	Dakshineshwar
Lower Ganga Zone	WB	Howrah	Damodar Confluence
Lower Ganga Zone	WB	East Midnapore	Rupnarayan Confluence
Lower Ganga Zone	WB	South 24 Parganas	Diamond Harbour
Lower Ganga Zone	WB	South 24 Parganas	Ganga Sagar



Dominant Source Categories
Agricultural runoff, Copper-based agrochemicals, Livestock and dairy waste, Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate, agricultural runoff
Plastic waste
Plastic waste, agricultural runoff (extreme Chlorpyrifos RQ = 98.46)
Municipal sewage, plastic waste, industrial effluent
Legacy pesticide, agricultural runoff
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Municipal sewage+ solid waste/landfill leachate + plastic waste
Agricultural runoff, Copper-based agrochemicals, Livestock and dairy waste, Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate, agricultural runoff
Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate + plastic waste
Urban plastic waste, Municipal sewage (domestic PVC, medical waste, cosmetics) + solid waste/landfill leachate
Plastic waste, untreated sewage (Caffeine as raw sewage marker)
Industrial effluent (Damodar valley industrial belt), plastic waste
Industrial effluent (thermal power plant), plastic waste
Port and shipping activity (anti-fouling paint leaching, ship repair/maintenance, hull scraping, port infrastructure corrosion), plastic waste, estuarine tidal remobilisation of legacy sediment Cu
Industrial effluent, Municipal sewage+ solid waste/landfill leachate + plastic waste, estuarine tidal remobilisation



Table 9.13 Gap Assessment and Targeted Interventions for the Critical Ecological Risk Stretches (Bihar and Uttar Pradesh)

State	Key Gaps
Point Pollution Sources: Gap Assessment and Targeted Interventions for the Critical Pollution Hotspots (Bihar and Uttar Pradesh)	
Uttar Pradesh (Brijghat-Ballia)	• STP Capacity Utilization and Treatment Gap: 1,303 MLD installed STP capacity and 1,105.2 MLD utilized capacity, still exhibits a treatment gap of 150 MLD (12%) • Regulatory non-compliance STPs (pre-March, 2024): 40 STPs employing diverse technologies (primarily SBR, ASP, and UASB) are in place, treatment performance remains sub-optimal, with only 6 STPs achieving >90% BOD removal efficiency and the majority operating below this threshold. Significant non-compliance (32 STPs with NGT norms and 22 failing faecal coliform standards), highlighting the need for improved operational efficiency and compliance under NMCG. • Drains Outfalls classified as "tapped" or "partially tapped" continue to discharge significant residual organic loads. Priority polluting drains include, Permiya Nala (Kanpur), City Jail Drain (Unnao), Rasoolabad Drain (Prayagraj), Nagwa Drain (Varanasi), Varuna (Varanasi), Railway Drain (Mughal Sarai)
Bihar (Buxar-Kosi Confluence)	• Regulatory non-compliance STPs (pre-March): 8 (5 NGT, 1 MoEFCC, 2 coliform) • Operations & Maintenance Crisis: Sewer network connectivity remains incomplete. Bihar's SBR plants are identical in design to those in Jharkhand, where they achieve ?70% BOD removal. Yet 71% of Bihar's SBRs fail below 50%. The delta between these two states is not engineering, it is operator accountability, power supply reliability, and maintenance budgets. • Sultanganj STP (10 MLD, MBBR) plant is non-compliant on four parameters simultaneously (COD, TSS, TN, TP) at only 50-70% BOD removal efficiency, indicating systemic process dysfunction. • Not a single STP in states employs any advanced tertiary/quaternary

Current Interventions, & Status	Proposed Intervention
7 STPs Under Progress including 3 in Prayagraj (Rajapur - 90 MLD; Naini - 50 MLD; Salori -40 MLD); 1 in Varanasi (55 MLD) ans 1 in Unnao (5 MLD). 9 are under Tendering across the Ganga towns in Uttar Pradesh A state-of-the-art 10 MLD STP at Varanasi employing A2O (Anaerobic-Anoxic-Oxic) technology has been commissioned, incorporating advanced secondary treatment systems to ensure compliant effluent discharge into the Ganga. Drain tapping and interception is the primary strategy under Namami Gange. Out of 118 identified drains across the Prayagraj-Ballia stretch, 63 have been tapped by 2023, leaving 55 drains still discharging untreated or partially treated sewage into the Ganga and its tributaries. In-situ bioremediation (dosing of bacterial cultures directly into drain flow) and ex-situ remediation (diversion to treatment before river entry) have been deployed at priority drains in Prayagraj and Varanasi.	• For STP Capacity Utilization, Treatment Gap & Regulatory non-compliance STPs: (1) Performance-based STP contracts: Convert existing O&M contracts to outcome-linked payments. STP operators paid only when effluent meets compliance norms. Penalty for non-compliance, bonus for exceeding standards. Apply to all 40 operational STPs. (2) Tertiary treatment retrofitting: Add UV/chlorination disinfection to all STPs failing FC standards (3) Real-time STP effluent monitoring: Install continuous online monitoring systems (OCEMS) at all STP outfalls linked to CPCB/UPPCB dashboard as non-compliant discharge triggers automatic regulatory action. (4) Independent third-party STP performance audits, quarterly, not annual, with public disclosure of results. For Drains Outfalls: • Priority drain-wise action plans for all untapped/partially tapped drains from Prayagraj to Ballia each drain gets a dedicated interception, diversion, and treatment solution with timeline. Separate stormwater and sewage systems • Tributary restoration of Varuna and Assi: Restore ecological function through dedicated sewage interception + riparian restoration + constructed wetland treatment at each drain-tributary confluence. • Residual drain treatment using nature-based solutions: For partially tapped drains with residual organic loads, deploy constructed wetland polishing at drain outfalls as demonstrated under Namami Gange at Kanpur. • Interim decentralised treatment for unconnected areas: Deploy DEWATS and community septic tank + constructed wetland systems in wards not reachable by trunk sewers within 3 years - don't wait for full sewer coverage. Lead Agency/Supporting Agencies: UP Jal Nigam, CPCB/SPCB.
• Total STPs: 26 (16 operational; 8 under progress; 2 under tendering) • Current interventions & status (Jan, 2026): • Bhagalpur: 43 drains outfalling into River Ganga intercepted and diverted to a 45 MLD STP. • Sultanganj: A 10 MLD STP intercepting 5 drains has been completed, and is presently under O&M. • Naugachia: A 9 MLD STP tapping 6 drains completed but operationalisation pending. • Kahalgaon: A 6 MLD STP intercepting 5 drains is	• Emergency compliance order: BSPCB to issue time-bound enforcement notice to Sultanganj STP operator: 90-day mandatory remediation for COD, TSS, TN, TP; financial penalty under EP Act 1986 for non-compliance. Lead Agency/Supporting Agencies: CPCB/ BSPCB. Naugachia STP operationalisation: NMCG / Bihar SPMG to commission the completed 9 MLD plant within 60 days; O&M contract to be awarded immediately. Lead Agency/Supporting Agencies: NMCG / Bihar SPMG Interim polishing measure: temporary constructed

State	Key Gaps
Bihar (Buxar-Kosi Confluence)	treatment process capable of removing emerging contaminants (pharmaceuticals, EDCs, microplastics, PFAs) • Lack of flood-resilient STP design mandates in a 73% flood-prone state, causing recurring plant shutdowns • Sewer network connectivity: Investments primarily concentrated in urban centres with centralized STPs serve only urban nodes. •

Diffuse Pollution Sources: Gap Assessment and Targeted Interventions for the Critical Pollution Hotspots (Bihar and Uttar Pradesh)

Agricultural Run-offs	
Uttar Pradesh (Prayagraj-Ballia)	• Intensive sugarcane-wheat-rice cultivation across UP. • Cultivation extends to immediate waterline on Ganga diara lands particularly in Varanasi, Prayagraj, Mirzapur, Ghazipur, Ballia districts. Eliminates natural riparian biofiltration. Sugarcane, UP's dominant crop, is water and chemical intensive, exacerbating runoff during monsoon flood irrigation. Extensive cultivation of cucurbits in dry-river beds/diara •

Current Interventions, & Status	Proposed Intervention
under implementation with ~77% physical progress.	wetland or aerated lagoon downstream of Sultanganj STP to provide supplementary treatment during plant remediation. Lead Agency/Supporting Agencies: NMCG / Bihar SPMG + implementing agency 1. Given the estrogenic load profile between Sultanganj and Kosi Confluence (CCC), tertiary treatment upgrades at Patna, Sultanganj, and Bhagalpur STPs are warranted but cannot be responsibly specified without an underlying evidence base. It is recommended to commission, as an immediate priority, a structured technical assessment comprising: 2. EDC effluent characterisation at the three STPs to establish facility-specific estrogenic load contributions; 3. assessment of the assimilative capacity of the Sultanganj-Kosi Confluence reach to determine the effluent quality standards required at each facility to protect downstream river water quality; and 4. retrofit feasibility assessment for tertiary oxidation at each plant. Outcomes should directly inform facility-specific treatment standards and an enforceable compliance timeline. • Existing centralised STPs need urgent flood-proofing: flood walls, submersible pumps, elevated electrical rooms. Future STPs must be sited above the highest flood level, the current practice of siting near the river for gravity inflow guarantees repeated monsoon shutdowns. • Buxar-Kosi stretch has ~89% rural population. Scientific and technical flood resilient abatement strategies specifically suited for the rural-dominant settlements along this corridor, where grid electricity is unreliable and institutional capacity is limited, is presented in Table 9.14: Lead Agency/Supporting Agencies: NMCG /CPCB & Bihar SPMG
• NMCG organic farming corridor initiated 2020. 75 Ganga Sahakar Grams announced (MoU with Shakar Bharati, Aug 2022) for natural farming promotion. NMCG promoting Zero Budget Natural Farming using Gobar Dhan (cow dung-based manure). Organic corridor relies entirely on voluntary adoption. No financial integration or technological mandate to shift large-scale commercial sugarcane and wheat farming away from synthetic inputs. UP Agriculture Department listed as implementing agency but lacks convergence with UPPCB or NMCG water quality	• Expand organic zone from 5 km linear buffer to sub-basin approach include tributary catchments (Yamuna, Gomti, Ramganga) where agrochemical loads originate. 1,140 km frontage demands watershed-level planning, not roadside buffer. Scale target from 25% to 50% chemical-free villages by 2028 with performance-linked funding. Lead Agency/Supporting Agencies: UP Agriculture Department (Directorate of Agriculture)/ NMCG (Arth Ganga funding). SMCG-UP (State Mission for Clean Ganga-UP's NMCG implementing arm). District Agriculture

State	Key Gaps
Diffuse Pollution Sources: Gap Assessment and Targeted Interventions for the Critical Pollution Hotspots (Bihar and Uttar Pradesh)	
Agricultural Run-offs	
Uttar Pradesh (Prayagraj-Ballia)	Soil Health Card (SHC) remains advisory. No linkage to subsidy disbursement. Farmers apply far above SHC-recommended doses. Excess nitrogen and phosphorus drive eutrophication in Ganga. • No constructed wetland or riparian buffer has been specifically designed, piloted, or documented for UP's sugarcane-dominated floodplain agriculture. • Inadequate bio-input supply and IPM infrastructure at scale. Small and marginal farmers in UP and Bihar lack knowledge or resources to adopt Integrated Pest Management. Agricultural extension service coverage in UP's Ganga belt is low relative to the scale of chemical input use. Bio-pesticides available but ineffective against key pests (sugarcane borers, brinjal shoot borers) without site-specific protocols. • Lack of Diffuse Pollution Tracking (Uttar Pradesh & Bihar):

Current Interventions, & Status	Proposed Intervention
targets. River Regulation Zone (2002) aims to regulate floodplain activities. remains largely unimplemented. No differentiation between permanent and seasonal riverbed land in any scheme. • Soil Health Cards distributed but not enforced. NMCG forestry interventions ongoing through UP Forest Department but designed for afforestation, not agrochemical interception. UP has denser KVK network along Ganga than Bihar. IIVR Varanasi provides vegetable IPM protocols. UP State Bio-pesticide Laboratory at Lucknow exists. But coverage to Ganga corridor diara and floodplain farmers remains negligible against the volume of conventional agrochemical use. ATMA extension services stretched thin. CPCB operates real-time water quality monitoring stations on Ganga but all stations measure conventional parameters (pH, DO, BOD, turbidity, fecal coliform). No pesticide, nutrient loading, or agrochemical parameter is included in real-time monitoring.	Officers in 27 Ganga-front districts. • Mandatory prohibition of chemical pesticides/herbicides on all diara/riverbed cultivation. Implement River Regulation Zone (2002) to restrict chemical-intensive cultivation within 500m of waterline on exposed riverbeds. Incentivise shift from sugarcane to cucurbits/vegetables on diara lands, transition payment funded through sugar mill cess. UP Revenue Department's existing diara/khadar land classification in revenue records enables enforcement. Lead Agency/Supporting Agencies: UP Revenue Department (diara land identification and compliance mapping). UPPCB (ecologically sensitive zone notification)/ UP Agriculture Department (transition incentive design). UP Sugar Industry and Directorate of Sugar (sugar mill cess mechanism). ICAR-Indian Institute of Sugarcane Research, Lucknow (sugarcane-to-cucurbit transition protocols). District Ganga Committees (cross-departmental coordination). • Transform SHC from advisory to accountability instrument: cap subsidised fertiliser quantity to SHC-recommended dose at point-of-sale. UP Cooperative Federation retailers to verify SHC before dispensing subsidised urea/DAP. Pilot in 5 Ganga-front districts (Varanasi, Prayagraj, Kanpur, Mirzapur, Ballia) before statewide rollout. UP's political weight can drive the central policy amendment needed. Phased: Year 1 advisory with farmer education, Year 2 mandatory with subsidy conditionality. Lead Agency/Supporting Agencies: Department of Fertilisers (GoI) for central policy amendment. UP Agriculture Department for state-level implementation/ UP Cooperative Federation (point-of-sale enforcement). SHC portal administrators. District Agriculture Officers (farmer education and grievance redressal). PM-KISAN DBT infrastructure (conditionality linkage). • Build a "Full-Spectrum Interception Chain" as detailed in Table 9.15: Lead Agency/Supporting Agencies: NMCG (design and fund) State Forest Department, Bihar Rural Works Department (drain infrastructure), Gram Panchayats (O&M) • Deploy KVK block-level bio-input production units across all 27 Ganga-front districts. IIVR Varanasi to develop corridor-specific IPM protocols for sugarcane, rice, and cucurbit systems. Convergence with PMFME (PM Formalisation of Micro Food Processing Enterprises) for bio-input micro-enterprises run by SHGs. Scale Trichoderma,

State	Key Gaps
Diffuse Pollution Sources: Gap Assessment and Targeted Interventions for the Critical Pollution Hotspots (Bihar and Uttar Pradesh)	
Agricultural Run-offs	
Uttar Pradesh (Prayagraj-Ballia)	

Current Interventions, & Status	Proposed Intervention
	Pseudomonas, neem formulations through UP Cooperative Federation retail network, point-of-sale integration. Lead Agency/Supporting Agencies: ICAR-KVKs in UP Ganga districts/ ATMA (farmer training and field school delivery). ICAR-IIVR Varanasi (vegetable/cucurbit IPM). ICAR-IISR Lucknow (sugarcane IPM). UP State Bio-pesticide Laboratory. UP Cooperative Federation. Pradhan Mantri Formalisation of Micro Food Processing Enterprises District Resource Persons. · Farmer awareness & community engagement: Launch IEC campaigns in corridor districts about dangers of pesticides, benefits of organics, and train farmer groups to self-monitor compliance. Encourage Watershed Committees. Lead Agency/Supporting Agencies: District Ganga Committees/ KVKs, ATMA, Watershed Committees, NGOs · Expand organic zone from 5 km linear buffer to sub-basin approach include tributary catchments (Yamuna, Gomti, Ramganga) where agrochemical loads originate. 1,140 km frontage demands watershed-level planning, not roadside buffer. Scale target from 25% to 50% chemical-free villages by 2028 with performance-linked funding. Lead Agency/Supporting Agencies: UP Agriculture Department (Directorate of Agriculture)/ NMCG (Arth Ganga funding). SMCG-UP (State Mission for Clean Ganga-UP's NMCG implementing arm). District Agriculture Officers in 27 Ganga-front districts. · Mandatory prohibition of chemical pesticides/herbicides on all diara/riverbed cultivation. Implement River Regulation Zone (2002) to restrict chemical-intensive cultivation within 500m of waterline on exposed riverbeds. Incentivise shift from sugarcane to cucurbits/vegetables on diara lands, transition payment funded through sugar mill cess. UP Revenue Department's existing diara/khadar land classification in revenue records enables enforcement. Lead Agency/Supporting Agencies: UP Revenue Department (diara land identification and compliance mapping). UPPCB (ecologically sensitive zone notification)/ UP Agriculture Department (transition incentive design). UP Sugar Industry and Directorate of Sugar (sugar mill cess mechanism). ICAR-Indian Institute of Sugarcane Research, Lucknow (sugarcane-to-cucurbit transition protocols). District Ganga Committees (cross-departmental coordination)

State	Key Gaps
Diffuse Pollution Sources: Gap Assessment and Targeted Interventions for the Critical Pollution Hotspots (Bihar and Uttar Pradesh)	
Agricultural Run-offs	
Uttar Pradesh (Prayagraj-Ballia)	

Current Interventions, & Status	Proposed Intervention
	• Transform SHC from advisory to accountability instrument: cap subsidised fertiliser quantity to SHC-recommended dose at point-of-sale. UP Cooperative Federation retailers to verify SHC before dispensing subsidised urea/DAP. Pilot in 5 Ganga-front districts (Varanasi, Prayagraj, Kanpur, Mirzapur, Ballia) before statewide rollout. UP's political weight can drive the central policy amendment needed. Phased: Year 1 advisory with farmer education, Year 2 mandatory with subsidy conditionality. *Lead Agency/Supporting Agencies:* Department of Fertilisers (GoI) for central policy amendment. UP Agriculture Department for state-level implementation/ UP Cooperative Federation (point-of-sale enforcement). SHC portal administrators. District Agriculture Officers (farmer education and grievance redressal). PM-KISAN DBT infrastructure (conditionality linkage). • Build a "Full-Spectrum Interception Chain" as detailed in Table 9.15: • Lead Agency/Supporting Agencies: NMCG (design and fund) State Forest Department, Bihar Rural Works Department (drain infrastructure), Gram Panchayats (O&M) • Deploy KVK block-level bio-input production units across all 27 Ganga-front districts. IIVR Varanasi to develop corridor-specific IPM protocols for sugarcane, rice, and cucurbit systems. Convergence with PMFME (PM Formalisation of Micro Food Processing Enterprises) for bio-input micro-enterprises run by SHGs. Scale Trichoderma, Pseudomonas, neem formulations through UP Cooperative Federation retail network, point-of-sale integration. Lead Agency/Supporting Agencies: ICAR-KVKs in UP Ganga districts/ ATMA (farmer training and field school delivery). ICAR-IIVR Varanasi (vegetable/cucurbit IPM). ICAR-IISR Lucknow (sugarcane IPM). UP State Bio-pesticide Laboratory. UP Cooperative Federation. Pradhan Mantri Formalisation of Micro Food Processing Enterprises District Resource Persons. • o Farmer awareness & community engagement: Launch IEC campaigns in corridor districts about dangers of pesticides, benefits of organics, and train farmer groups to self-monitor compliance. Encourage Watershed Committees. Lead Agency/Supporting Agencies: District Ganga Committees/ KVKs, ATMA, Watershed Committees, NGOs

State	Key Gaps
Diffuse Pollution Sources: Gap Assessment and Targeted Interventions for the Critical Pollution Hotspots (Bihar and Uttar Pradesh)	
Agricultural Run-offs	
Uttar Pradesh (Prayagraj-Ballia)	

Current Interventions, & Status	Proposed Intervention
	1) Establish agri-runoff monitoring stations at all major tributary confluences (Son-Ganga, Punpun-Ganga, Gandak-Ganga, Burhi Gandak-Ganga, Kosi-Ganga, Ganga-Gomti, Ganga-Ghaghra, Ganga Yamuna confluence), measuring total N, total P, pesticide residues, EOCs, sediment, microplastics. (2) Integrate nutrient and agrochemical parameters into CPCB Phase II stations across the Conservation Critical Corridor in UP and Bihar. (3) Commission canal return flow monitoring, UP Irrigation Department to install water quality sensors at all major canal tail-ends and return flow outfalls. This is a nationally unique opportunity: canal return flows are concentrated, measurable discharge points for diffuse agricultural pollution far easier to monitor and treat than sheet-flow runoff. (4) Commission bi-annual sediment and shallow groundwater agrochemical audits across diara and tal lands, baseline needed before any intervention can be evaluated (5) Deploy IoT/LoRaWAN nutrient sensors at agricultural drain outfalls (6) Develop sub-basin Diffuse Source Pollution Index for each major tributary, enabling source apportionment between industrial, urban sewage, and agricultural contributions. Lead Agency/Supporting Agencies: CPCB (national monitoring protocol development and integration into Phase II stations) SPCB (state-level routine monitoring and EOC institutionalisation)./ State Irrigation Department, UP Jal Nigam ICAR-IARI Regional Station (agrochemical residue analysis). IIT-BHU Varanasi, IIT Kanpur, NIT Patna (IoT sensor deployment and source apportionment modelling). State Agriculture Department (farm input data for fertiliser sales, crop type by district). State Revenue Department (land use mapping for monitoring site selection). NMCG (funding under Gyan Ganga). NABL-accredited labs at Lucknow, Varanasi, Prayagraj (analytical capacity), Patna. District Ganga Committees (coordination). SMCG-UP

State	Key Gaps
Diffuse Pollution Sources: Gap Assessment and Targeted Interventions for the Critical Pollution Hotspots (Bihar and Uttar Pradesh)	
Agricultural Run-offs	
Bihar (Buxar-Kosi Confluence)	• Intensive, unregulated application of toxic pesticides on Diara and Tal lands leading to acute, diffuse toxic runoff during monsoonal "first flush" from the surrounding extensive paddy, wheat and maize cultivation. • Cultivation extends to the immediate waterline, eradicating natural riparian vegetation, eliminating bio-filtration, and accelerating toxic soil erosion. • Major tributary catchments (Kosi/Gandak/Ghaghra) and monsoon-runoff continually reintroduce pesticides into the Ganga. Organic buffers on riverbanks cannot stop this flood-driven contamination. • No constructed wetland or riparian buffer has been specifically designed, piloted, or documented for Bihar's flood-prone Ganga stretch, a critical gap given that Bihar has India's largest floodplain wetland area (209,000 hectares) and its STPs consistently fail to meet faecal coliform standards • Lack of Diffuse Pollution Tracking (as described above)

Current Interventions, & Status	Proposed Intervention
• Establishment of organic corridors schemes along the Ganga in Patna, Buxar, Bhojpur, Saran, Vaishali, Samastipur, Khagaria, Begusarai, Lakhisarai, Bhagalpur, Munger, Katihar and Nalanda located on the banks of river Ganga. The scheme has shown mixed results. Relies entirely on voluntary adoption; lacks the financial integration and technological mandate to shift large-scale commercial agriculture away from synthetic inputs. Other core issues include limited scale of organic zones, persistent use of agrochemicals driven by yield concerns, market failures for organic produce, and insufficient monitoring.	• Expand and diversify organic zone: Extend support beyond 500m bank (e.g. up to 3 km in targeted areas, and include key tributary catchments). *Lead Agency/Supporting Agencies:* Bihar State Agriculture Department (Directorate of Agriculture)/ NMCG, District Agriculture Officers, KVKs • Strengthen market linkages: Create an "Organic Ganga" brand with assured procurement (e.g. via government institutions, eNAM (National Agriculture Markets) mandis, tie-ups with retailers/processors) to ensure price premium. *Lead Agency/Supporting Agencies:* Ministry of Agriculture (eNAM integration)/ APEDA, State Agricultural Marketing Board, FPOs • Improve local bio-input supply & IPM support *Lead Agency/Supporting Agencies:* ICAR-KVKs (Krishi Vigyan Kendras) in corridor districts/ ATMA (Agricultural Technology Management Agency), State Bio-pesticide Labs • Enhance certification & enforcement by linking corridor subsidies to third-party organic certification; implement random residue testing of produce. Penalize chemical use in corridors (e.g. zero-spray buffer zones with fines). *Lead Agency/Supporting Agencies:* BSPCB + Agriculture Department jointly/ FSSAI, Accredited certification bodies • Farmer awareness & community engagement: Launch IEC campaigns in corridor districts about dangers of pesticides, benefits of organics, and train farmer groups to self-monitor compliance. Encourage Watershed Committees. *Lead Agency/Supporting Agencies:* District Ganga Committees/ KVKs, ATMA, Watershed Committees, NGOs • Linkage of fertiliser subsidy disbursement to soil health card-based nutrient recommendations. • Lead Agency/Supporting Agencies: Department of Fertilisers (GoI) + State Agriculture Dept/ Soil Health Card portal, fertiliser retailers • Design and implementation of a payment-for-ecosystem-services mechanism for upstream agricultural nutrient management. *Lead Agency/Supporting Agencies: NMCG (design and fund)*/ State Finance Department, Gram Panchayats • Link farm subsidies directly to environmental compliance via "Cross-Compliance". Lead Agency/Supporting Agencies: *Ministry of Agriculture + MoEFCC jointly/ BSPCB, District Agriculture Officers* • Build a “Full-Spectrum Interception Chain” as detailed in Table 9.15.

State	Key Gaps
Diffuse Pollution Sources: Gap Assessment and Targeted Interventions for the Critical Pollution Hotspots (Bihar and Uttar Pradesh)	
Agricultural Run-offs	
Bihar (Buxar-Kosi Confluence)	
Diffuse & Point Sources (Plastic Waste):	
Brijghat to Kosi Confluence	Uttar Pradesh: infrastructure exists but leakage persists UP generates 375,950 TPA. 514 Material Recovery Facility (MRF) across 514 ULBs (2,575 TPD capacity). 89 recycling/co-processing facilities. 834,790 SUP challans and ₹1.3 Cr penalties issued (Jul-Dec 2022). But enforcement is entirely urban. Bihar: infrastructure missing + leakage extreme Bihar generates 53,232 TPA of plastic waste. 63,474 tons sent directly to landfills. Only 18 registered recyclers. Zero advanced co-processing. Floodplain litter densities 28× higher than shorelines. Rural domestic macro-plastic (packaging, SUP, sachets, disposables): Floodplain litter densities 28× higher than shorelines. 10-25% of all generated plastic is littered and not routed to recycling (UNEP CounterMEASURE). Packaging debris = 43% of total observed river debris. Lack of rural solid/plastics waste collection . Diffuse Agricultural Plastic Runoff: Widespread use of plastic mulch, polymer-coated agrochemicals, and improper disposal of pesticide packaging directly on rural floodplains leading to microplastic contamination. · Flood-Driven Contaminant Flushing: Uttar Pradesh: Ganga floods affect Ballia, Ghazipur, Varanasi, Prayagraj districts annually. Lower flood extent than Bihar Bihar: 73% of state area flood-affected. Floodplain settlements generate more plastics waste than shorelines Post-monsoon plastics spike confirms floods as primary transport mechanism.

Current Interventions, & Status	Proposed Intervention
	Lead Agency/Supporting Agencies: NMCG (design and fund) State Forest Department (vetiver), Bihar Rural Works Department (drain infrastructure), Gram Panchayats (O&M)
	.
Uttar Pradesh Plastic waste used in road construction (100 tons) in major cities. Ganga Gram three-bin pilots at drain outfalls. 834,790 challans signal massive non-compliance, not success. Rural areas completely unserved despite urban infrastructure build-out.	Uttar Pradesh Route macro-plastics from river trash skimmers and floodplain sweeps into existing cement kiln co-processing network (48 units, 33,705 MT disposed). Decentralise SUP ban enforcement to Panchayat level. *Institutional Mechanism:* ULBs extend MRF coverage to peri-urban/rural clusters. Panchayats empowered for SUP enforcement with penalty-retention incentive.
Bihar 141 ULBs submit PWM reports; SUP ban notified (2018/2021) but rural enforcement absent. 102 producers and 6 recyclers issued violation notices. No rural MRFs. No co-processing infrastructure. Waste data likely excludes rural areas entirely; 87% collection efficiency figure reflects ULBs only.	Bihar Link rural MRFs with regional cement kilns (Dalmia, UltraTech have Bihar plants) for co-processing. Establish block-level plastic buy-back centres. Enforce EPR on identified brand owners. Crack down on illegal SUP distribution in floodplain villages. *Institutional Mechanism:* District Ganga Committees + BSPCB joint enforcement. SHG-run MRFs for livelihood linkage.
Swachh Bharat Mission Phase II (rural component) mandates Solid and Liquid Waste Management in designated Ganga villages, but lacks specific protocols targeting agricultural plastics in both states. No Extended Producer Responsibility coverage exists for agrochemical packaging at the national level.	Introduce EPR mandate for agrochemical packaging (amend PWM Rules 2024), applicable to both states. Establish dedicated agricultural plastic drop-off hubs at Panchayat level. Promote biodegradable mulch alternatives. ICAR-KVK extension network for farmer awareness *Institutional Mechanism:* State Agriculture Departments + SPCBs joint enforcement. ICAR-KVK as extension arm. Agrochemical manufacturers bear collection cost under EPR. National-level amendment needed from MoEFCC.
NMCG trash skimmers operate only within urban municipal limits in both states. Skimmers capture floating macro-plastics after river entry, not prevention. No pre-monsoon floodplain cleaning protocol in either state	Extend skimmer deployment to rural ghat clusters. Uttar Pradesh: Leverage existing 514-MRF network for post-collection processing. Bihar: larger flood area, weaker infrastructure. Mandate pre-monsoon plastic cleanup across diara and tal lands (April–May). Deploy vetiver bio-filtration swales at rural drain-mouths. Link to MGNREGA for labour funding. *Institutional Mechanism:* Gram Panchayats execute pre-monsoon drives. MGNREGA funds labour. District Ganga Committees coordinate with flood forecast

State	Key Gaps
Diffuse & Point Sources (Plastic Waste):	
Brijghat to Kosi Confluence	• Cremation and ritual plastics (synthetic shrouds, plastic garlands, polythene offerings, thermocol decorations): • Uttar Pradesh: Far higher ritual intensity, Varanasi (80-100 cremations/day), Prayagraj (Kumbh), Kanpur, Mirzapur ghats. Thermocol idol/decoration waste massive during festivals. UP stretch receives heaviest ritual plastic load on entire Ganga. • Bihar: Major ghats at Buxar, Patna, Munger, Bhagalpur. Daily ritual offerings with synthetic materials enter river directly. Tourism/pilgrimage documented as significant microplastic source. • Fishing and boating waste (ghost nets, nylon lines, polystyrene floats) • Uttar Pradesh: Ganga fisheries concentrated in Prayagraj-Ghazipur stretch. Ghost gear density lower than Bihar but significant at confluences (Yamuna-Ganga, Ghaghra-Ganga). Fishing nets = all nylon/plastic. Lack of end-of-life disposal infrastructure. Bihar: Buxar-Kosi stretch supports major inland fisheries. 73% of ghost gear found in High-Biodiversity Zone (includes Vikramshila Gangetic Dolphin Sanctuary, Bhagalpur). Short gear lifespans, high turnover, zero disposal system. Threatens endangered Gangetic dolphin, freshwater turtles, otters.

Central Pollution Control Board [CPCB], 2022; (CPCB, n.d.-a, n.d.-b); CPCB], 2023; Ulrich et al., 2009; Ministry of Jal Shakti [MoJS], 2025)

Table 9.14 Recommended Tiered Abatement Framework for Rural Point-Source Pollution: Buxar-Kosi Pollution Corridor

Abatement Strategy Tier	Settlement Size	Recommended System
Tier 1: On-Site Sanitation with Passive Filtration	<500 pop*	Twin-pit latrines + rice husk biochar drain filters
Tier 2: Decentralised Biological Treatment	500-2,000 pop	DEWATS: Anaerobic Baffled Reactor + Anaerobic Filter + Planted Gravel Filter
Tier 3: Hybrid Engineered-Natural Systems	2,000-5,000 pop	DEWATS + constructed wetland (Vertical Flow + Horizontal Flow) on elevated embankment (≥1.5m above HFL)
Tier 4: Advanced Decentralised Treatment	5,000-15,000 pop	Solar-Powered Membrane Aerated Biofilm Reactor (containerised) on flood-proof platform pilot at 1–2 locations first

Current Interventions, & Status	Proposed Intervention
	agencies. NMCG extends skimmer procurement beyond municipal zones. UP ULBs provide downstream MRF processing capacity.
NMCG ghat development improved infrastructure but did not mandate plastic-free zones. No alternative material supply chain for biodegradable offerings in either state. Culturally sensitive enforcement-only approaches fail. Devotees resist restrictions. Biodegradable alternatives exist (clay lamps, cotton shrouds, flower garlands) but are not priced competitively or systematically available at ghats. Enforcement agencies avoid confrontation at religious sites.	Establish "plastic-free ghat zones" co-managed by religious institutions (not state enforcement). Subsidise biodegradable ritual kits at ghat vendor points. NMCG to partner with temple trusts. Ban thermocol idol/decoration material. UP needs priority given volume: pilot at Varanasi, scale to Prayagraj. Bihar: pilot at Patna ghats. Institutional Mechanism: Religious institutions and temple trusts as primary implementers. NMCG awareness co-designed with dharmacharyas. Municipal bodies enforce thermocol ban at ghat perimeters. UP Waqf/Mandir trusts for site-specific adoption.
No fisheries-specific plastic waste policy in either state. Fishing gear regulations exist but are ineffective. Nylon 6 nets have high recycling value (carpets, textiles) but no collection chain exists in Bihar or UP. Fisher communities in both states have severely limited appropriate disposal options. Worn-out nets dumped on banks or in river. No buy-back or recycling linkage despite nylon 6 market value. Gear marking/registration absent, abandoned gear untraceable.	Establish nylon net buy-back programme at fish landing sites in both states. Partner with nylon recycling industry (nylon 6 ? carpet/textile fibre - proven globally). Introduce gear marking and registration. Periodic ghost gear retrieval in Vikramshila Sanctuary (Bihar) and Kashi Turtle Sanctuary (UP). Institutional Mechanism: Bihar/UP Fisheries Departments + NMCG biodiversity wing. Fisher cooperative societies as collection agents. WII/ZSL/ICAR-CIFRI technical support. Buy-back funded through EPR-like levy on net manufacturers.

Justification for Deployment	Flood Resilience
Zero cost, village-producible. Twin-pit handles human waste; biochar filters greywater and drain runoff. Rajgir, Bihar: 91-96% fluoride removal. Sacrificial design:rebuilt post-monsoon at negligible cost.	Moderate
Zero electricity, gravity-flow, all local materials. 500+ installs in 14 states (CDD Society). 85-95% BOD removal. O&M: ?3,000-5,000/year.	Moderate-High sealed underground chambers survive submersion; self-restarts
84-97% BOD removal. NMCG/IIT Roorkee 2023 guidelines exist for Bihar. Native macrophytes (Typha, Phragmites, Canna) locally available. CW adds nutrient polishing beyond DEWATS alone.	High requires elevation above HFL (budget 20-30% extra)
>98% BOD. 90% less energy than conventional STP. Pre-assembled; installs in 10 days. Remote monitoring reduces operator dependency. Needs Bihar-specific validation.	High container units elevatable or relocatable

Abatement Strategy Tier	Settlement Size	Recommended System
Tier 5: Riparian Phytoremediation and Ecological Buffers	Corridor-wide	Riparian buffers (See Species palette in Tables 9.16 and 9.17)
Tier 6: Real-Time Environmental Surveillance	Corridor-wide	IoT/LoRaWAN water quality monitoring

**pop: Population*

Table 9.15 Recommended Full-Spectrum Pesticide Interception Chain intervention framework for agricultural pollution abatement Bihar Flood-Prone Agricultural Catchments

Stage	Intervention	Mechanism / design note
Stage 1: Source Control (On-Farm)		
Stage 1	Biochar-amended soil reactive barriers *Pilot phase recommended before mainstreaming*	Amended field margins adsorb pesticide residues and immobilise heavy metals before runoff leaves the farm boundary
Stage 1	Integrated livestock waste biodigesters + effluent irrigation	Diverts high-nitrogen slurry from open discharge into closed digestion; treated effluent reused as fertigation input, reducing synthetic fertiliser demand
Stage 1	Precision fertigation infrastructure *Aspirational; requires capital subsidy and sustained extension support*	Drip systems with soil-moisture sensors calibrate application to crop demand; reduces urea application by est. 30-40%
Stage 2: Process Control (During Transport)		
Stage 2	Controlled drainage + water table management	Adjustable weirs in field drains hold water table high post-rain, reducing drainage volume and extending denitrification contact time in soil profile
Stage 2	Ecological interception ditches + grassed waterways	Vegetated conveyance channels slow runoff velocity, trap sediment-bound pesticides, and support aquatic macrophyte uptake along the transport pathway
Stage 2	Contour bunding	Earthen bunds along field contours intercept sheet flow, promoting infiltration and reducing peak runoff volume reaching waterways during monsoon events
Stage 2	Saturated buffer zones (tile-drain diversion)	Subsurface drainage routed horizontally through saturated riparian soil before discharge; denitrification removes 40–70% of nitrate load under anaerobic conditions

Justification for Deployment	Flood Resilience
Only technology that improves with flooding: traps sediment, rebuilds banks, intercepts agricultural runoff. Roots 3-4m deep. Already in NMCG forestry programme. Zero operational cost.	Very High survives submersion, self-restoring
CPCB: 36+ stations operational. LoRaWAN: 15-45 km rural range at milliwatt power. AI models: 96.9% forecast accuracy. Essential for adaptive management across all tiers	Moderate–High sensors on 4-5m poles; sacrificial ghat nodes replaced annually; gateways on telecom towers

Primary pollutant target	Lead agency
Organophosphates, pyrethroids, heavy metals	ATMA / KVK with ICAR-RCER
Ammonium-N, BOD, pathogens	BREDA / Panchayati Raj
Urea-N, phosphate	PMKSY (Per Drop More Crop component) as primary financing instrument; DAH&F for extension and technical support; PM-KUSUM for solar pump energy subsidy.
Nitrate-N, pesticide load	WDC-PMKSY / WRD Bihar-drainage line treatment under watershed plans can incorporate adjustable weir structures, making this eligible for PMKSY funding if included in District Irrigation Plans.
Sediment-bound pesticides, suspended solids	BSPCB / District Agriculture Office
Runoff volume, sediment	WDC-PMKSY (Watershed Development Component) as primary; BWDC / MGNREGA convergence for labour mobilisation.
Nitrate-N	WRD Bihar / ICAR-RCER

Stage	Intervention	Mechanism / design note
Regulatory Instrument: Agrochemical Use Restriction		
Regulation	Mandatory no-spray buffer belts (1 km from river) with transition to organic inputs *Incentive-first with prohibition as backstop; phased over 3–5 years*	Prohibits aerial and ground application, bulk storage, and retail sale of synthetic toxic pesticides within defined riparian zone; mandates organic input transition backed by Ganga Ecosystem Services Payment scheme
Incentive	Ganga Ecosystem Services Payment scheme *Funding via NMCG / CAMPA; payments tied to verified*	Direct payments to farmers maintaining riparian buffers and constructed wetlands on private land; compensates opportunity cost of land taken out of cultivation within no-spray belt
Stage 3: End Treatment (At Catchment Boundary) - Flood-Adaptive Layered Design		
Stage 3	Sediment retention basins / settling ponds *Non-negotiable first cell; sized at 20–30% of total wetland area*	Captures 400–1,200 mg/L suspended solids characteristic of Bihar monsoon discharge before downstream wetland cells; designed for annual mechanical desludging post-monsoon recession
Stage 3	Riparian buffer strips (forested + grassed multi-zone) *Table 9.16-9.17 provides plant species palette for riparian NbS*	Multi-layer buffer (grass → shrub → native tree) provides velocity attenuation, particulate filtration, and bank stabilisation; requires post-flood replanting protocol embedded in MGNREGA work calendar
Stage 3	Crop-cycle constructed wetland cells (Kharif / Rabi phased) *Bypass valve required; cells isolated during peak monsoon inundation*	Treatment cells phased to post-transplanting (Oct-Nov) and post-Rabi (Apr-May) windows; bypassed during active monsoon to prevent hydraulic overloading and macrophyte loss
Stage 3	Agricultural constructed wetlands-in-situ systems (edge-of-field) *Table 9.16-9.17 provides plant species palette for riparian NbS*	Free water surface or subsurface flow cells provide continuous nutrient polishing between flood pulses; macrophyte establishment protected by upstream settling pond
Stage 3	Floating wetlands *Anchoring rated for Bihar flood debris and high-velocity flow*	Buoyant HDPE mat systems rise with water level, sustaining treatment continuity through deep inundation events that would destroy fixed-bed infrastructure; most flood-resilient Stage 3 component

Stage 3: Recommended Operational Flow Sequence

Agricultural field → Settling Pond → Riparian buffers → Crop-cycle cells (Kharif / Rabi) → In-situ wetlands → Floating wetlands → Receiving waterbody

Institutional maintenance framework (village committees, MGNREGA labour linkages, disaster-relief financing triggers) spans entire sequence and is a condition of system viability across successive monsoon cycles. Diversion constructed wetlands excluded from main channel siting given thalweg instability of Kosi, Bagmati, and Gandak rivers.

Primary pollutant target	Lead agency
All synthetic pesticides and agrochemicals	BSPCB + State Agriculture Dept; notification under EP Act 1986
Behavioural: sustains compliance with Stages 1-3	NMCG / District Collector offices
Suspended solids, sediment-bound pesticides	BSPCB / implementing NGO
Sediment, nutrients, bank erosion	Forest Dept Bihar / Panchayat
Urea-N, organophosphates, pyrethroids	BSPCB / ICAR-RCER design support
Residual N, P, BOD	BSPCB / implementing agency
N, P, BOD during inundation	BSPCB / specialist contractor

Stage	Intervention	Mechanism / design note
Stage 4: Monitoring (Source to End Treatment)		
Stage 4	Ganga Agricultural Catchment Monitoring Programme (GACAMP) *Modelled on Denmark's DAMP; prerequisite for scaling any Stage 1–3 intervention*	(a) Representative micro-catchments across Critical Conservation Corridors: diverse soil types, crop systems, irrigation methods (b) Continuous water quality sensors at all drain outlets and downstream river points (c) Farm-level fertiliser, pesticide, yield, and management data from participating farms (d) Mandatory 4-yearly Agricultural Pollution Status Report feeding directly into policy revision

Note: Stage 4 monitoring is not optional without it no Stage 1-3 intervention can be evaluated for effectiveness or recommended for scale-up. Diversion CWs excluded from main channel siting given documented thalweg instability of Kosi, Bagmati, and Gandak rivers.

PMKSY "Har Khet Ko Pani" irrigation expansion in Bihar catchments should be conditioned on simultaneous adoption of controlled drainage structures;unmanaged irrigation network expansion accelerates runoff channelisation and pesticide transport, compounding the pollution load the interception chain is designed to intercept.

Table 9.16 Flood-Tolerant Species Framework for Bihar Riparian Design: Three-Zone Riparian Buffer Design

Zone	Spatial Range	Flood Regime	Key Species
Zone 1: Active Bank	0–5 m	Extreme inundation (2–4 months submergence)	*Vetiveria zizanioides* (Vetiver) *Saccharum spontaneum* (Kans) *Phragmites karka* *Cynodon dactylon* (Doob)
Zone 2: Lower Floodplain	5–15 m	Seasonal flooding, partial submergence	*Dalbergia sissoo* (Shisham) *Acacia catechu* (Khair) *Pongamia pinnata* (Karanj) *Tamarix dioica* (Jhau) *Bamboo spp.*
Zone 3: Upper Floodplain / Terrace	15–30+ m	Occasional flooding, well-drained soils	*Terminalia arjuna* (Arjun) *Syzygium cumini* (Jamun) *Bombax ceiba* (Semal) *Madhuca longifolia* (Mahua) *Ficus racemosa* (Gular)

Table 9.17 Species Palette for Engineered Nature-Based Systems

Category	Species	Role in CW Systems
Primary Macrophytes	*Typha angustifolia / T. latifolia*	Nutrient uptake, pollutant removal
	Phragmites australis / karka	Oxygen transport, rhizofiltration
Support Species	*Cyperus spp.*	Sediment trapping, nutrient cycling
	Canna indica	Aesthetic + nutrient removal

Primary pollutant target	Lead agency
All pollutants: cross-stage performance verification	CPCB / BSPCB / NMCG data cell; 4-yearly report to MoEFCC

Ecological Functions	Evidence-Based Performance
Soil stabilization, erosion control, rapid colonization of bare sediments	Vetiver roots reach 3–4 m depth in 1 year; increases soil cohesion by 119.6% and friction angle by 81.96%; reduces soil loss by 94–97% Kans grass is dominant pioneer (Prominence Value: 2.0) Doob grass highest prominence (5.3) in Ganga floodplains
Pioneer stabilization, nitrogen fixation, bank reinforcement, rapid biomass accumulation	Shisham–Khair form natural riparian association Pongamia survives prolonged submergence, tolerates salinity up to 12–19 dS/m Bamboo provides strong root matrix for bioengineering
Long-term bank stability, canopy formation, carbon sequestration, livelihood support	Arjuna shows highest carbon sequestration (9.54 t C ha^{-1} yr^{-1}) Deep-rooted species provide structural anchorage and ecosystem services

Performance Indicators
Highest bioconcentration & translocation factors among tested species
Dominant species in floodplain wetlands
High adaptability in wetland gradients
Proven in engineered CW systems

9.5 TEMPORAL PATTERNS OF THE GANGA RIVER (2018-2025)

The temporal pattern analysis reveals that India's regulatory and enforcement infrastructure is producing measurable results for contaminants it was designed to control, while simultaneously failing to address emerging class of contaminants that fall entirely outside its framework (Table 9.18 and Figure 9.23).

Legacy and regulated contaminants (heavy metals, organochlorine and organophosphate pesticides) show statistically significant river-wide declines, confirming that the EP Act, Stockholm Convention, and Insecticides Act are producing genuine outcomes. However, extreme site-specific exceedances persist at CCC hotspots (DDT at Gomti Confluence, Chlorpyrifos at Kahalgoan), demonstrating that basin-scale compliance does not translate to ecological safety within dolphin habitat.

Emerging and unregulated contaminants (phthalates, BPA, pharmaceuticals, personal care products, steroids) show no consistent decline, and BPA, the only contaminant class showing sustained year-on-year escalation, has increased approximately 5x since 2022. This divergence is structural, not incidental, driven by five systemic gaps: (i) no Indian regulatory framework prescribes discharge standards, ambient criteria, or monitoring mandates for any emerging contaminant; (ii) their sources are diffuse and population-driven (household plastics, sewage, consumer products, landfills), scaling with consumption rather than responding to facility-level enforcement; (iii) STPs commissioned under Namami Gange use conventional processes (activated sludge, UASB) with limited removal efficiency for DEHP, BPA, steroids, and pharmaceuticals; (iv) India's accelerating plastic consumption (~10% CAGR) creates a cumulative, irreversible BPA source term from environmental plastic stock; and (v) the absence of statistical significance between certain monitoring periods for emerging contaminants does not indicate stability but reflects high spatial and seasonal variance inherent to diffuse-source pollutants, masking underlying loading trends.

Addressing this gap requires a fundamentally different intervention architecture. Without this structural shift, the Ganga's ecological risk profile will be increasingly dominated by estrogenic and plastic-derived contaminants even as legacy pollution declines, creating the paradox of a river that is getting statistically cleaner by old metrics while becoming ecologically more dangerous by new ones.



Table 9.18 Temporal patterns of legacy and emerging contaminants in Ganga River

Contaminant	Temporal Pattern (2018-2025)	Drivers of Observed Pattern	Ecological Implication
REGULATED CONTAMINANTS: Source controls producing measurable river-wide improvement			
ΣHms (Cu, Cr, Ni)	↓ Declining (p=0.016, 2018→2025)	Industrial effluent regulation under EP Act; tannery CETPs and closures under Namami Gange; strengthened enforcement with mandatory online monitoring; upgraded CETPs; closure of non-compliant facilities; and strategic drain interception. Remark: Regulatory model is working at river scale. But declining median masks persistent bioaccumulative risk	Cu still exceeds toxicity threshold at 54% of monitoring stations (2025) because metals are non-degradable and sediment stock continues trophic transfer.
ΣOCPs (DDT, DDE, HCH)	↓↓ Steep decline (p<0.001, 2018→2022)	Stockholm Convention ratification (2006); Complete agricultural ban of Target OCPs. Natural depletion of banned legacy POPs through environmental degradation, photodegradation, and sediment burial following regulatory bans. Agricultural transformation via IPM and ZBNF adoption, farmer capacity building, riparian buffers and constructed wetlands and shift toward newer pesticide classes. Remark: DDTs High Risk at Gomti Confluence (2025) indicates continued illegal use or unmonitored vector control at state-specific tributaries. Chlorpyrifos High Risk particularly at Kahalgoan, Bihar indicates neurotoxicant persists at extreme levels at specific CCC sites within dolphin foraging zones. Unlike European Union (banned 2020), No Indian regulatory standard exists for restricted Chlorpyrifos.	River-wide success pattern undermined by hyper-localised crisis., proving that river-wide compliance statistics are meaningless for dolphin conservation without site-specific enforcement particularly at tributary confluences. OPPs share the same pattern as OCPs. Chlorpyrifos is an acetylcholinesterase inhibitor that directly suppresses prey availability for dolphins.
ΣOPPs (Chlorpyrifos)	↓↓ Steep decline (p<0.001, 2018→2022) >80% reduction		
UNREGULATED EMERGING CONTAMINANTS: No regulatory framework, point and diffuse population-driven sources, STP pass-through			
BPA	↑↑ ESCALATING (p<0.001, 2022→2025)	India's plastic consumption growing ~10% CAGR. Cumulative BPA leaching from polycarbonate, thermal receipts, rigid packaging. Single-use ban (2022) excludes BPA-containing product categories. Landfill leachate is an irreversible, growing source. Remark: No Indian regulatory standard exists.	BPA is a potent estrogen receptor agonist. High Risk at Kosi Confluence (Tier-1 dolphin habitat) means environmental concentration is 31x the threshold levels. Current trajectory will make BPA the dominant driver of GERI risk. Without intervention, this trend is irreversible.

Contaminant	Temporal Pattern (2018-2025)	Drivers of Observed Pattern	Ecological Implication
ΣPAEs (DEHP)	↕ Fluctuating (p<0.001 both shifts) Peaked 2024; declined 2025	Ubiquitous plastic contamination. 2024 peak likely flood-driven plastic waste mobilisation. Decline in 2025 may reflect sampling timing, not source reduction. STPs have near-zero DEHP removal. Remark: No Indian regulatory standard exists. No monitoring protocol exists in CPCB framework.	Despite 2025 slight decline, DEHP exceeds threshold at 67% of all stations, the most spatially widespread exceedance in the dataset. Its ubiquity means even low per-site estrogenic contribution accumulates across the entire river.
ΣSteroids (E2)	↕ Site-specific extremes	Sewage discharge containing endogenous Estrogens; livestock waste, untreated drain discharges. Variable STP operational efficiency (requires ozonation or activated carbon). Remark: No Indian regulatory standard exists. No monitoring protocol exists in CPCB framework.	E2 has the lowest Threshold (0.4 ng/L) and highest estrogenic potency of any compound monitored. High Risk equivalent to 44x the no-effect level. Fish feminisation at this magnitude is not a risk projection; it is a biological certainty. Directly threatens dolphin prey base reproductive viability.
ΣPharma (Ibuprofen, Caffeine)	↕ No net pattern (p=0.002, 2024→2025)	Population growth increasing pharmaceutical consumption. Variable STP operational efficiency. Hospital effluent unregulated for specific pharmaceutical limits. High seasonal and spatial variance mask any underlying trend. No take-back programme for unused medicines; no extended producer responsibility for pharmaceutical manufacturers. Remark: No Indian regulatory standard exists. No monitoring protocol exists in CPCB framework.	Absence of consistent trend does not mean the problem is stable; it means diffuse-source variance overwhelms temporal signal. Ibuprofen still exceeds threshold at 7 stations.
ΣPCPs (TCS, TCC)	↔ Cyclical No net change from 2022 (p<0.001, 2024→2025)	Millions of diffuse domestic sources (greywater, bathing ghats, consumer products). Three years of monitoring with zero net improvement. Cyclical fluctuation reflects seasonal loading variation, not intervention effect. Cannot be addressed through point-source enforcement. Requires consumer product reformulation or greywater treatment mandates. Remark: No Indian regulatory standard exists. No monitoring protocol exists in CPCB framework.EU has restricted Triclosan in biocidal products; India has no equivalent	Low individual toxicity but chronic endocrine disruption potential.

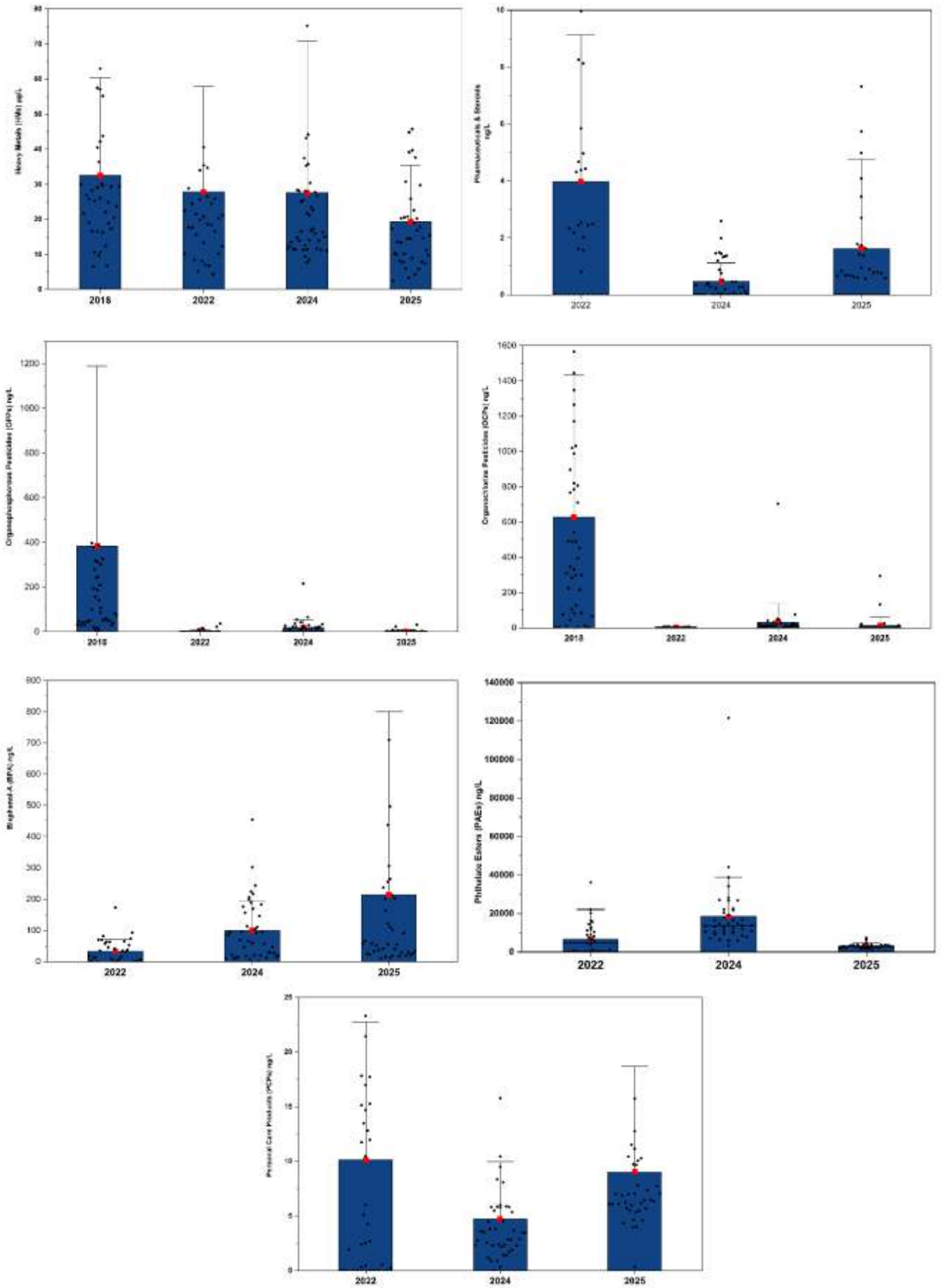


Figure 9.23 Temporal patterns of Legacy and Emerging Endocrine-Disrupting Chemicals (EDCs) & Heavy Metals (HMs) in Ganga River

9.6 POLLUTION THREAT ASSESSMENT: GAP IDENTIFICATION AND INTERVENTION

While Table 9.13 addressed targeted interventions for the CRITICAL ecological risk stretches in Bihar and Uttar Pradesh, the pollution challenges facing the Ganga extend beyond these hotspots. Of the 39 monitored stations, 19 are classified HIGH, 8 MODERATE, and 7 MONITORING, each with distinct gap profiles that require interventions scaled to their specific source-pathway configurations. Table 9.19 below presents the comprehensive gap assessment across all zones of the Ganga (Upper, Middle, and Lower), structured by gap type (Capacity, Performance, and Coverage), and identifying for each documented gap its underlying driver, scale of impact, root cause, current response status, and recommended intervention. The gaps identified across the Ganga River fall into three distinct categories, each requiring a fundamentally different policy response (Table 9.19). Capacity gaps relate to infrastructure that has been sanctioned but remains incomplete. Performance gaps relate to infrastructure that is operational but does not deliver its intended outcomes. Coverage gaps relate to pollution loads for which no intervention exists at any scale. The distinction is critical: capacity gaps require accelerated execution, performance gaps require governance and fiscal reform, and coverage gaps require the creation of entirely new policy instruments. This river-wide framework ensures that while immediate resources are directed to the CRITICAL stretches, the systemic and structural gaps that sustain contamination across the entire basin are addressed in parallel.





Table 9.19 Gaps, Drivers, Root Cause, and Interventions

Gap type	Gap	Driver	Scale	Root cause
Capacity gaps: infrastructure sanctioned but not operational				
Capacity	Untreated sewage gap of approxi mately 2,340 MLD; effective gap likely higher given STP utilisation rates of 54-75%. Approximately 2,633 MLD of sanctioned capacity under construction or tendering (Figure 9.24)	Demographic growth	CRITICAL	Sewage generation CAGR (4.68%) exceeds treatment capacity CAGR (4.31%). Land identification delays, statutory clearances, and re-tendering due to technology or cost changes add 3-5 years to project delivery cycles.
Capacity	321 of 517 drains in 5 Ganga states remain untapped, discharging polluted water into the Ganga. 125 of 188 priority drains in Uttar Pradesh remain untapped. Similar shortfalls in Bihar and West Bengal (Figure 9.25).	Demographic growth Institutional weakness	CRITICAL	Drain interception projects lag behind STP construction. New drains form as unplanned peri-urban growth extends beyond existing sewer networks. No mechanism links urban expansion approvals to drain management.
Performance gaps: infrastructure operational but underperforming				
Performance	Drains classified as "tapped" or "partially tapped" continue to discharge significant residual organic loads. WII monitoring of priority drains in UP (2021-2025) confirmed persistently high contaminant loads. (Figure 9.25 & 9.26)	Institutional weakness	CRITICAL	Interception infrastructure overwhelmed during monsoon and peak-flow conditions. Ageing and poorly maintained interception structures. Absence of post-interception performance monitoring as a standard protocol.
Performance	Existing STPs operating at 55-60% utilisation. Installed capacity of 1,957 MLD in Ganga front towns, of which only 1,064 MLD utilised. (Figure 9.24)	Institutional weakness	CRITICAL	Trunk sewer networks required to convey sewage from households and drains to STPs have not been completed at the same pace as plant construction. ULBs lack fiscal capacity and technical resources for sewer network extension and maintenance.
Performance	23 of 41 STPs in Ganga districts violating prescribed faecal coliform discharge standards. Only 12 STPs compliant. 34 of 35 operational STPs failing to meet at least one prescribed parameter. (Figure 9.24)	Institutional weakness	HIGH	O&M expenditure is the first budget line reduced when ULB finances are constrained. Disinfection systems (chlorination, UV) non-functional at multiple plants. Absence of certified operators. No performance-linked accountability framework.

Current response	Recommended intervention
216 sewerage projects sanctioned at Rs 34,809 crore. 138 STPs operational at 3,806 MLD. Target of 7,000 MLD cumulative capacity by December 2026.	Establishment of a single-window clearance mechanism for STP projects across Ganga basin states. Provision for mandatory on-site or cluster-level sewage treatment in all new urban development through amendment to state building regulations.
Comprehensive drain mapping and prioritisation across all five Ganga main-stem states. 155 of 170 polluted drains tapped in Uttarakhand. Drain interception projects sanctioned in major towns. 60 MLD STP with interception of Durga Drain sanctioned in Varanasi at Rs 274 crore.	Linkage of urban development approvals to mandatory drain management provisions. Time-bound interception programme for all priority drains.
Drains classified as tapped based on infrastructure installation, not verified post-interception performance. No systematic monitoring of residual discharge from tapped drains.	Institution of mandatory post-interception performance monitoring for all drains classified as tapped. Reassess interception capacity under peak-flow conditions and incorporate monsoon bypass management into design standards
STPs commissioned under hybrid annuity and DBOT models. O&M responsibility transferred to ULBs. CPCB performance evaluation of Ganga front town STPs conducted in 2019.	Prioritisation of sewer network completion as a co-equal investment component in all future STP project sanctions. Institutionalisation of dedicated O&M financing through a ring-fenced sewage treatment cess or earmarked central transfers to ULBs.
Discharge standards prescribed. CPCB compliance reports published. No consequence mechanism for sustained non-compliance by ULB-operated STPs.	Introduction of performance-linked grant disbursement to ULBs contingent on STP compliance with prescribed discharge standards. Provision for certified operator deployment at all commissioned treatment facilities. Mandatory operational audit cycle.

Gap type	Gap	Driver	Scale	Root cause
Performance gaps: infrastructure operational but underperforming				
Performance	Existing, upgraded, and newly commissioned STPs designed for conventional parameters (BOD, TSS, FC) and not equipped to remove emerging contaminants (pharmaceuticals, microplastics, EDCs, PFAs).	Policy absence	HIGH	STP technology specifications in project sanctioning have not been updated to reflect the evolving contaminant profile of urban sewage. Current discharge standards do not prescribe limits for emerging contaminants. No tertiary or advanced treatment provision in the majority of sanctioned projects.
Performance	380+ grossly polluting industries non-compliant with prescribed effluent discharge norms despite monitoring infrastructure and inspections.	Perverse incentives	HIGH	Cost of non-compliance (periodic fines, delayed closure proceedings) remains lower than cost of continuous ETP operation. Enforcement fragmented across CPCB, SPCBs, and district administration. Closure directions issued but inconsistently enforced.
Coverage gaps: pollution loads with no corresponding intervention				
Coverage	Agricultural nutrient and pesticide runoff unaddressed. Dominant source of diffuse loading through non-point surface runoff and groundwater seepage, contributing an estimated 30-40% of total nutrient load.	Policy absence	HIGH	No regulatory framework for non-point source pollution equivalent to the discharge standards applicable to point sources. Fertiliser subsidy structure makes over-application of nitrogen and phosphorus economically rational for individual farmers.

Current response	Recommended intervention
STPs commissioned using SBR, AAO, and UASB technologies. Contaminant profiling studies ongoing under NMCG research programmes. No revision of design standards initiated.	Revision of STP technology specifications for future sanctions to include tertiary treatment capability for priority emerging contaminants. Phased retrofitting programme for existing STPs at ecologically sensitive and high-population locations. Notification of discharge standards for identified emerging contaminants
OCEMS installed at 885 of 1,072 identified GPIs. Annual third-party inspections conducted. Closure directions issued to non-compliant units under Section 5 of the E(P) Act.	Operationalisation of automated penalty mechanisms linked to real-time OCEMS deviations. Revision of effluent charge schedules to exceed ETP operating costs. Incorporation of environmental compliance criteria in public procurement frameworks.
No dedicated programme under Namami Gange or state-level initiatives targets agricultural pollution in the Ganga basin. Soil health card scheme exists but is not linked to subsidy disbursement or pollution abatement objectives.	Linkage of fertiliser subsidy disbursement to soil health card-based nutrient recommendations. Transform the Soil Health Card from an advisory tool into an accountability instrument Design and implementation of a payment-for-ecosystem-services mechanism for upstream agricultural nutrient management. Link farm subsidies directly to environmental compliance via “Cross-Compliance” Create a “Ganga Ecosystem Services Payment” scheme: pay farmers incentives for maintaining riparian buffers and constructed wetlands on their land. Build a “Full-Spectrum Interception Chain”: **STAGE 1** - SOURCE CONTROL (On-Farm) Biochar-Amended Soil Filters (Reactive Barriers) + Integrated Livestock Waste Biodigesters + Effluent Irrigation + Precision Fertigation Infrastructure (Drip + Sensor Systems) **STAGE 2-** PROCESS CONTROL (During Transport) Controlled Drainage Systems (Water Table Management) + Ecological Interception Ditches (Eco-Ditches) + Contour Bunding + Grassed Waterways (Erosion Control Infrastructure) + Saturated Buffer Zones (Tile-Drain Diversion to Buffers) **STAGE 3** -END TREATMENT (At Catchment Boundary) Riparian Buffer Strips (Forested + Grassed Multi-Zone) + Agricultural Constructed Wetlands (Edge-of-Field CWs) + Sediment Retention Basins / Farm Ponds (Catch Basins) Establish a “Ganga Agricultural Catchment Monitoring Programme” modelled on Denmark's DAMP: (a) select representative agricultural micro-catchments across the Ganga River, particularly across Critical Conservation Corridors” (covering different soil types, crop systems, and irrigation methods); (b) install continuous water quality sensors at all drain outlets + downstream river points; (c) collect field-level fertiliser/pesticide use, crop yield, and management data from participating farms; (d) mandate 4-yearly “Agricultural Pollution Status Report” that directly feeds into policy revision.

Gap type	Gap	Driver	Scale	Root cause
Coverage gaps: pollution loads with no corresponding intervention				
Coverage	Atmospheric deposition of heavy metals, PAHs, and nitrogen compounds from vehicular and industrial emissions onto the river surface. Contribution unmonitored and unquantified.	Policy absence	HIGH	Atmospheric deposition pathway is not included in the CPCB Ganga water quality monitoring framework. No programme links air quality management to river water quality outcomes. Source apportionment for airborne contributions has not been conducted.
Coverage	Solid waste and plastic leakage at ghats and urban stretches. 71% of Ganga front towns lack proper municipal solid waste management infrastructure. Seasonal spikes during festivals and Kumbh Mela.	Institutional weakness Policy absence	HIGH	Municipal solid waste processing infrastructure absent or non-functional in the majority of Ganga front towns. No mandate for source segregation at municipal level. Ritual immersion materials (non-biodegradable idols, synthetic floral offerings) unregulated.
Coverage	Groundwater contamination migrating into the Ganga through baseflow seepage. Sources include landfill leachate, septic tank percolation, industrial waste dump infiltration, and fertiliser percolation.	Policy absence	HIGH	No programme links groundwater quality management to river water quality outcomes. Groundwater contamination monitored under a separate institutional framework (CGWB) with no integration into Ganga programme objectives.
Coverage	Tributary pollution loading the Ganga main stem. Major tributaries (Yamuna, Kosi, Ghaghra Ramganga, Gomti) enter the Ganga with pollution loads that degrade main-stem water quality downstream of each confluence.	Institutional weakness	HIGH	Tributary pollution abatement falls under state jurisdiction with variable investment and enforcement. No integrated main-stem-plus-tributary pollution load management framework. Yamuna contributes a disproportionate share of the Ganga pollution load at and below Prayagraj.
Coverage	Rural sewage in the Ganga basin almost entirely unserved. Rural treatment coverage estimated at less than 1%. 65% of India's population resides in rural areas.	Policy absence Institutional weakness	HIGH	Namami Gange programme focuses on the 110 Ganga front towns. Rural settlements along the river and its tributaries lack any sewage collection or treatment infrastructure. Swachh Bharat Mission addresses open defecation but not greywater or septage management in most rural areas.

Current response	Recommended intervention
No monitoring or intervention exists for this pathway within the Ganga programme framework.	Inclusion of atmospheric deposition parameters (heavy metals, PAHs, nitrogen compounds) in the CPCB Ganga water quality monitoring network. Commissioning of a source apportionment study for airborne pollutant contributions to river water and sediment quality.
Surface cleaning operations at select ghats. Festival-specific temporary waste management deployments at pilgrimage centres. Ganga Praharis engaged in awareness activities.	Establishment of municipal solid waste processing infrastructure in all 110 Ganga front towns. Notification of mandatory source segregation under municipal solid waste management rules. Regulation of immersion materials through prescribed biodegradability standards.
Central Ground Water Board monitors groundwater quality at district level. No linkage to Namami Gange programme interventions. No assessment of groundwater-to-river contamination transfer at Ganga front towns.	Assessment of groundwater-to-river contamination pathways at priority Ganga front towns. Integration of CGWB groundwater quality data into NMCG monitoring framework. Regulation of landfill siting and containment standards within the Ganga floodplain.
Yamuna rejuvenation projects sanctioned under Namami Gange. Individual tributary projects at various stages. No integrated tributary load management or confluence-point monitoring protocol.	Establishment of tributary-specific pollution load budgets linked to main-stem water quality targets at each confluence. Mandatory confluence-point monitoring for all major tributaries. Integration of state-level tributary interventions into the NMCG programme framework with shared accountability.
ODF declared in gram panchayats along the Ganga under Swachh Bharat Mission. Faecal sludge treatment plants operational at limited locations (e.g. 125 KLD FSTP in Rudrapur). No systematic rural sewage programme.	Expansion of decentralised and faecal sludge treatment infrastructure to rural settlements within a defined corridor along the Ganga main stem and priority tributaries. Convergence of Namami Gange and Swachh Bharat Mission-Gramin for greywater and septage management in riverine gram panchayats.

Gap type	Gap	Driver	Scale	Root cause
Coverage gaps: pollution loads with no corresponding intervention				
Coverage	Lean-season flow deficit concentrating pollutants even where absolute loads have decreased.	Hydrological stress	CRITICAL	Upstream abstractions at dams and multiple barrages reduce lean-season flows below ecological and dilution thresholds. Groundwater extraction at approximately 250 km^3/year depletes aquifer contributions to baseflow. Climate change altering monsoon intensity and lean-season precipitation.
Coverage	Sewage generation growing faster than treatment capacity. CAGR of generation (4.68%) exceeds treatment (4.31%). The gap is widening structurally.	Demographic growth Policy absence	CRITICAL	Urban population growth in Ganga basin towns at 2-3% annually. Centralised STP model requires 5–7-year delivery cycles per project. No mandate for decentralised treatment in new developments. Each new urban resident adds to the centralised load with no offsetting intervention.

Scale: CRITICAL = Immediate ecological impact HIGH = Significant unaddressed load

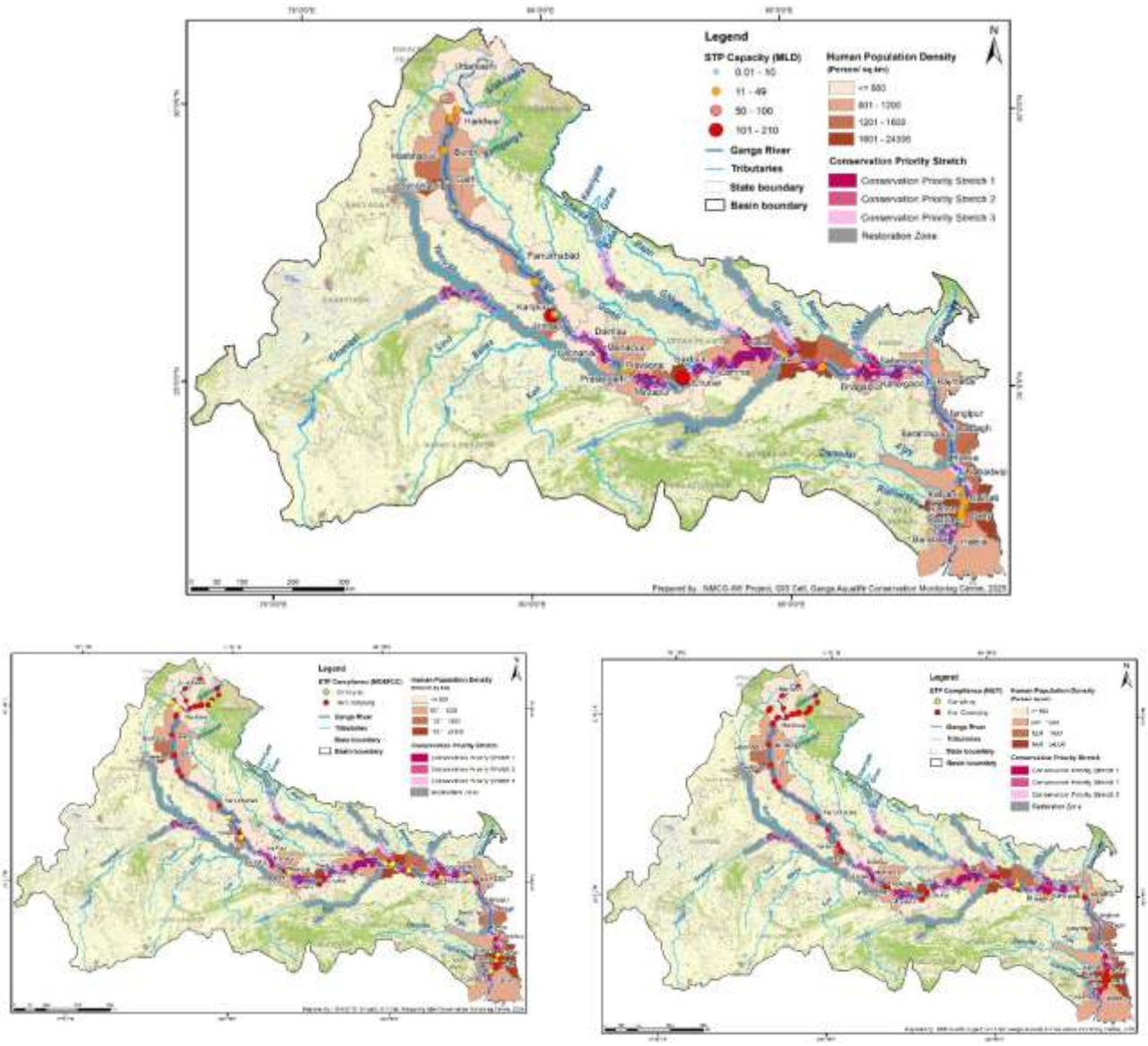
Drivers: Demographic growth (3 gaps); Institutional weakness (7 gaps); Perverse incentives (1 gap); Policy absence (7 gaps); Hydrological stress (1 gap)

Note: Institutional weakness and policy absence collectively underlie 14 of the 15 identified gaps, indicating that governance reform and new policy instruments are the highest-leverage intervention targets for sustainable pollution abatement. Central Pollution Control Board [CPCB], 2022; (CPCB, n.d.-a, n.d.-b); CPCB], 2023; Ulrich et al., 2009; Ministry of Jal Shakti [MoJS], 2025)



Current response	Recommended intervention
Environmental flow norms notified but not operationalised in dam and barrage operating rules.	Operationalisation of notified environmental flow norms through mandatory incorporation into dam and barrage operating rules. Implementation of catchment-level groundwater recharge programmes. Integration of flow restoration (Aviral Dhara) and water quality (Nirmal Dhara) as interdependent programme objectives with unified monitoring.
STP construction continues under Namami Gange Phase II. No parallel demand-side intervention or decentralised treatment mandate.	Adoption of the sewage generation-to-treatment CAGR ratio as a primary programme performance indicator. Mandatory provision for decentralised treatment in all new urban development in Ganga basin states. Introduction of demand-side load management measures including water use efficiency standards and greywater reuse mandates.

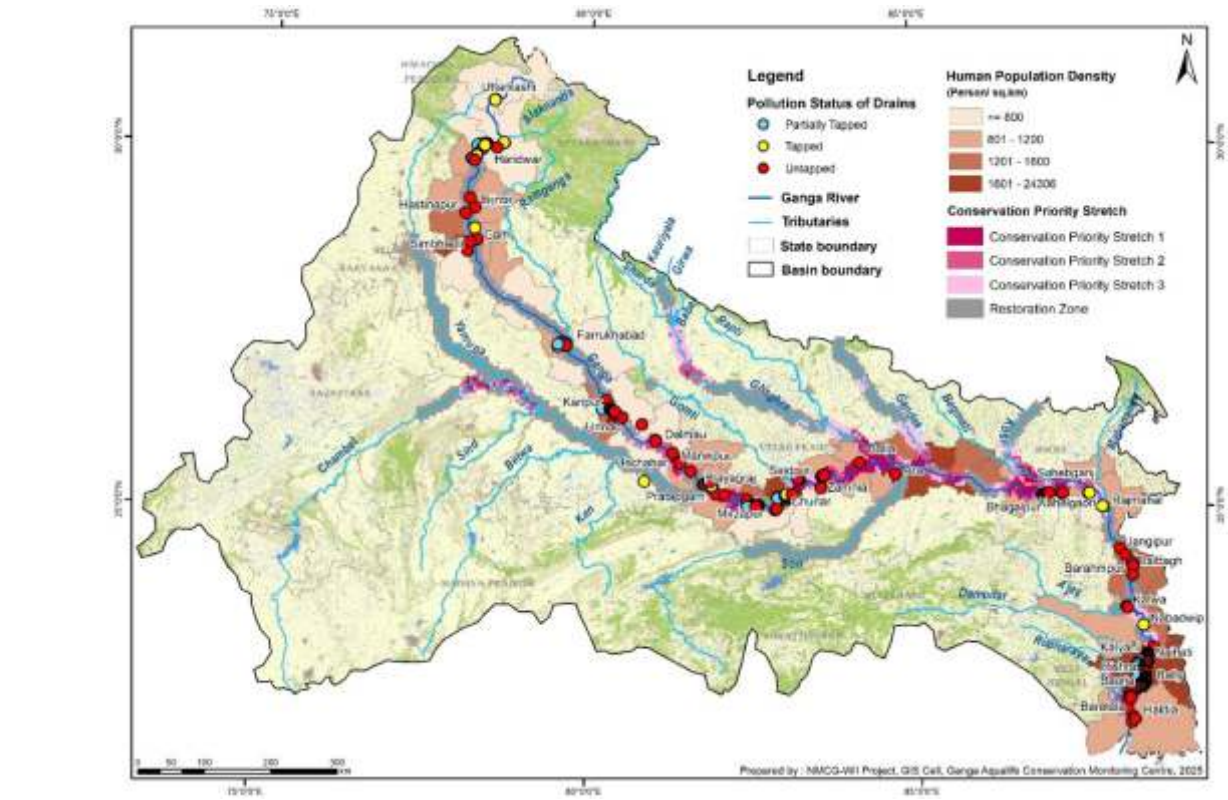




State-by-State Performance & Technology Deployment

State	West Bengal	Uttar Pradesh	Bihar	Jharkhand	Uttarakhand
STPs	42	40	8	3	53
Technologies Deployed	WSP/OP×23, ASP×9, SBR×6, TP×3, FBAS×2	ASP×8, SBR×7, UASB×7, FSTP×3, FOR×3, MBBR×3, WSP×3, +4 others	SBR×7, MBBR×1	SBR×3	SBR×22, EC×17, MBBR×9, ASP×3, SBT×1
BOD Removal Distribution	33% failing · 50% ≥70% (of 30 measured)	11% failing · 67% ≥70% (of 36 measured)	71% failing · 0% ≥70% (of 7 measured)	0% failing · 100% ≥70%	19% failing · 75% ≥70% (of 48 measured)
Verdict	Moderate Risk	Adequate	CRITICAL	Strong	Adequate

Figure 9.24 Spatial Distribution, Capacity, and Performance of Sewage Treatment Plants Across the Ganga Basin



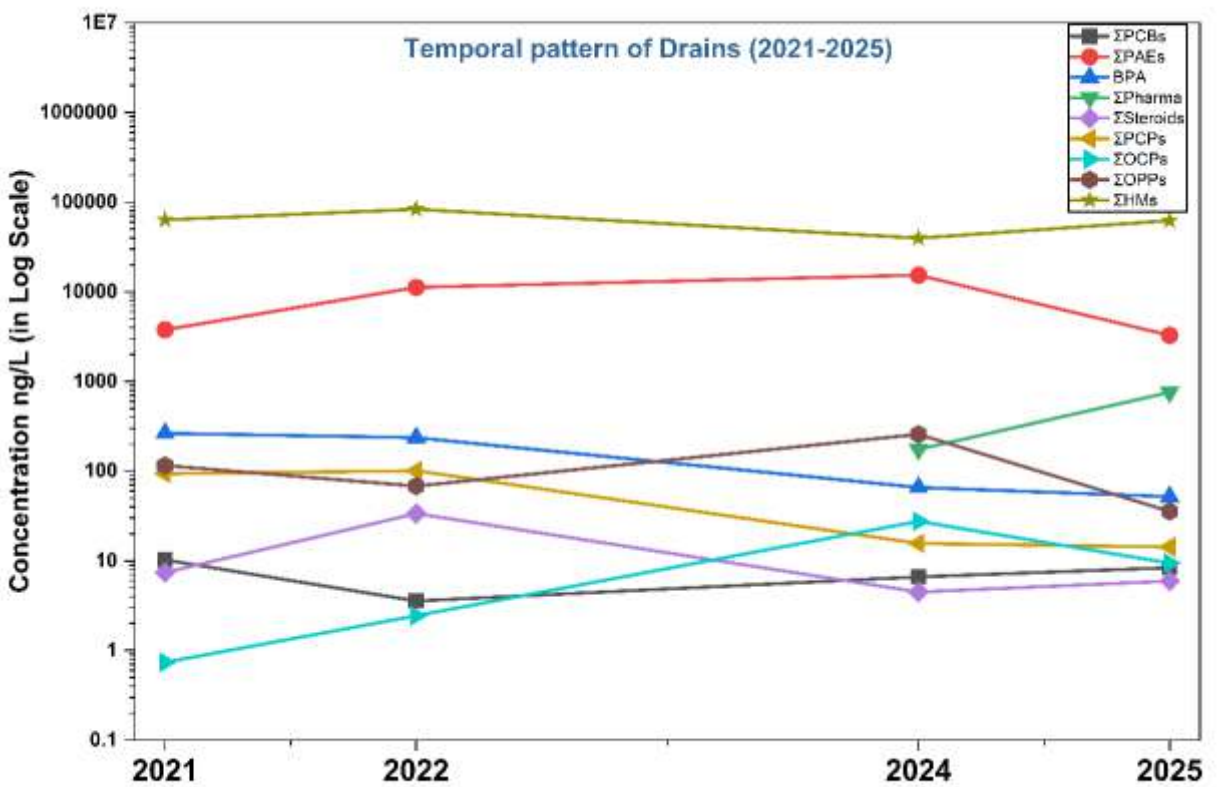
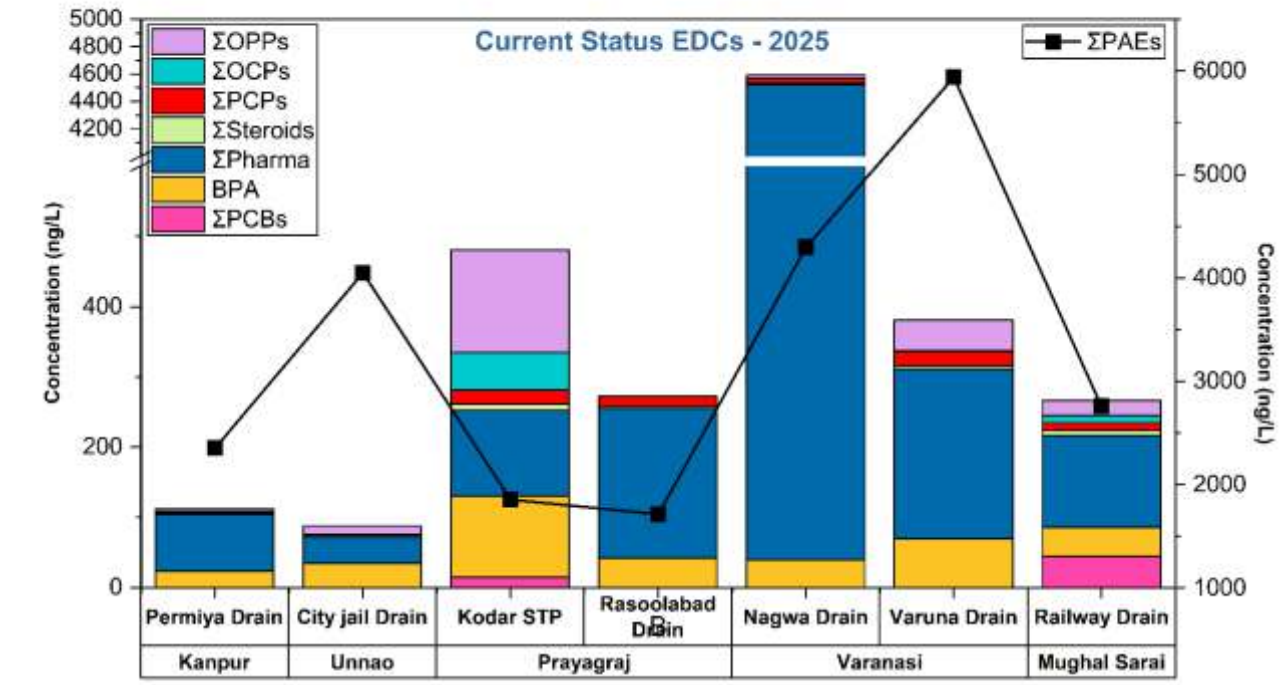
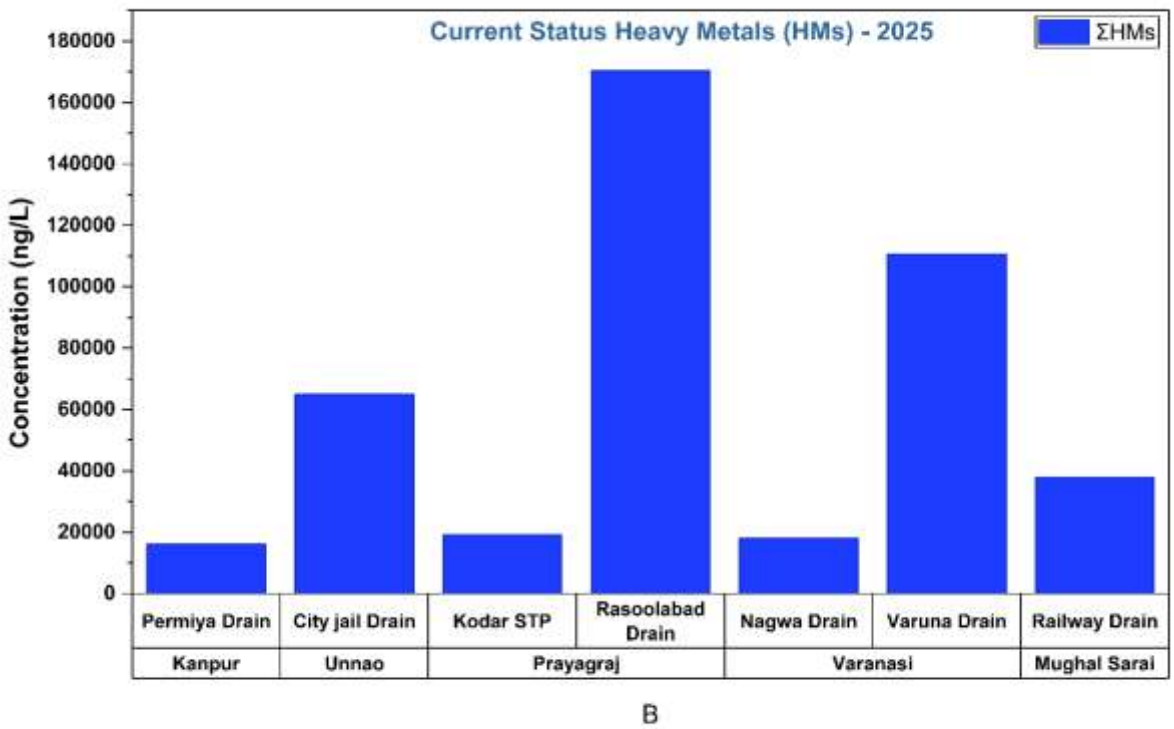


Figure 9.25 (a) Spatial distribution and status of priority drains (tapped, partially tapped, and untapped) across the Ganga River (b) Drain Pollution Status and Temporal Trends (2021-2025)



A



B

Figure 9.26 EDCs and Heavy Metal burden of drains across Uttar Pradesh

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CHAPTER 10

ANTHROPOGENIC STRESSORS



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SUMMARY

Freshwater ecosystems are increasingly threatened by interacting anthropogenic stressors, particularly in large river systems such as the Ganga. This study provides a spatio-temporal assessment of multiple human-induced pressures using a Biodiversity Evaluation Unit (BEU)-based framework across four sampling years (2018-2024). Key stressors examined included fishing, sand mining, ferry activity, untapped drain discharge and physical barriers.

Spatial analysis indicates that high biodiversity zones are disproportionately exposed to anthropogenic stressors, with distinct longitudinal patterns along the River. While upper stretches are primarily affected by hydrological alterations due to dams and barrages, the middle and lower stretches experience compounded pressures from pollution, extractive activities, and increasing navigation intensity. Temporal trends reveal a decline in traditional extractive pressures such as fishing and mining, contrasted by a marked increase in ferry and navigation activities, indicating a structural shift toward infrastructure-driven stressors. These emerging pressures introduce new ecological risks, including habitat disturbance, altered hydrodynamics, and impacts on sensitive species such as the Gangetic dolphin.

The study further highlights that these stressors operate cumulatively and synergistically, intensifying ecological disruption, fragmenting habitats, and reducing ecosystem resilience. Hydrological barriers, in particular, disrupt connectivity, impede species migration, and modify sediment and flow regimes, with cascading impacts on biodiversity and ecosystem functioning. The findings underscore that piecemeal or sectoral interventions are insufficient. It calls for an integrated, cohesive, basin-scale management approach that prioritizes pollution control, regulation of extractive activities, restoration of ecological connectivity, and incorporation of ecological safeguards into navigation and development planning.

10.1 INTRODUCTION

Freshwater ecosystems worldwide are undergoing rapid degradation and loss due to intensifying anthropogenic pressures, with large river systems being particularly vulnerable to cumulative environmental stressors (Dudgeon et al., 2006; Vörösmarty et al., 2010). Despite constituting only 0.49% of global freshwater resources, rivers play a disproportionately critical role in sustaining ecological integrity and human well-being (Okpoli & Iselowo, 2019; Wang et al., 2023). Globally, river ecosystems support nearly 10% of total biodiversity, with a substantial proportion currently under threat, underscoring the urgency of conservation efforts (Living Planet Report, 2020). Rivers also function as ecological corridors, facilitating species migration, genetic exchange, and gene flow essential for maintaining ecosystem resilience (Palmer & Ruhi, 2019).

Among the large river systems, the Ganga River represents a critically important yet highly stressed ecosystem, supporting exceptional biodiversity while sustaining millions of people and simultaneously experiencing severe ecological decline (Sarkar et al., 2012; Singh & Singh, 2020). The dual role as both an ecological hotspot and a socio-economic lifeline renders the river particularly vulnerable to unsustainable human exploitation. Over the decades, the Ganga River and associated floodplains have experienced substantial disturbances due to competitive and conflicting use of riverine resources (Sarkar et al., 2012).

Globally, nearly 80% of sewage and industrial effluents are discharged into river systems without adequate treatment, significantly accelerating water quality deterioration. A primary driver of degradation of the Ganga River is the continuous influx of pollutants from agricultural runoff, industrial discharge, and untreated domestic sewage. These pollutant inputs introduce excessive nutrient loads and toxic contaminants-including endocrine-disrupting compounds (EDCs) and microplastics-thereby altering water chemistry and disrupting biological processes (Pal et al., 2010; Sah et al., 2024 a, b, c; Sharma et al., 2025). Nutrient enrichment frequently leads to eutrophication, resulting in algal blooms, hypoxia, and widespread ecological impacts (Smith et al., 1999; Wurtsbaugh et al., 2019). Such shifts can transform river systems from biologically diverse states to degraded, low-oxygen regimes dominated by tolerant species, resulting in altered food webs, which ultimately undermine essential ecosystem services (MEA, 2005; Richter et al., 2010).

The riverine resources of the Ganga River have multiple competitive and conflicting uses; for example, water is needed for agriculture, industries, domestic purposes, hydroelectricity, and navigation, while also being essential for maintaining ecological flows that sustain aquatic biodiversity and ecosystem processes. Similarly, the river banks and associated floodplains function as critical habitat for aquatic and semi-aquatic species, supporting key life history processes such as breeding, nesting, foraging, and refuge from predators, or the river banks can be used for agriculture. However, these riverscapes are increasingly converted or modified for agricultural and other human uses, leading to trade-offs between ecological integrity and socio-economic demands. Overexploitation of biological resources, particularly through unregulated and destructive fishing practices, further contributes to decline in fish diversity and abundance (Allan et al., 2005; Sarkar et al., 2010; Choudhary et al., 2023). Intensive harvesting can lead to recruitment overfishing, where populations fail to replenish due to excessive removal of breeding individuals. Indiscriminate fishing gear also results in bycatch, affecting non-target and endangered species such as the Gangetic dolphin and gharial (Reeves et al., 2003; Kelkar & Dey, 2020; Badola et al., 2025). Given the key role of fish in maintaining trophic structure, such declines can trigger cascading effects across food webs and reduce overall ecosystem resilience (Estes et al., 2011; Sarkar et al., 2012). These impacts are compounded by the introduction of non-native species through expanding aquaculture practices. Non-native species often outcompete indigenous fauna due to high adaptive capacity and absence of natural predators, thereby reducing native biodiversity and ecosystem stability (Mack et al., 2000; Britton et al., 2010). When combined with other stressors, such invasions can accelerate ecosystem impairment and hinder recovery processes.

Physical alterations of riverine habitats also represent a major driver of ecological change. Unsustainable sand and gravel mining has significantly modified river morphology and sediment dynamics, reshaping habitat availability and destabilizing channel structure (Kondolf, 1997; Koehnken et al., 2020). The proliferation of unregulated mining activities in the Ganga River has further intensified habitat fragmentation and ecological instability (Padmalal & Maya, 2014; Kamboj et al., 2022; Singh et al., 2023).

Hydrological modifications resulting from dams and barrages have further compounded these challenges by altering natural flow regimes and disrupting longitudinal connectivity. These barriers impede migration pathways, restrict gene flow, and limit access to critical breeding and feeding habitats for several aquatic species, including the golden mahseer and the Gangetic dolphin (Sonkar & Gaurav, 2020; Yadav et al., 2020; Zarri et al., 2022). Such fragmentation increases vulnerability to local extinction and alters sediment transport and floodplain dynamics, thereby affecting downstream productivity (Nilsson et al., 2005). More recently, navigation activities such as ferry and barge movement have emerged as additional stressors, particularly along the densely populated stretches of the River. Motorized boats and ferries generate turbulence, elevate pollution loads, and modify hydrodynamic conditions, leading to reduced plankton productivity and disruption of aquatic food webs (Nowacek et al., 2007; Bickel et al., 2011; Burgin & Hardiman, 2011; Garrison & Tang, 2014). Prolonged

disturbance may also induce behavioral and physiological stress responses in aquatic fauna, as has been found in the case of Gangetic dolphin (Dey et al., 2019).

However, despite increasing recognition and evidence of these stressors in recent literature, limited studies have systematically evaluated their combined spatial and temporal impacts along the entire length of the Ganga River (Shukla et al., 2018; Mohapatra et al., 2023; Zafar & Kumari, 2024). Furthermore, the absence of integrated frameworks for assessing multiple anthropogenic pressures has constrained the development of effective river management strategies. Therefore, the present study adopts a multi-stressor perspective to evaluate the spatial distribution and temporal trends of key anthropogenic pressures along the Ganga River using a systematic BEU-based approach. By integrating multiple stress indicators, the study aims to identify critical hotspots and provide an integrated assessment of ecological pressures to support evidence-based conservation and sustainable management of the river system.

10.2 METHODS

The entire Ganga River was segmented into 5 km stretches, hereafter referred to as Biodiversity Evaluation Units (BEUs), using Geographic Information System (GIS) and remote sensing techniques implemented in ArcGIS 10.3. Details are provided in Chapter 2 of this report. Data on multiple anthropogenic stressors were systematically collected at the BEU level during biodiversity monitoring surveys conducted across four sampling years (2018, 2019, 2020, and 2024).

Temporal variation in anthropogenic stressors was evaluated based on field observations of fishing, ferry, and mining activities recorded during the monitoring periods. Fishing intensity was quantified by enumerating active fishing boats and deployed fishing nets within each BEU during survey transects. Similarly, mining intensity was assessed by recording the number of operational extraction units, including earthmovers, dredgers, trucks, and tractors associated with sand and gravel extraction. The encounter rate (ER) for mining was calculated as the total number of active units per BEU divided by the BEU length (5 km) and expressed as units per kilometre (km^{-1}). Pollution sources were quantified by documenting the number of drainage outlets, sewage discharge points, and industrial effluent outlets within each BEU. Ferry activity was assessed based on the frequency of ferry boat encounters recorded during surveys and standardized as encounter rates (km^{-1}) to ensure comparability across BEUs and sampling periods.

In addition, major physical barriers, including dams and barrages along the Ganga River, were identified, geo-tagged, and incorporated into the spatial database for subsequent analysis. For spatial interpretation, High Biodiversity Zones (HBZs) identified in the Phase I of the NMCG-WII project (WII-GACMC, 2019) were grouped into upper, middle and lower zones of the Ganga River, with HBZ-1 representing the upper zone, HBZ-2 and HBZ-3 the middle zone, and HBZ-4, HBZ-5, and HBZ-6 the lower zone of the Ganga River.

10.3 RESULTS & DISCUSSION

10.3.1 Fishing

Fishing is a long-standing traditional activity of the local communtiites residing along the Ganga River and constitutes a critical source of food and livelihood. However, increasing fishing pressure, particularly through unregulated and destructive practices, poses a significant threat to aquatic biodiversity and ecosystem stability (Sarkar et al., 2010; Choudhary et al., 2023). Fishing activities were recorded across all BEUs, indicating widespread exploitation of riverine resources. Notably, the highest concentration of fishing activity was observed in HBZ-3 to HBZ-6 (Figure 10.1). The encounter rate of fishing activities marked a temporal variation across the study period, with the highest value recorded in 2020 (5.40 km^{-1} ± 0.41 SE), followed by 2019 and 2018, while the lowest encounter rate was observed in 2024 (Figure 10.2).



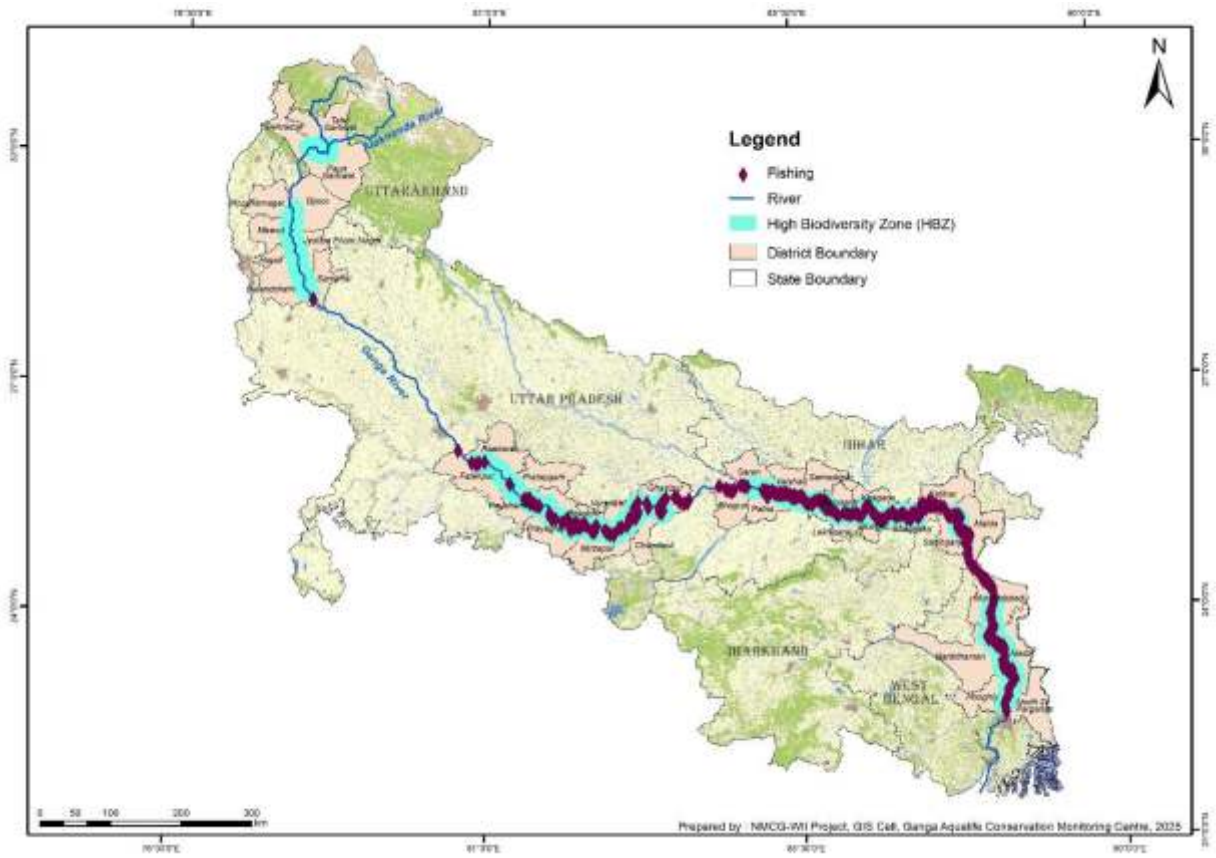


Figure 10.1 Spatial distribution of fishing activities along the Ganga River

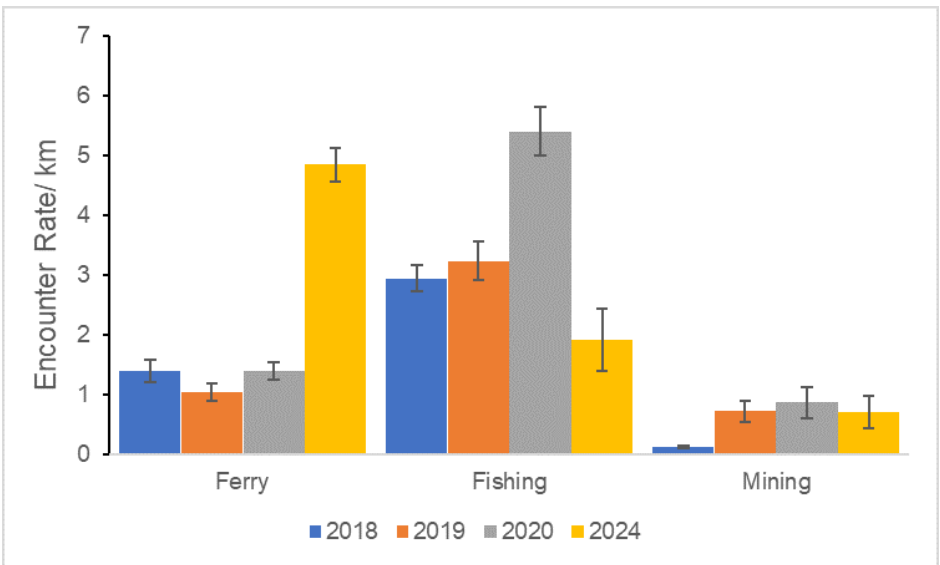


Figure 10.2 Encounter rate (km^{-1}) of different anthropogenic threats along the Ganga River during four monitoring years

The concentration of fishing effort within HBZs indicates a strong association with fish availability, as these ecologically productive stretches are likely to support higher biomass and species diversity. Comparable spatial patterns have been reported in other river systems, where fishing effort is disproportionately focused in biologically rich habitats (Allan et al., 2005; Sarkar et al., 2012). This localized intensification can accelerate resource depletion and increase ecological stress within key habitat zones. Recent studies elsewhere further demonstrate that such fishing hotspots are particularly vulnerable to rapid stock declines under sustained anthropogenic pressure (Reid et al., 2019; Tickner et al., 2020). Temporal variation in fishing intensity further indicates the influence of dynamic socio-economic and environmental factors, including fluctuations in fish stock

availability, livelihood dependence, and regulatory enforcement. Similar patterns have been documented in large river systems, where fishing effort responds to both ecological conditions and human pressures (Choudhary et al., 2023; FAO, 2024). Emerging evidence also highlights the role of climate variability and altered hydrological regimes in shaping fish distribution and catch dynamics, thereby influencing fishing patterns over time (Grill et al., 2019; Arthington et al., 2021). The relatively lower encounter rate recorded in 2024 may indicate reduced effort, regulatory interventions, or shifts in resource availability; however, further investigation is required to clarify these drivers.

Persistent unregulated fishing, particularly involving destructive methods, can degrade spawning grounds, reduce population sizes, and disrupt trophic interactions. These alterations may propagate through the food web, affecting ecosystem structure and functional dynamics (Sarkar et al., 2010; Estes et al., 2011). The observed patterns, therefore, underscore the need for targeted management interventions in ecologically sensitive zones to balance livelihood requirements with long-term sustainability of the riverine ecosystem.



10.3.2 Mining

Mining activities, particularly sand extraction and stone quarrying, constitute a significant anthropogenic stressor affecting the structural and ecological integrity of the Ganga River system (Pandey et al., 2023; Zafar & Kumari, 2024). The present study revealed marked temporal variation in mining intensity across the four monitoring years. The highest mining encounter rate was recorded in 2020 (0.86 km^{-1} ± 0.25 SE), followed by 2019 and 2024, while the lowest was observed in 2018 (Figure 10.2). Spatial analysis indicated that mining activities were predominantly concentrated within HBZ-4 and HBZ-6, suggesting a higher susceptibility of these ecologically important stretches to extraction pressures (Figure 10.3).

The spatial clustering of mining activities within these zones likely reflects favourable geomorphological and sedimentary conditions that facilitate resource extraction (Li et al., 2024). However, intensified mining pressure in such biodiversity-rich regions can substantially modify river morphology, disrupt sediment transport dynamics, and degrade habitat quality (Kaur et al., 2025). These alterations may, in turn, influence channel stability and reduce habitat heterogeneity, which is critical for sustaining aquatic biodiversity. Unregulated mining practices have been widely reported to disturb natural flow regimes, accelerate riverbank erosion, and deteriorate water quality, thereby adversely affecting both aquatic and riparian ecosystems (Ouma et al., 2022). In HBZs, these disturbances can result in the loss of critical breeding habitats and displacement of native species (Damseth et al., 2024), resulting in long-term ecological consequences. Sustained and unregulated mining within HBZs may ultimately compromise the ecological integrity and functional resilience of the river system, with cascading impacts on biodiversity and the livelihoods of communities dependent on these freshwater resources (Sonter et al., 2018).

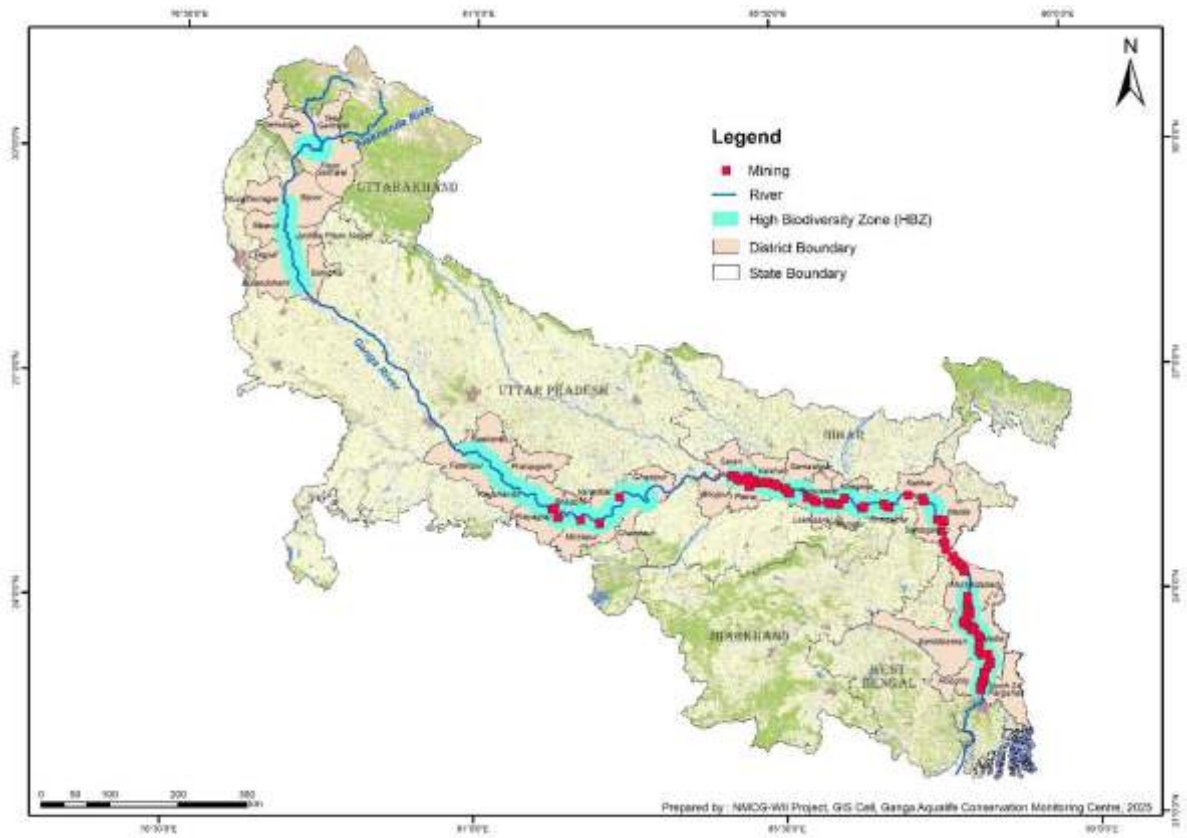


Figure 10.3 Spatial distribution of sand mining activities along the Ganga River

10.3.3 Agricultural Drainage and Industrial Effluent Outlets

Pollution arising from agricultural runoff, industrial discharge, and untreated sewage represents a major anthropogenic stressor affecting the water quality and ecological integrity of the Ganga River system. These inputs introduce excessive nutrients, pesticides, heavy metals, endocrine-disrupting compounds (EDCs), and organic wastes into the river, thereby altering its physicochemical characteristics and disrupting biological processes (Xu et al., 2022; Mishra et al., 2023). The present study revealed that pollution load was highest in HBZ-2, followed by HBZ-3 and HBZ-6 (Figure 10.4). The concentration of pollution within these high-biodiversity zones indicates their increased vulnerability to contaminant influx and accumulation, likely due to intensified anthropogenic activities and nutrient loading in these stretches. Such spatial patterns suggest that ecologically significant zones may act as sinks for pollutants, thereby experiencing disproportionate ecological stress. Elevated nutrient inputs in these zones can promote eutrophication, resulting in algal blooms, hypoxic conditions, and subsequent stress on aquatic organisms (Wurtsbaugh et al., 2019). In addition, untreated sewage discharge further exacerbates water quality degradation, intensifying ecological pressures on aquatic systems (Bhat & Qayoom, 2021). The accumulation of pollutants in biodiversity-rich areas can adversely affect native species, leading to declines in fish populations and disruption of aquatic food webs (Chakraborty, 2021). Over time, sustained exposure to such stressors may drive habitat degradation, biodiversity loss, and reduced ecosystem resilience. Collectively, these pollution pressures may significantly compromise the ecological integrity of the river system and adversely affect the livelihoods of communities dependent on its resources (Grizzetti et al., 2017).



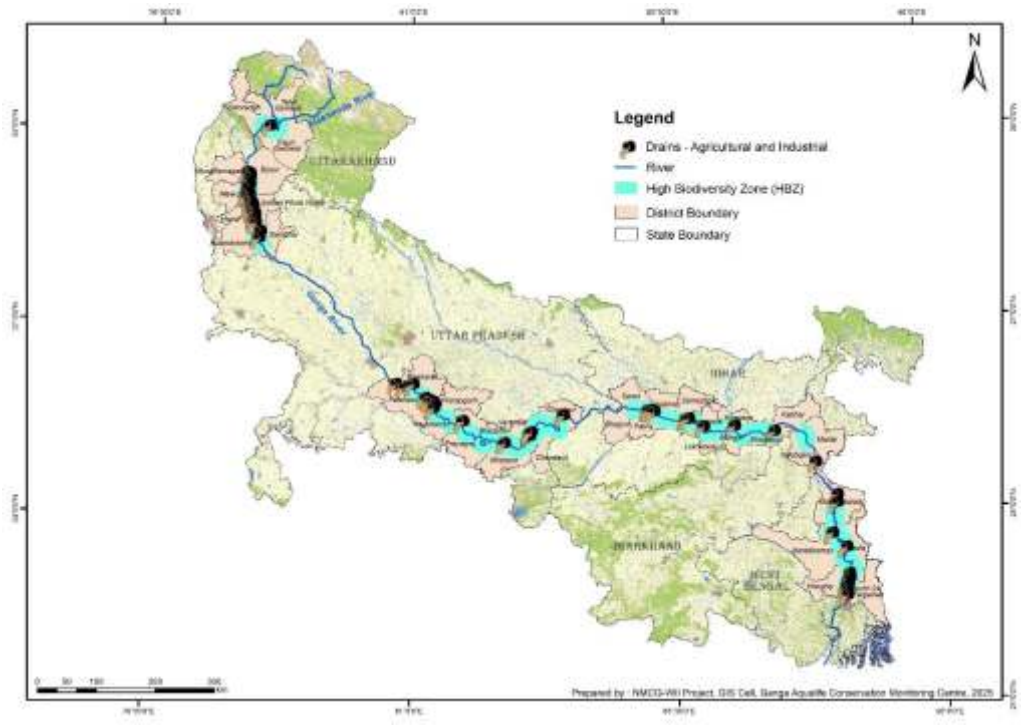


Figure 10.4 Spatial distribution of major agricultural and industrial effluent discharge points along the Ganga River

10.3.4 Ferry

Ferry operations represent a significant human-induced activity along the Ganga River, particularly in densely populated regions, contributing to localized ecological impacts and changes in water quality. Vessel movement alters hydrodynamic conditions, while propeller action resuspends sediments and disturbs benthic habitats (Burgin & Hardiman, 2011). The ferry operation is also known to result in mortality or injury of the Gangetic dolphin (Mallick, 2014; Badola et al., 2025) and Chinese river dolphin or Baiji (*Lipotes vexillifer*) (Zhou et al., 1979; Turvey, 2009). In addition, the discharge of untreated waste and sewage from boats can further increase contaminant inputs into the river system, thereby exacerbating physicochemical alterations (Sarkar et al., 2019; Zhang et al., 2024). The present study revealed marked temporal variation in ferry activity across the sampling years. The highest ferry encounter rate was in 2024 (4.85 km^{-1} ± 0.28 SE), while the lowest was in 2019 (1.03 km^{-1} ± 0.15 SE) (Figure 10.2). Spatially, ferry-associated disturbances were most prominent in HBZ-6, followed by HBZ-4 and HBZ-5 along the Ganga River (Figure 10.5).

The elevated intensity of vessel movement within these zones indicates increased pressure on biologically important habitats. Such activity can adversely affect sensitive aquatic species by altering behavioural responses, disrupting communication, and interfering with movement and migration processes. Previous studies have demonstrated that boat traffic can induce avoidance behaviour, elevate stress levels, and modify habitat use in aquatic fauna, particularly in species dependent on acoustic and hydrodynamic cues (Nowacek et al., 2007; Garrison & Tang, 2014). Over time, sustained navigation pressure, particularly when acting in combination with other stressors, can alter habitat use patterns and reduce the suitability of critical zones for sensitive species. These impacts may ultimately influence ecological functioning and affect communities dependent on riverine resources (Dudgeon et al., 2006; Halpern et al., 2008).



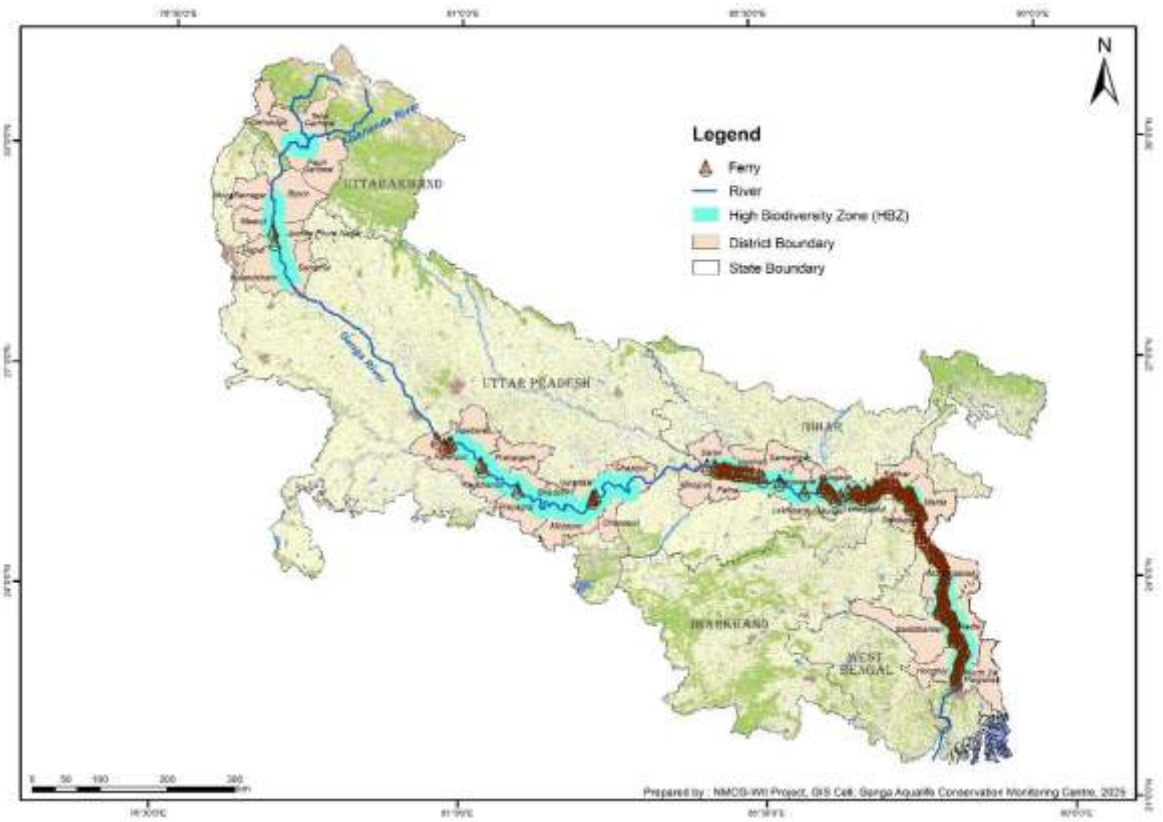


Figure 10.5 Spatial distribution of ferry operations along the Ganga River

10.3.5 Dams and Barrages

Dams and barrages represent major hydraulic interventions in the Ganga River system, significantly modifying natural hydrological regimes and ecological processes. While these structures provide essential benefits such as water storage, irrigation, and hydropower generation, they also induce substantial changes in river hydromorphology and longitudinal connectivity. The present study identified six dams and seven barrages along the Ganga River, which act as key barriers for species movement, influencing river continuity and flow dynamics (Figure 10.6). The oldest physical barrier on the Ganga River is the Bhimgoda barrage, built in 1854, with the objective of diverting the Ganga River's water to the doab region (landscape between two rivers, here the Yamuna and the Ganga) for agriculture and related economic development. Later, more barrages and dams were built across the Ganga River; of these, the ecologically significant ones are the Bijnor barrage and the Farakka barrage. These structures, particularly the Bhimgoda barrage is known to have restricted the home range of the Gangetic dolphin (Das et al., 2022), as about 90% water is diverted from the barrage for agriculture through the Upper Ganga Canal, which resulted in low depth regime downstream of the Bhimgoda barrage, while the Farakka barrage is known to have altered the salinity regime and associated fish assemblage in the Ganga River (Suresh et al., 2017).

These physical barriers restrict migration pathways and gene flow of aquatic organisms, limiting access to critical breeding and feeding habitats and contributing to declines in aquatic faunal assemblages (Zarri et al., 2022). In addition, the obstruction of sediment transport reshapes riverbed morphology and reduces downstream sediment deposition, thereby influencing habitat structure and floodplain productivity (Kondolf, 1997; Nilsson et al., 2005). Alterations in natural flow regimes and seasonal flooding patterns further influence floodplain wetlands and associated ecosystems that support high biological diversity (Poff et al., 1997; Bunn & Arthington, 2002). Such hydrological modifications can fragment riverine habitats and drive shifts in species distribution. Moreover, these barriers exert pronounced pressure on sensitive and endangered species, including the golden mahseer, Gangetic dolphin, and gharial, by restricting movement and disrupting key life-history processes (Reeves et al., 2003; Yadav et al., 2024). Chapters on floral diversity and macroinvertebrates highlight the impact of the barrages and dams on the species assemblages. Over time, sustained hydrological alteration can reduce habitat connectivity and modify ecosystem functioning, with implications for both aquatic communities and human populations dependent on riverine resources (Richter et al., 2010).

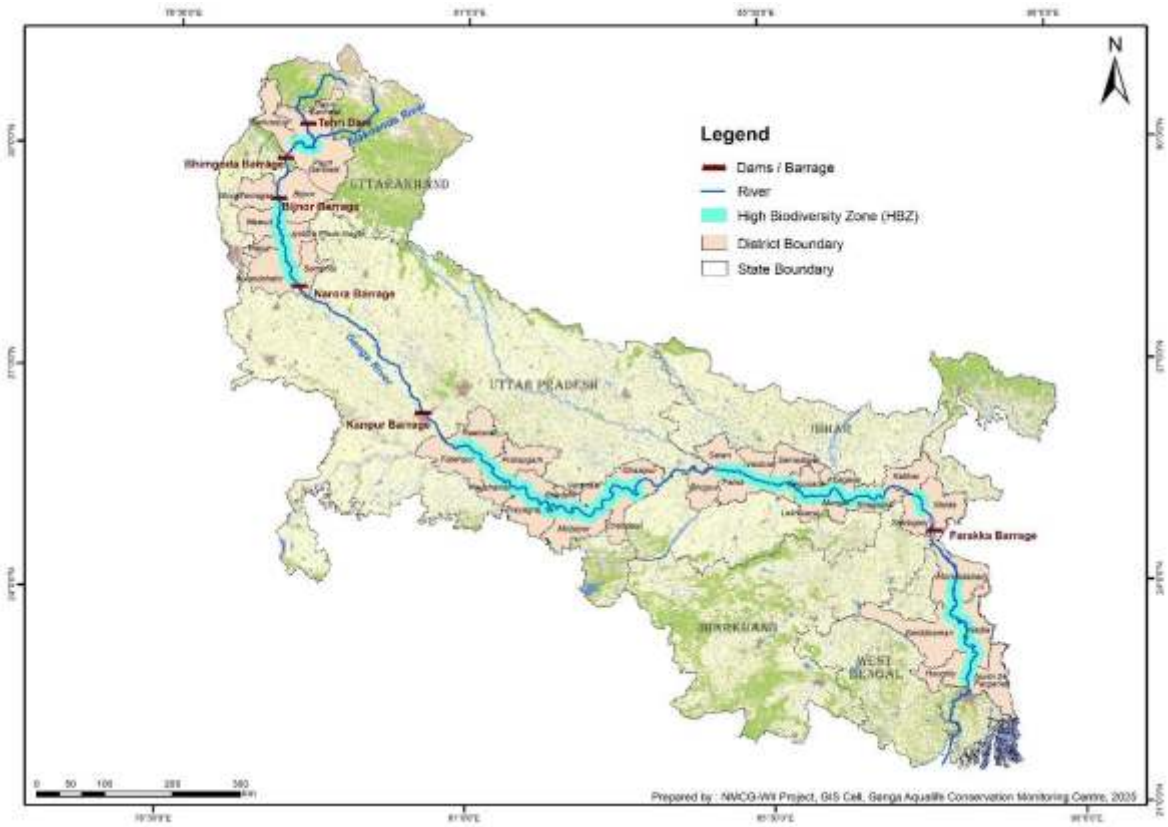


Figure 10.6 Spatial distribution of dams and barrages along the Ganga River

10.3.6 Trends in anthropogenic threats

Analysis of 414 BEUs across the study period revealed divergent temporal trajectories among the major stressors, reflecting a structural shift in the nature of anthropogenic pressure on the Ganga River system.

Ferry intensity exhibited an overall increasing trend over the study period (R^2 = 0.87, p = 0.06), although the relationship was statistically marginal. At the BEU level, increasing trends were observed in 78.74% of BEUs, while 12.80% showed decreasing trends, and approximately 1% exhibited no change in ferry presence (Figure 10.7). In contrast, fishing activity displayed a weak declining trend over time (R^2 = 0.31, p = 0.43). A decreasing trend was observed in the majority of BEUs (59%), whereas 28% of BEUs showed increasing trends, and approximately 5% exhibited no change (Figure 10.7). Mining activities were absent in 53% of the BEUs along the Ganga River. Among the BEUs where mining was recorded, 16% showed decreasing trends, 12% exhibited increasing trends, and 18% remained unchanged. Overall, mining intensity demonstrated a weak increasing trend; however, this trend was not statistically significant (R^2 = 0.28, p = 0.46).



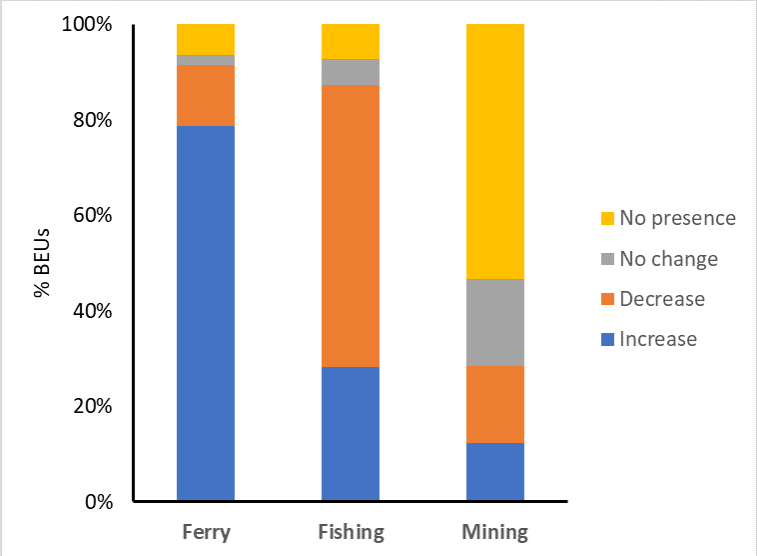


Figure 10.7 BEU level changes in different anthropogenic pressures between 2018 and 2024

10.4 CONCLUSIONS

The present findings demonstrate that the Ganga River is experiencing pervasive and interacting anthropogenic pressures that are collectively eroding its ecological integrity. Pollution, overexploitation, habitat degradation, and hydrological modifications do not operate in isolation; rather, their cumulative and synergistic effects intensify ecological disruption and threaten both biodiversity and river-dependent livelihoods. The observed longitudinal variation in stressors underscores the need for spatially differentiated management. Hydrological alterations dominate the upper stretches, while the middle and lower reaches are increasingly shaped by combined pressures from pollution, extractive activities, and intensified navigation. The presence of major barriers further compounds these impacts by disrupting ecological connectivity, particularly for migratory species.

Notably, recent trends indicate a shift from traditional extractive pressures toward infrastructure-driven stressors, with increasing navigation intensity emerging as a key concern. While such developments support economic objectives, they introduce new ecological risks that remain insufficiently addressed in current management frameworks. Taken together, these findings highlight that piecemeal interventions will be inadequate. Effective conservation of the Ganga River requires an integrated, basin-scale approach that explicitly accounts for cumulative impacts, through multi-dimensional targeted interventions. Strengthening wastewater treatment, regulating extractive activities, restoring connectivity, and embedding ecological safeguards within navigation planning are critical priorities. At the same time, incorporating community-based initiatives and addressing emerging pollutants will be essential for long-term resilience.

Ultimately, sustaining the Ganga River will depend on aligning ecological priorities with development agendas through coordinated, evidence-based, and participatory management. Without such an approach, the continued intensification of anthropogenic pressures is likely to further compromise the river's ecological and socio-economic functions.



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CHAPTER 11

GENETIC ASSESSMENT OF AQUATIC SPECIES IN THE GANGA RIVER

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SUMMARY

This chapter presents a comprehensive genetic assessment of select aquatic fauna (fishes, turtles and dolphin) in the Ganga River, using mitochondrial DNA (mtDNA) sequencing and microsatellite genotyping to evaluate genetic diversity, gene flow, and population demography across multiple taxa. In fish taxa, analysis of *Wallago attu* (176 samples; 2420 bp concatenated mtDNA) revealed high haplotype diversity (Hd = 0.984) paired with low nucleotide diversity (π = 0.006), indicative of a post-bottleneck rapid demographic expansion. Three phylogenetic clades were identified, lacking strict river-wise geographic concordance, suggesting basin-wide diversification driven by selective pressures rather than physical isolation. AMOVA demonstrated that 84.70% of genetic variation resides within populations, confirming high inter-tributary connectivity. Bayesian Skyline Plot analysis dated the major population expansion to approximately 0.04 million years ago during the late Pleistocene. For Sperata seenghala and S. aor, high haplotype diversity (Hd > 0.71) was recorded across three Indian river systems. Two divergent mtDNA lineages of S. seenghala were identified within the Ganga. AMOVA revealed substantial among-group differentiation (62.56%), with the Brahmaputra population exhibiting the highest genetic divergence (25.3%), potentially qualifying it as a distinct Evolutionary Significant Unit (ESU). Bagarius bagarius displayed extremely low COI-based genetic diversity (Hd = 0.051; π = 0.00009), with slightly higher variation detected via Cyt b, suggesting population decline attributable to habitat fragmentation and anthropogenic pressures.

In the genetic analysis of turtles, the critically endangered *Batagur dhongoka* (92 samples; 1591 bp concatenated mtDNA) from two rehabilitation centres revealed high haplotype diversity (Hd = 0.93) with low nucleotide diversity (π = 0.002-0.003). Microsatellite-based Bayesian clustering identified two weakly differentiated genetic clusters, with low inter-population FST values (mtDNA: 0.003; microsatellites: 0.074). G-W index analyses indicated genetic bottlenecks in both populations, consistent with historically low effective population sizes. For *Lissemys punctata andersoni*, five distinct phylogeographic lineages were resolved across the Asian Flap-shelled Turtle (AFT) complex, with divergence times traced to the

Cretaceous (~116 MA). Population expansion was detected in L. p. andersoni from approximately 1.25 MA, while other lineages exhibited demographic stability. Batagur baska displayed moderate haplotype diversity (Hd = 0.782) but very low nucleotide diversity (π = 0.00125), with Bayesian Skyline Plots evidencing a population decline initiated ~25 kya. Among Pangshura species, high haplotype diversity was recorded in *P. tentoria* and *P. tecta*, with maternal gene flow detected across multiple river systems.

Further, the complete mitogenome of *Platanista gangetica* (16,319 bp) was characterised. Control region analysis revealed remarkably low genetic diversity (Hd = 0.534; π = 0.00097), consistent with historical founder effects and inbreeding. Phylogenetic analyses confirmed the species' basal cetacean placement, more closely allied to Mysticeti than to other river dolphins. These findings collectively point out the necessity of managing river systems as integrated conservation units, establishing Evolutionary Significant Units for genetically distinct lineages, implementing genetic monitoring programmes, and mitigating anthropogenic stressors including habitat fragmentation, overfishing, and illegal trade across the Ganga River.

11.1 INTRODUCTION

Conservation genetics plays a crucial role in addressing the challenges posed by habitat loss, climate change, and other threats to biodiversity. By integrating genetic information into conservation planning, scientists can make more informed decisions to ensure the long-term survival of endangered species and the health of ecosystems. The main goals of conservation genetics are to understand the genetic factors influencing the viability of populations, identify and manage threats to genetic diversity, and develop strategies for sustainable conservation. Genetic diversity of species has been correlated with individual fitness and the adaptive capacity of populations in the face of environmental changes. The reduction in genetic variability ultimately heightens the risk of extinction. Small populations face increased vulnerability to inbreeding and loss of genetic diversity due to genetic drift. Habitat fragmentation, another significant threat to various species, exacerbates these issues by impeding gene flow between populations. The levels of genetic diversity within populations and the divergence between them are anticipated to be influenced by the degree of fragmentation. As the geographic distance between fragments or the duration of isolation increases, the expectation is for a decline in genetic diversity within smaller populations, leading to population divergence.

Currently, a diverse set of molecular genetics techniques is being applied to evidence sources from a broad range of taxa, encompassing aquatic life conservation. This expansive application holds immense potential for the preservation of many endangered aquatic species. The assessment of genetic diversity encompasses various methodologies, such as examination of karyotypes and single-locus markers (including allozymes, mitochondrial DNA, restriction fragment length polymorphisms), employing random amplified polymorphic DNA, examining mtDNA sequences, scrutinising nuclear DNA sequences, and utilising microsatellites (simple sequence repeats). Currently, mitochondrial and nuclear DNA sequence data are the most informative methods for characterising genetic variability at or above the level of populations. Molecular markers offer a powerful toolset for unravelling population genetic structures, deciphering phylogeographic relationships, identifying management units (MUs - defined by shared distinctive allele frequencies among populations), and delineating evolutionarily significant units (ESUs) - characterised by robust phylogenetic structures based on multilocus mtDNA or nuclear DNA variations).



11.1.1 Conservation challenges for freshwater biodiversity

Freshwater ecosystems harbour over 40 per cent of the global fish species, underscoring their critical ecological significance. However, despite their immense value, numerous lakes, rivers, and wetlands worldwide face severe degradation due to human activities. Alarmingly, these aquatic ecosystems are undergoing decline at a rate outpacing that of terrestrial ecosystems. This concerning trend highlights the urgent need for concerted conservation efforts to mitigate the detrimental impact of human activities on aquatic habitats. The Ganga River is home to

various fish assemblages, with over 265 species reported across the system. Some studies have documented up to 143 freshwater species throughout its various stretches (Das et al.,2023; Sarkar,2023; Das et al.,2010). Various economically significant fish species, including *Tor tor*, *Wallago attu*, *Labeo rohita*, *Cabdio morar*, *Mystus seenghala*, play an important role in providing livelihood to local communities and serve as indicators of river health and ecological integrity (ICAR-CIFRI 2016; Sarkar, 2012; Das et al., 2010, 2023).

Turtles are one of the most threatened biotas on earth, with 40% of all extant turtles facing extinction risk (Stanford et al., 2020). The riverine ecosystem of India, particularly in one of the largest rivers, the Ganga, supports rich fauna and flora, including a major population of the species and subspecies of *Lissemys, Pangshura*, and *Batagur*. Among aquatic mammals, the Gangetic dolphin (*P. g. gangetica*) inhabits the major rivers of the Ganga River basin, apart from the Brahmaputra, Meghna, Karnaphuli-Sangu, Karnali, Sapta Koshi, and Narayani rivers of India, Bangladesh Nepal and potentially Bhutan (Sinha and Kannan, 2014; Smith et al., 2001; Sinha et al., 2000).



11.1.2 Threats

The historic distribution ranges of many aquatic species have shifted and are being increasingly confined to restricted zones. Primarily, human activities such as habitat destruction/fragmentation, hunting, and human-mediated translocation have influenced the distribution, population structure, and genetic diversity of aquatic species. Therefore, a study on genetic variability is crucial to identify the fitness of individuals, which regulates adaptation to changes in environmental conditions and stress. Degradation of genetic diversity reduces the adaptive potential and increases the chances of inbreeding, which poses the risk of extinction of the species. There have been very few scientific efforts, with almost no baseline information on the genetic status of threatened or endangered aquatic species of the Ganga River System. Hence, genetic assessment is crucial for the conservation and management of this key freshwater species (Geist, 2011). Genetics helps to determine the extent of genetic diversity within and among populations, which is essential for understanding the species' evolutionary potential and adaptive capacity. Low genetic diversity can make populations more susceptible to disease, environmental changes, and reduce their chances of long-term survival (Nonić and Šijačić-Nikolić, 2020; Booy et al., 2000).

11.1.3 Conservation Genetics of Fishes

Molecular markers have been extensively used in population genetic studies (Zhao et al., 2013; Wei et al., 2013; Sun et al., 2012). Mitochondrial DNA is inherited maternally and has proven to be a useful molecular marker in studying fish populations due to its small size, relatively rapid base substitution rate, and lack of recombination (Guo et al., 2004). Furthermore, the varying evolution rate in different regions makes mtDNA suitable for research at various levels of evolution (Galtier et al., 2009; Cann et al., 1984).

Limited research has been conducted on the genetic characteristics of *W. attu*, focusing mainly on the species' biology (Chen et al., 2009; He and Chen, 2007; Wu et al., 1999), barcoding, and phylogeny from the Indus River (Sajjad et al., 2023). The genus Sperata is one of the largest catfish that belongs to the family Bagridae and is widely distributed in India, Pakistan, Bangladesh, Afghanistan, and Nepal (Talwar & Jhinghran, 1991). The genus *Sperata* was previously known as *Aorichthys/Mystus* and was recognised as one of the most commercially important catfish species (Froese and Pauly, 2011; Saigal & Motwani, 1961). Due to their high nutritional value and low number of intramuscular bones, Sperata species have a huge demand in South Asian countries (Mohanty et al., 2012). Based on the morphological characteristics, four species of Sperata are currently recognised from Asia (Ng & Kottelat, 2013; Ferraris & Runge, 1999; Talwar & Jhinghran, 1991; Day, 1878). These four species are as follows: *S. seenghala*

(Sykes, 1839), *S. aor* (Hamilton, 1822), *S. acicularis* (Ferraris & Runge, 1999), and *S. aorella* (Blyth, 1858). Catfish can tolerate wide ranges of temperature (38-40°C), low dissolved oxygen, and salinity along with variable water conditions, because of their robust air-breathing system (Yadav et al., 2018; 2017). Among the four species of the genus *Sperata*, the giant river-catfish (*S. seenghala*) and the long-whiskered catfish (*S. aor*) have a wide distribution in the Indian subcontinent and are recognised as 'Least Concern' in the IUCN Red (Gupta, 2015). High anthropogenic activities in the Ganga River system, such as extensive fishing, water abstraction, pollution, siltation, and invasion of exotic species, are threatening the *Sperata* populations. Previous studies on giant river catfish focused on the genetic assessment of *S. seenghala* using Randomly Amplified Polymorphic DNA (RAPD) markers (Garg et al., 2014; Saini et al., 2010), mtDNA markers (Kumari et al., 2017), and microsatellite markers (Acharya et al., 2019). The microsatellite-based stock discrimination of *S. aor* revealed the existence of three genetic stocks from the connected vicinity of the Ganga River (Nazir & Khan, 2017). Reliable sampling is essential for resolving the two species' genetic structure and diversity. An appropriate management plan for a different stock can be prepared by incorporating reliable knowledge about existing lineages from species distribution. Due to the maternal mode of transmission and more rapid evolution than the nuclear genome, mitochondrial DNA (mtDNA) provides reliable information on the relationships among closely related species and populations (Brown et al., 1979). In particular, the mtDNA control region (CR) is a highly variable portion and estimated to have five times the substitution rate as the rest of the sequences in mtDNA (Parsons et al., 1999; Aquadro & Greenberg, 1983). For this reason, mtDNA markers are widely acceptable for population genetics studies (Gupta et al., 2018; Wan et al., 2004).

Bagarius bagarius, also known as the dwarf goonch, is a large predatory catfish native to freshwater ecosystems (Saha et al., 2021). It stands out due to its environmental, cultural, and economic significance across India. Found throughout the Ganga River system and extending into the Brahmaputra and other major river systems, this member of the Sisoridae family plays an important role as a top predator, helping to regulate aquatic food webs and maintain ecosystem balance (Saha et al., 2021). Its distribution spans several countries, including India, Nepal, Bangladesh, and Pakistan, where it is not only an integral part of local fisheries but also holds cultural value in many riparian communities (Zeng et al., 2025). Despite its presence across a broad geographic range, they are increasingly threatened by habitat degradation, pollution, dams and barrages, and overexploitation. B.bagarius is currently listed as 'Vulnerable' according to the IUCN Red List (Ng, 2022). Through molecular tools such as mitochondrial DNA sequencing or microsatellite markers, population structure can be detected, cryptic lineages identified, and the question of whether geographically separated groups should be treated as distinct Evolutionarily Significant Units (ESUs) or Management Units (MUs) is evaluated (Abdul-Muneer, 2014; Hoshino et al., 2012; Ashley and Dow,1994). Studies have corroborated

the population status and structure using mitochondrial markers by Nagarajan et al (2016), and also by traditional morphological and meristic approaches, by Paul et al. (2019), which together provide a comprehensive understanding of the species' genetic differentiation and taxonomic clarity across its distribution range. Lashari et al (2016) assembled the full mitochondrial genome (~16,457 bp) from a *Bagarius* specimen sampled in Pakistan's Indus River, containing all 13 protein-coding genes, 2 rRNAs, and 22 tRNAs.

Cabdio morar (Hamilton, 1822), a small cyprinid fish, a member of the Danionidae family, plays a vital role in sustaining food webs, trophic interactions, and biodiversity (Coad et al.,2018; Barman et al.,2024; Assam State Wetland Authority,2024). Its presence reflects the health of the freshwater ecosystem, and it is valued for both its ecological role and as a part of the natural heritage of the Ganga basin (Das et al., 2023). Although classified as Least Concern, it faces extensive ecological pressures in the Ganga River basin (WII-NMCG 2018). Its distribution spans the middle and lower Gangetic plains, and populations are concentrated in relatively undisturbed zones (WII-NMCG, 2018; Das et al., 2023). Most research on C. morar focuses on morphological variation, especially differences in body shape and size across river populations. However, genetic studies are largely limited to basic DNA barcoding, and there is a lack of detailed population genetics or gene flow research for this species. This highlights a significant gap in understanding its genetic diversity (Singh et al., 2025; Kundu et al., 2022). Conservation genetics is crucial for addressing this gap, as it provides insights into the genetic structure, diversity, and connectivity of populations-information essential for effective management and long-term survival of the species (Frankham, 2010). Since genetic diversity is directly linked to individual fitness and a population's ability to adapt to environmental changes, a reduction in genetic variability can lead to increased inbreeding, decreased resilience. Expanding conservation genetics research on *C. morar* is essential for its sustained survival and for guiding targeted management efforts in the Ganga River system

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11.1.4 Turtles

All six extant *Batagur* species are categorised as 'Critically Endangered' (CR) in the IUCN Red List. The three-striped roofed turtle, *B. dhongoka*, is a freshwater turtle confined to northern India (Ganga River basin), Nepal, and Bangladesh (Das et al., 2019; Praschag et al., 2019). Once inhabiting the Ganga basin, the *B. dhongoka* populations are now drastically declining throughout their range by over 80%, due to unsustainable human pressure that has deteriorated riverine habitats (Rashid et al., 2000). As a result, the population of *B. dhongoka* has been extirpated from the Gomti River, a tributary of the Ganga, with a major population now restricted to the National Chambal Sanctuary, India (Das et al., 2019). Consequently, there is a critical need to reevaluate the present distribution of this species (Choudhury et al., 2000). Habitat loss and degradation are the principal threats to *B. dhongoka's* survival, as it degrades nesting sites, nursery habitats and basking sites and decrease food availability. Additionally, this species is used for subsistence consumption and is involved in some commercial trade, with recent confiscations reported in Malaysia and China (Das et al., 2019). Due to the increasing decline in its native range and a corresponding rise in international seizures, *B. dhongoka* has gained the highest level of protection within its native regions. In 2022, it was included in Schedule I of the Indian Wildlife (Protection) Act, 1972 and added to Appendix II of CITES.

The Northern River Terrapin, also known as *Batagur baska*, is a large, iconic riverine species found in estuaries of the Sundarbans region, spanning across Bangladesh and into parts of India (Praschag and Singh, 2019). Historically, the population of B. baska extended from Orissa and West Bengal in India, to Bangladesh and Myanmar (lower Ayayarwady, Sittaung, and Thanlwin), and in the south of the Kra River on Thailand's Andaman Sea coast (Iverson 1992). However, subsequent research revealed that the populations in southern and eastern regions constitute a separate species, known as the southern river terrapin Batagur affinis (Praschag et al. 2008). Presently, *B. baska* has been eradicated from most of its former range, and there have been no reports of viable wild populations of *B. baska* in the last 20 years, indicating that the species may have become extinct across much of its range (Mallick et al., 2021). It is now recognised as one of the 25 most critically endangered turtle species globally (Rhodin et al. 2011) and is considered ecologically extinct (Weissenbacher et al. 2015).

Maintaining diversity is not only critical for the conservation of small populations but is also the basis for the success of any long-term breeding programme. Identifying populations that have recently undergone bottlenecks, such as the case with *B. baska*, is paramount due to its implications for genetic diversity. Bottlenecks can escalate inbreeding, diminish genetic variation, and perpetuate harmful allele fixation, thereby compromising a population's adaptability and elevating extinction risks (Luikart and Cornuet, 1998). Yet, detecting recent bottlenecks poses challenges, given the often-elusive historical population sizes and genetic diversity levels. Understanding the genetic makeup of *B. baska* is essential for shaping effective conservation strategies and management plans.

Further, under the National Mission for Clean Ganga project the Wildlife Institute of India, Dehradun, the Turtle Rescue and Rehabilitation Centre (TRRC) at Sarnath, Varanasi, and the Ganga Aqualife Rescue and Rehabilitation Centre (GARRC), Narora, were established in Uttar Pradesh. Given the challenges and reduction in the population size of freshwater turtles in the Ganga River, and as part of conservation efforts, Turtle Breeding and Rehabilitation Centres play a crucial role in bolstering population numbers and providing valuable support to management initiatives. The GARRC exclusively received rescued individuals, comprising those either injured or accidentally entangled in fishing nets within the local vicinity.

The softshell turtles are ancient, morphologically highly diverse and have globally affected by a variety of direct and indirect threats (Ernst and Barbour 1989; Choudhury et al. 2000; Li et al. 2017). The presence of shiny, leathery, and pliable skin, flattened body shape with fleshy lips, and highly modified skulls is a unique feature that distinguishes them from hard-shell turtles (Meylan 1987; Ernst and Barbour 1989). Asian flapshell turtle (AFT) belongs to the family Trionychidae; genus *Lissemys* is confined to South Asia and western Southeast Asia (Webb 1982; Hossain et al. 2010; Uetz et al. 2016). Currently, three subspecies of *L. punctata* are recognised from India: *L. p. andersoni* (spotted northern Indian



flapshell turtle) is confined to Pakistan, north India, Nepal, Bangladesh, western Myanmar; *L. p. vittata* (unspotted, central Indian flapshell turtle is found in central to peninsular India, and *L. p. punctata* (unspotted, southern Indian flapshell turtle is restricted to southern peninsular India (Talukdar 1979; Das and Gupta 2011). L. scutata is distributed from the Ayeyarwady (Irrawady), Sittaung, and

and Yunnan, China (Ernst and Barbour, 1989; Ernst et al., 2000; Fritz and Havaš, 2007; Rhodin et al., 2010).

The Geoemydidae family, previously known as Bataguridae, encompassing the highly threatened turtle group, plays a pivotal role in freshwater ecosystems (Van Dijk et al., 2000; IUCN, 2021). Comprising primarily freshwater turtles, with some adapted to estuarine and terrestrial habitats, the family Geoemydidae reflects diverse ecological adaptations (Van Dijk et al., 2000). With 71 extant species, Geoemydidae is closely related to land tortoises (Family Testudinidae; Rhodin et al.,, 2011). The genus Pangshura belongs to the family Geoemydidae, shows significant sexual dimorphism and relatively smaller-sized turtles, with maximum shell lengths ranging from 20 to 26.5 cm (Ernst et al., 2000). Despite their ecological importance, *Pangshura* faces severe threats, with four extant species-*P. tecta*, *P. tentoria*, *P. smithii*, and *P. sylhetensis*-distributed across the Southeast Asian landscape. Additionally, a now-extinct species, *P. tatrotia*, existed during the Pliocene epoch in the Siwalik Hills of Pakistan (Walter & Tyler, 2010). Fossil records from the Siwalik Hills and Narmada Valley deposits indicate the historical presence of Pangshura in India since at least the Pleistocene epoch (Baruah, Devi, & Sharma, 2016). Further classification reveals multiple existence of subspecies of *Pangshura*, such as *P. tentoria tentoria*, *P. tentoria circumdata*, *P. tentoria flaviventer*, *P. smithii*, and *P. smithii pallidipes*, each displaying distinct morphological characteristics (Praschag et al., 2007).

Presently, the IUCN status designates *P. tecta* as vulnerable, *P. smithii* as near threatened, *P. tentoria* as least concern, and *P. sylhetensis* as critically endangered, emphasising the urgent need for conservation measures. However, despite their ecological and conservation significance, all species of *Pangshura* face imminent threats, including egg harvesting, overexploitation for food, and habitat alteration. Given their precarious status, comprehensive genetic studies are imperative for effective conservation planning. The utilisation of molecular data has been widely used in Testudine systematics and conservation genetics, contributing to the identification of new species, assessment of population structure, and elucidation of evolutionary and phylogenetic relationships (Murphy et al., 2013; Spitzweg et al.,., 2018; Le et al., 2006).

The Ganga River has suffered from intense human intervention; the continuous monitoring of such a population of freshwater turtles should guide the critical issues related to conservation. Low genetic variability and gene flow lead to genetic bottlenecks and the failure of species to endure changes in the environment (Keller and Waller 2002). Using various molecular markers, a wild stock can be successfully identified and characterised for better stock management, species recovery, and reintroduction program (Gupta et al. 2018). Genetic data evaluating the variability within and among populations



would significantly contribute to developing more powerful conservation strategies

11.1.5 Mammal: Genetic assessment of the Gangetic dolphin (*Platanista gangetica*)

As a large mammal of the river Ganga, the Gangetic dolphin (*P. gangetica gangetica*) experiences many risks, such as fragmented populations, pollution, dams, barrages, low water levels, and illicit capture for their oil and meat. The extracted oils are used to catch catfish in the net fishery (Jones, 1982). These threats are long-lasting and challenging to manage; therefore, the distribution, range, and population size of dolphins are drastically declining (Sinha and Sharma, 2003). Hence, the species is listed under the IUCN Red List as "Endangered" (Braulik and Smith, 2019) and protected in Schedule I of the Indian Wildlife (Protection) Act, 1972. It is included in Appendix I of the Convention on International Trade in Endangered Species of Flora and Fauna (CITES) and was recently upgraded to Appendix I in the Convention on Migratory Species (CMS). The genus Platanista is considered the most primitive among all other dolphins with a diverse evolutionary history (Xiong et al., 2009; Yan et al., 2005; Verma et al., 2004; Yang et al., 2002; Nikaido et al., 2001; Hamilton et al., 2001; Cassens et al., 2000; Guang and Kaiya, 1999; Árnason, 1996; Messenger, 1994; De Muizon, 1994).

Recent information about the mitogenome level characterisation of the Gangetic dolphin and the detailed relationship with its subspecies and other river dolphins is lacking, which would help to differentiate them. For an effective management plan, it is vital to understand the genetic pattern and adaptive potential of endangered Gangetic dolphins from their distribution range.

Therefore, knowledge of the complete mitogenome not only provides information about species identification but also offers a wide range of genomic characterisation, which is useful for studying the evolutionary and demographic history of the species and population (Avise, 1989; Brown et al., 1982).

The primary objective of this chapter is to assess genetic diversity, gene flow, population structure, and demographic history of selected aquatic taxa in the Ganga River system using mitochondrial and microsatellite markers. The resulting evidence base is intended to inform long-term conservation and genetic resource management. For fishes, the study evaluates population genetic structure and demographic patterns of Wallago attu, and examines genetic relationships and diversity in *Sperata seenghala* and *Sperata aor*. It also assesses haplotype and nucleotide diversity in *Bagarius bagarius*, including the identification of shared and unique haplotypes across the basin. For turtles, the analysis focuses on genetic diversity and population structure of *Batagur dhongoka*, with particular relevance to management of Rescue and Rehabilitation Centres. Additional assessments include genetic diversity, gene flow, and population structure of *Lissemys* spp. using mtDNA and nuDNA markers; phylogenetic relationships, demographic patterns, and lineage diversification in Asian freshwater turtles (AFT); and evolutionary relationships and demographic trends of *Batagur baska* based on mitochondrial markers. The study also investigates the *Pangshura* genus using the cytochrome b gene to delineate genetic lineages and infer historical demographic changes in relation to past climatic variability. Finally, the study evaluates genetic diversity in the Gangetic dolphin (*Platanista gangetica*) through analysis of the mtDNA control region and complete mitogenome sequences, including gene organisation, base composition, and codon usage.



11.2 METHODS

11.2.1 Current Techniques used in Conservation Genetics

Mitochondrial DNA Sequencing

Mitochondrial DNA (mtDNA) stands out as a prominent population genetic marker, owing to a confluence of intrinsic and technical characteristics. Its relatively rapid rate of base substitution, haploid nature, and maternal inheritance collectively provide invaluable insights into the genetic diversity, population structure, and evolutionary history of species. The process of DNA sequencing involves discerning each nucleotide (base) within a specified target region of DNA, commonly known as the genetic marker.

Microsatellite genotyping

Microsatellites are widely accepted and versatile genetic markers, finding numerous applications in population genetics, conservation biology, and evolutionary studies. These genetic markers comprise arrays of DNA sequences characterised by tandem repeats of mono-, di-, tri, and tetra-nucleotide units, distributed widely across the genomes of eukaryotic species. Their codominant nature, high polymorphism, and mode of inheritance make them exceptionally well-suited for exploring population structures and conducting pedigree analyses. Additionally, microsatellites are adept at discerning differences among closely related species. The automated application of PCR for microsatellites allows for the efficient identification of simple sequence repeat polymorphisms. Furthermore, only small amounts of blood samples or alcohol-preserved tissue are required for their analysis. Notably, most microsatellites are noncoding, rendering their variations independent of natural selection. These unique characteristics position microsatellites as ideal genetic markers for applications in conservation genetics.



We employed three specific mtDNA regions, including Cyt b, COI, and CR, to analyse the genetic characteristics of *W. attu* populations present in Ganga River system. The information gathered through this research will provide fundamental knowledge necessary for the management of the species' genetic resources and the development of long-term conservation strategies. We used wide-range geographic sampling over different locations of the Ganga River and other major rivers for comprehensive genetic insight into *Sperata* lineages. *B. dhongoka* was studied using three mitochondrial DNA regions and microsatellite DNA markers, focusing on *B. dhongoka* from two Turtle Rescue and Rehabilitation centres.

11.3 RESULTS

11.3.1 Genetics of Fishes

I. Sequence variations, haplotype distribution, and genetic structure of *Wallago attu*

Analysis of 176 *Wallago attu* samples using a concatenated mtDNA dataset (2420 bp) identified 108 unique haplotypes and 80 polymorphic sites (Figure 11.1). While the Ganga River exhibited the highest diversity with 62 haplotypes, frequent haplotype sharing between the Ganga, and other rivers suggests significant genetic interchange, whereas the Ramganga, Kosi, and Rapti populations maintained unique lineages. Median-joining network and phylogenetic analyses revealed three distinct genetic clades that do not strictly align with river-wise geography, indicating complex evolutionary interactions across the system. Notably, Clade III-comprising individuals from the Ganga, Gandak, and Ghaghra-forms a basal lineage, representing the most genetically diverse group within the Ganga River System.

Genetic diversity and genetic differentiation

The genetic assessment of *Wallago attu* across the Ganga River System (GRS) revealed high levels of haplotype diversity (Hd = 0.984) paired with low nucleotide diversity (pi = 0.006), suggesting a population that underwent rapid expansion after a historical bottleneck (Table 11.1). The Ganga River emerged as the most genetically diverse hub, followed by the Ghaghra and Sharda rivers. While pairwise values indicated significant differentiation between certain tributaries-most notably between the Ramganga and Rapti-the lowest differentiation was found between the Ganga and Ghaghra, reflecting high gene flow in those regions. This is further supported by AMOVA results, which show that the vast majority of genetic variation (84.70%) exists within individual populations rather than between them, indicating a high degree of connectivity across the river system (Table 11.2).



Figure 11.1 Sampling sites of *Wallago attu* from the Ganga River System

Genetic diversity and genetic differentiation

The genetic assessment of *Wallago attu* across the Ganga River System (GRS) revealed high levels of haplotype diversity (Hd = 0.984) paired with low nucleotide diversity (pi = 0.006), suggesting a population that underwent rapid expansion after a historical bottleneck (Table 11.1). The Ganga River emerged as the most genetically diverse hub, followed by the Ghaghra and Sharda rivers. While pairwise values indicated significant differentiation between certain tributaries-most notably between the Ramganga and Rapti-the lowest differentiation was found between the Ganga and Ghaghra, reflecting high gene flow in those regions. This is further supported by AMOVA results, which show that the vast majority of genetic variation (84.70%) exists within individual populations rather than between them, indicating a high degree of connectivity across the river system (Table 11.2).

Table 11.1 Comparative statistics and neutrality tests of *Wallago attu*. Sample size (N), polymorphic sites (S), number of haplotypes (H), haplotype diversity (Hd), nucleotide diversity (Pi), the sum of squared deviations (SSD), and Harpending's raggedness index (Rg)

River	N	S	H	Hd	Pi	Fu's FS	Tajima's D	SSD	Rg
Ganga	**102**	**70**	**62**	**0.984± 0.005**	**0.0063**	**-23.73***	**0.462**	**0.011**	**0.0038**
Ramganga	5	1	2	0.600± 0.175	0.0002	0.626	1.224	0.054	0.400
Sharda	18	29	12	0.961± 0.026	0.005	0.049	2.066	0.012	0.013
Sarayu/Ghaghra	13	44	10	0.962± 0.041	0.0062	0.186	0.290	0.026	0.024
Rapti	7	23	6	0.952± 0.096	0.003	-0.308	-1.00	0.170*	0.052
Gandak	12	23	6	0.848± 0.074	0.0039	2.953	1.078	0.081	0.168*
Kosi	19	23	10	0.860± 0.070	0.0046	1.606	2.700	0.033	0.072
Overall	176	80	108	0.99± 0.002	0.0062	-2.66	0.973	0.055	0.105

Table 11.2 AMOVA of mtDNA sequences for seven populations of *Wallago attu* from the Ganga River and its tributaries. Degree of freedom (df), genetic differences between populations (Fst), within populations (Fsc), and among groups (Fct).

Source of variation	df	Sum of squares	Variance components	Percentage of variation	Fixation index	p-value
Among groups	5	148.78	0.81432	10.11	FCT= 0.101	0.099
Among populations within groups	1	16.47	0.41841	5.19	FSC= 0.057	0.048
Within populations	169	1153.41	6.82	84.70	FST=0.152	P<0.001
Total	175	1318.67	8.05			

Population demography

Neutrality tests and mismatch distribution analyses indicate historical population stability for *Wallago attu* across most of the system; however, the Ganga River shows a significant signal of recent demographic expansion. These results are corroborated by non-significant SSD and Harpending's raggedness index values. Bayesian skyline analysis further reveals that following a prolonged period of stasis, the population underwent a rapid expansion phase approximately 0.04 million years ago (Figure 11.2).

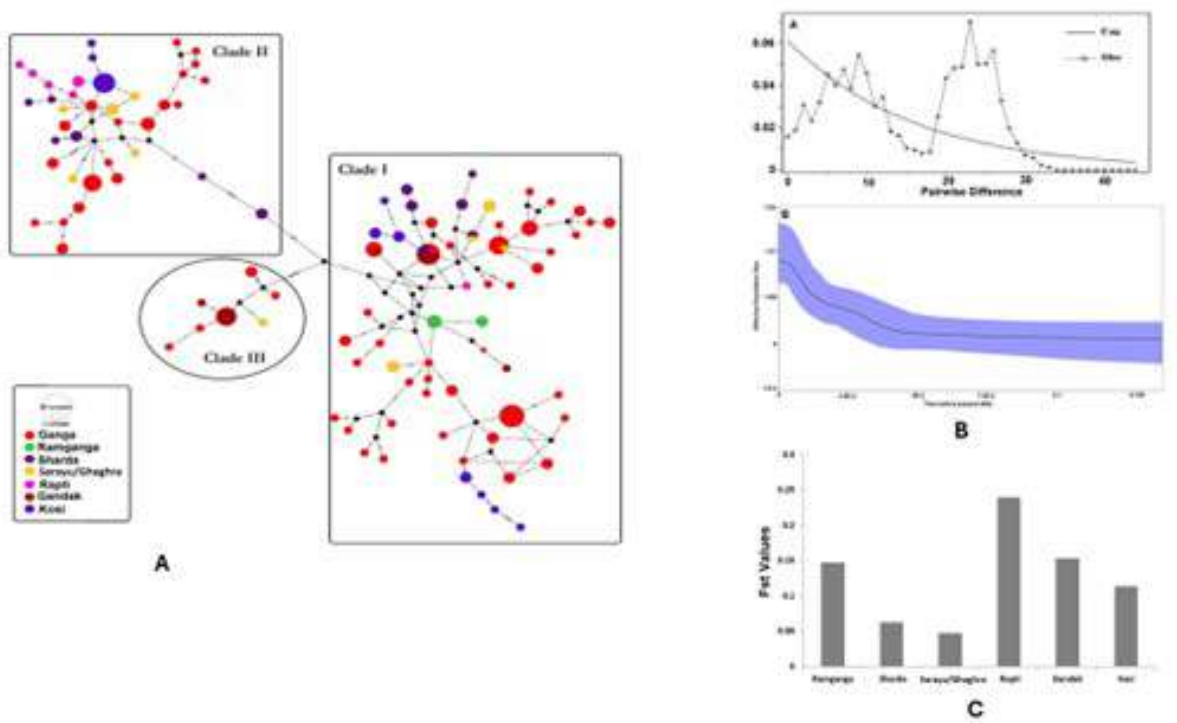


Figure 11.2 (A) The median-joining network is based on the concatenated dataset of three mtDNA regions, COI, Cyt b, and CR of *Wallago attu*, (B) Mismatch distribution graph for the overall populations of *Wallago attu* from the Ganga River Basin and Bayesian Skyline plot showing changes in effective population size (Ne) over time (x-axis) (C) Genetic differentiation among *Wallago attu* populations.



II. Genetics of *S. seenghala* and *S. aor*

About 870 bp sequences of CR from 131 samples of *S. seenghala* from eight different sites and 78 samples of *S. aor* from four sites of the Ganga River were obtained (Figure 11.3). Twenty-five sequences of *S. seenghala*, belonging to the Ganga, Mahanadi, and Brahmaputra Rivers, were retrieved from NCBI GenBank. A total dataset of 156 sequences of *S. seenghala* and *S.aor* from the Ganga River was used in the present analysis. The haplotype diversity (Hd) of *S.seenghala* from the Ganga River was very high, with an Hd of 0.943 ± 0.008 (Table 11.3). In contrast, the haplotype diversity from the Mahanadi and Brahmaputra rivers was 0.717 ± 0.056 and 0.820 ± 0.065, respectively. While the nucleotide diversity was observed to be the lowest from the Ganga River, with π = 0.012 ± 0.001. About 37 haplotypes (Hap 1 to Hap 37) of *S. seenghala*, and 28 haplotypes (Hap 38 to Hap 65) of *S.aor* were estimated from the Ganga River. Interestingly, 4 haplotypes (Hap 34 to Hap 37) of *S. seenghala* from the Ganga River formed a distinct group, separate from the other groups.

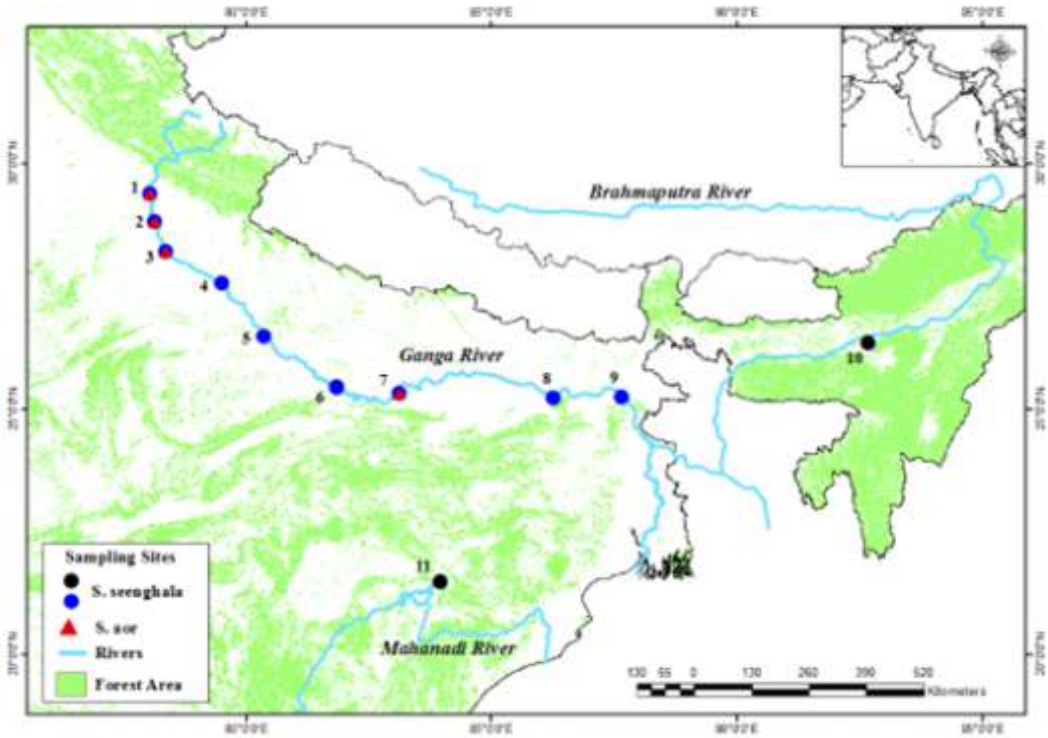


Figure 11.3 Sampling locations of *Sperata seenghala* and *Sperata aor* in the Ganga River

Table 11.3 Comparative Haplotype diversity of *S. seenghala* and *S. aor*

	Sperata seenghala		*Sperata aor*	
Parameters	**Ganga**	**Mahanadi**	**Brahmaputra**	**Ganga**
n	156	25	25	78
Nh	37	4	9	28
S	86	136	173	42
Ts/Tv	69/19	94/49	11/15	37/5
h (±SD)	0.943 (0.008)	0.717 (0.056)	0.820 (0.065)	0.934 (0.016)
π (±SD)	0.012 (0.001)	0.049 (0.012)	0.034 (0.017)	0.009 (0.0008)
Neutrality Analysis				
Tajima's D (P)	-1.314 (0.061)	0.498 (0.669)	-1.149 (1.02)	-0.295 (0.399)
Fu's Fs (P)	-4.662 (0.152)	31.053 (1.00)	1.107 (0.717)	-4.900 (0.109)
Mismatch analysis				
SSD (P)	0.2500 (0.770)	0.171 (0.00)	0.492 (0.60)	0.014 (0.480)
r-index (P)	0.0062 (0.900)	0.261 (0.00)	0.058 (1.00)	0.007 (0.910)

Molecular phylogeny and network

While comparing with other river systems, Mahanadi formed a distinct basal clade II. The *S. aor* and the Brahmaputra sequences formed distinct clade-III and IV. Two sequences of Brahmaputra (Hap 3) were merged with the haplotype of Ganga *S. seenghala*, and three sequences of Mahanadi (Hap 69) were clustered with the haplotype of *S. aor.* The median-joining network of all recognised haplotypes strongly indicated the presence of multiple lineages in *S. seenghala* from the studied river. The clustering pattern obtained from network analysis is highly supportive of phylogenetic analysis.

Genetic differentiation

A few sequences of Brahmaputra and Mahanadi were merged with Ganga *seenghala* and *S. aor*, respectively, therefore the factual mean pairwise genetic distance was estimated based on their clustering pattern. The analyses demonstrated significant genetic differentiation between all the lineages of *Sperata*. The genetic distinction between two known species, i.e, *S. seenghala* (Clade IA) and *S. aor* (Clade III) is 0.175. Considering these estimates as a reference for species-level variation, the Brahmaputra population is genetically more diverse (0.25 to 0.28) than the other studied lineages. The genetic differentiation between two lineages of *S. seenghala* (Clade IA and IB) from the Ganga is 0.048, whereas it was comparatively higher for Mahanadi, 0.076 to 0.080. The analysis of molecular variance indicated a high degree of structuring among the populations. A large proportion of genetic variation was attributable to the difference among the groups, 62.56% and the differentiation among populations within the groups, 29.46% (Table 11.4). The FSC and Fst values were found to be significant, P<0.05 (Table 11.4).

Table 11.4 Hierarchical analysis of molecular variance (AMOVA) for *S. Seenghala* from the Ganga and other rivers

Source of variation	d.f.	Sum of squares	Variance components	% of variation	Fixation indices	P values
Among groups	3	11195.790	45.5	62.56	FCT: 0.625	0.11±0.01
Among populations within groups	1	552.709	21.43	29.46	FSC: 0.786	0.000
Within populations	279	1619.695	5.80	7.98	FST: 0.920	0.000

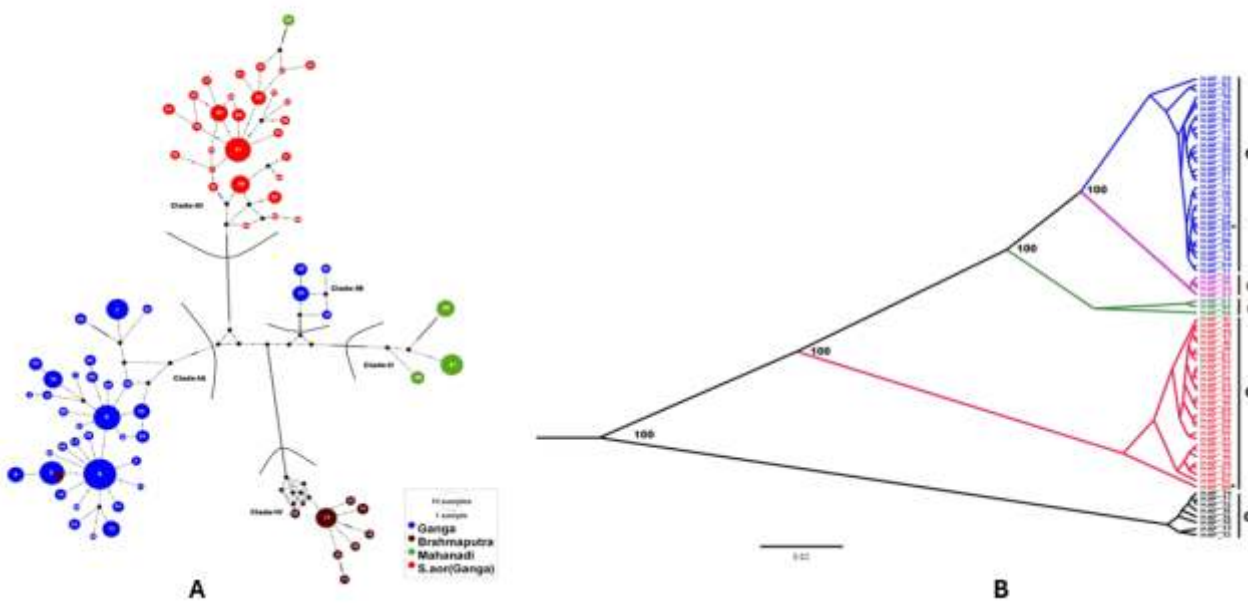


Figure 11.4 (A) Median-joining network of Sperata species, (B) The Bayesian tree for the phylogenetic resolution between the *S. seenghala* form Ganges, Mahanadi, Brahmaputra, and *S. aor* Ganges

III. Genetic Diversity of *Bagarius bagarius*

The genetic diversity of *Bagarius bagarius* was estimated using two mitochondrial fragments, including COI (581~bp) and Cyt b (711~bp). The observed haplotype diversity from the COI fragment was found to be very low (Hd =0.051 ± 0.048), and very low nucleotide diversity (Pi)=0.00009 ± 0.00041, suggesting extremely low genetic diversity (Table 11.5). The haplotype (Hd) and nucleotide diversity (Pi) observed from the Cyt b fragment were found to be moderate with values of 0.588 ± 0.062 and 0.00142 ± 0.00034, respectively. The neutrality test values (Fu's F and Tajima's D) were found to be non-significant (P > 0.05).

Table 11.5 Genetic diversity in *B. bagarius* from COI and Cyt b fragments. Sample size (n), Number of polymorphic sites (P), Number of haplotypes (H), Haplotype Diversity (Hd), Nucleotide diversity (Pi), Standard Error (SD)

S.No	Fragment	n	P	H	Hd ± SD	Pi ± SD	Fu's F	Tajima's D
1	COI	39	1	2	0.051 ± 0.048	0.00009 ± 0.00041	-1.82	-1.12
2	Cyt b	40	8	5	0.588 ± 0.062	0.00142 ± 0.00034	-1.07	-1.32

The haplotype network estimated by the neighbour-joining method using 39 COI sequences identified only 2 haplotypes (Hap_1 and Hap_2) across 6 river systems, including the Ganga, Yamuna, Ghaghra, Gomti, Gandak, and Girwa rivers (Figure 11.5). Hap_2 is the central haplotype, shared widely across all six rivers, with the Ganga River contributing the highest proportion, followed by the Yamuna and Ghaghra, and minor representations from Gomti, Gandak, and Girwa. In contrast, Hap_1 is unique to the Ganga River and differs from Hap_2 by a single mutational step. These patterns provide important insights into the evolutionary dynamics and connectivity of freshwater species across the Ganga River systems.

The haplotype network, analysed by using 40 Cyt b sequences, unveiled 5 haplotypes (Hap_1 - Hap_5) distributed across the river system. Hap_1 is the most dominant haplotype, comprising the largest number of individuals, and is widely shared across several rivers. Hap_2, also shared among multiple river systems, reflects some degree of genetic mixing. Hap_3 and Hap_4 are lower in frequency and are unique to the Ganga River, arising from three mutational events each. Meanwhile, Hap_5 is shared between the Gomti and Girwa rivers, is more localised and appears in fewer individuals, with Hap_3 and Hap_4 being found only in the Ganga River, suggesting regional specificity or recent diversification events.

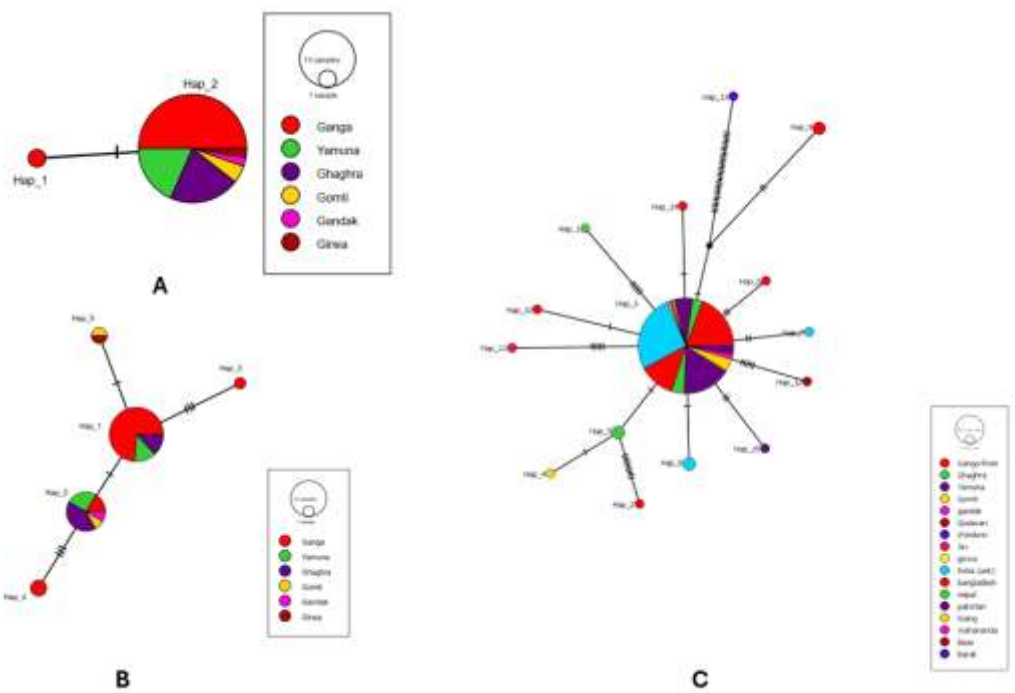


Figure 11.5 (A) Median Joining network of *B. bagarius* using COI from the Ganga River, (B) Median Joining network of *B. bagarius* using Cyt b from the Ganga River, (C) Median Joining network of *B. bagarius* using COI from the Ganga and its tributaries in India

Phylogeny

Maximum likelihood phylogenetic analysis based on mitochondrial cytochrome c oxidase subunit I (COI) sequences revealed a well-resolved topology that clearly illustrates the genetic relationships among *B. bagarius* individuals sampled from the present study and conspecific sequences retrieved from GenBank representing multiple river systems across India and adjacent regions. The phylogeny was reconstructed using haplotype-reduced data to avoid overrepresentation of identical sequences, while maintaining geographic representation across river systems. All COI sequences of *B. bagarius* clustered into a single monophyletic lineage, indicating conspecificity of samples obtained from diverse riverine habitats (Figure 11.6). The tree exhibited short internal branch lengths among most Indian riverine haplotypes, reflecting low levels of mitochondrial divergence across populations. Samples from major river systems, including the Ganga and other rivers of India, were interspersed throughout the tree rather than forming discrete river-specific clades. Although the overall topology lacked deep bifurcations, minor substructuring was evident in the form of slightly elongated branches associated with samples from geographically peripheral river systems. However, these lineages did not form strongly supported, exclusive clades, and their divergence remained shallow relative to interspecific distances observed within the genus.

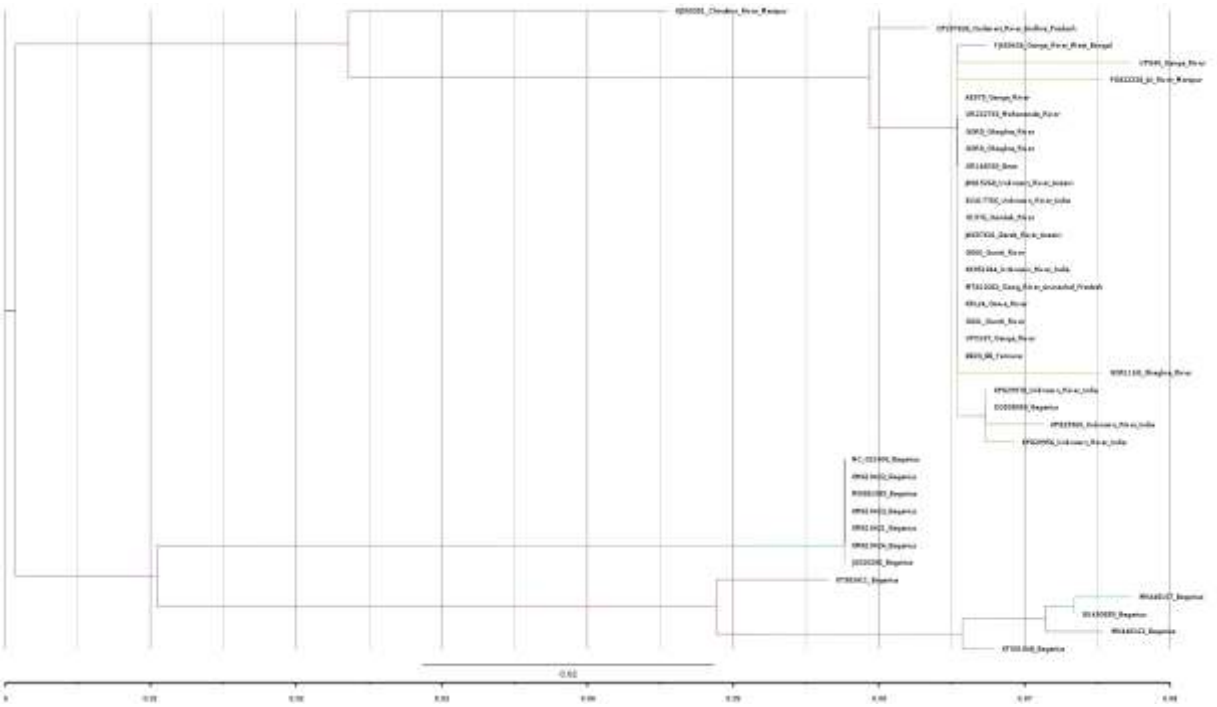


Figure 11.6 Phylogenetic assessment of *B. bagarius*

IV. Genetics of *C. morar*

A 517-bp segment of the mitochondrial COI gene was analysed across 57 specimens of *Cabdio morar* collected from four river systems, including the Ganga River. The Ganga River population (n = 38) exhibited the highest sample size, revealing 11 haplotypes with 16 polymorphic sites, a haplotype diversity (*Hd*) of 0.721 ± 0.068, and a nucleotide diversity (π) of 0.00597 (Table 11.6).

Table 11.6 Diversity indices of the C. morar samples from the Ganga River compared to other rivers

River	N	S	H	Hd ± SD	π	Fu's Fs (P)	Tajima's D
Ganga	**38**	**16**	**11**	**0.721 ± 0.068**	**0.00597**	**1.501**	**-0.61366**
Chambal	9	9	5	0.826 ± 0.120	0.00580	0.047	-0.43284
Son	8	5	2	0.429 ± 0.169	0.00414	3.747	0.50437
Kosi	2	1	2	1.000 ± 0.500	0.00193	------	------
Overall	57	20	14	0.734 ± 0.048	0.00618	- 2456	-0.82184

Note: N = Sample size, S = Polymorphic sites, H = Number of haplotypes, Hd = Haplotype diversity, π = Nucleotide diversity, Hd ± SD = Deviation in Haplotype diversity.

The mitochondrial COI gene analysis of 57 C. morar specimens across the Ganga and other rivers revealed a moderately diverse genetic landscape defined by 14 distinct haplotypes. The Ganga acts as the primary reservoir of variation, harbouring 11 haplotypes and 16 polymorphic sites (Hd = 0.72), Other rivers had a similar diversity index, but all were lower than the Ganga and Chambal rivers. The median joining network identifies Hap_3 as the central ancestral haplotype, serving as the genetic foundation for all the other rivers and highlighting the historical connectivity of the entire basin. The Ganga River demonstrated significant localised evolution, with eight unique haplotypes branching directly from this central node (Figure 11.7). The integration of the Son River into the ancestral gene pool indicates active historical migration and a lack of significant physical barriers to gene flow between the major tributaries of the main stem of the Ganga River.

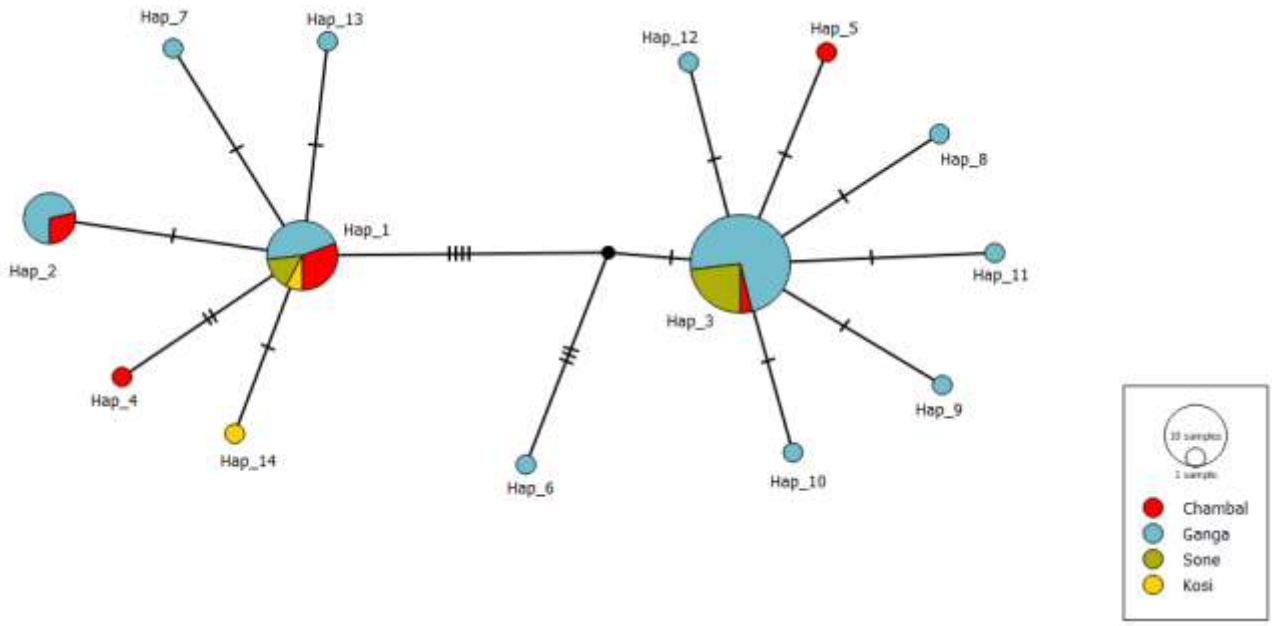


Figure 11.7 Median joining network of *C. morar* from the Ganga River

11.3.2 Conservation Genetics of Turtles

I. Genetic diversity of *Batagur dhongoka*

Two mtDNA fragments were obtained from 92 samples (Figure 11.8); after alignment, 1140bp of cyt b and 451bp of the control region were generated, producing a concatenated mtDNA fragment of 1591bp. All generated sequences were deposited in GenBank (OQ378390 - OQ378573). In the overall samples, 15 variable sites were observed, thus accounting for only 0.94% of the total sites. All 15 were parsimony-informative sites, comprising 13 transitions and two transversions. We identified 31 haplotypes with an average of 4.59 nucleotide differences (K) in both TRRC and GARRC populations. Among 31 haplotypes, 28 were detected in TRRC with K=4.55, and six were found in GARRC with K=3.39, while four haplotypes (H1-H4) are common in both populations. The haplotypes (h) and nucleotide diversity (π) of TRRC were 0.932 ± 0.013 and 0.002 ± 0.00012, respectively, and those of GARRC were 0.845 ± 0.074 and 0.002 ± 0.0002, respectively (Table 11.7).



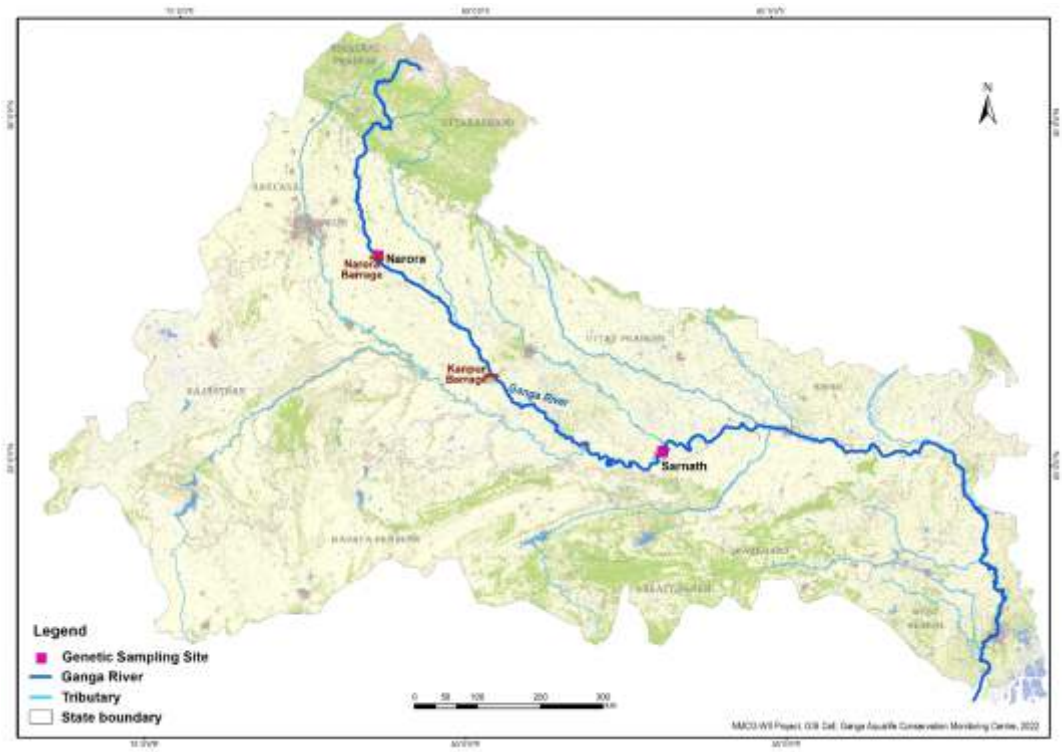


Figure 11.8 Map of the study area showing sampling sites of *Batagur dhongoka* along the Ganga River

Table 11.7 Summary of genetic diversity in *Batagur dhongoka* populations based on concatenated mtDNA (Cyt b + CR) and ten microsatellites, where n number of samples, H haplotype, Hd haplotype diversity, and π nucleotide diversity

Population/Region	Mitochondrial DNA						
	N	H	Hd	π	K	Tajima's D*	Fu's FS *
Turtle Rescue & Rehabilitation Centre (TRRC) Sarnath, Uttar Pradesh, India	80	29	0.93	0.003	4.6	2.04	-12.3
Ganga Aqualife Rescue & Rehabilitation Centre (GARRC) Narora, Uttar Pradesh, India	12	6	0.85	0.002	3.4	1.816	0.015
Total	**92**	**31**	**0.94**	**0.002**	**4.6**	**1.56**	**-1.86**

The mean number of alleles (Na) in TRRC and GARRC was 5 and 3.4, respectively, with comparative allelic richness (Ar) in TRRC (Ar = 3.84) and GARRC (Ar = 3.4), with a mean Ar = 3.82 (Table 11.8). The observed heterozygosity (Ho) and expected heterozygosity (HE) in TRRC were Ho: 0.487; HE: 0.493, and in GARRC were Ho: 0.497; HE: 0.50, with mean Ho: 0.495; HE: 0.495. The mean inbreeding coefficient (FIS) value for both the rescued *B. dhongoka* populations was greater than the mean FIS of 0.028, indicating a heterozygote deficiency, which may be attributed to the Wahlund effect and the population not being in HWE

Table 11.8 Summary of genetic diversity in *Batagur dhongoka* populations based on ten microsatellites along the Ganga River

Population/Region	Na	Ar	Ho	HE	FIS
Turtle Rescue & Rehabilitation Centre (TRRC) Sarnath, Uttar Pradesh, India	5	3.84	0.487	0.493	0.018
Ganga Aqualife Rescue & Rehabilitation Centre (GARRC) Narora, Uttar Pradesh, India	3.4	3.4	0.497	0.5	0.038
Total	4.1	3.82	0.495	0.494	0.028

Na number of alleles, Ar allelic richness, HO observed heterozygosity, HE expected heterozygosity, FIS inbreeding coefficient, *all P-values > 0.01 (not significant)

Genetic structure, differentiation and migration

The haplotypes' genealogy showed four shared haplotypes (H1- H4), which consist of 38 individuals, representing 41% of the total study population, out of which H3 and H4 represented the core haplotypes. In TRRC, the majority of the haplotype contained a single sequence. We performed the FCA and the Structure analysis of individual microsatellite genotypes. The Bayesian clustering analysis under the admixture model implemented in Structure suggested the existence of two genetic clusters based on high ΔK (mean likelihood of K (Mean LnP(K) = -1787.306). The two identified genetic clusters showed some level of genetic admixture and were not assigned to their populations (cluster with an estimated membership >0.800). The two genetic signatures observed in TRRC indicate that the individuals of the TRRC population shared a similar genetic ancestry with the GARRC population.

The genetic differentiation level between the studied populations of *B. dhongoka* was lower in mtDNA: F_{ST} = 0.003, whereas a comparatively higher value was observed based on microsatellite: F_{ST} = 0.074. Furthermore, the rate of self-distribution within the GARRC population was 0.9649 (95% CI: 0.8730-0.999), while the TRRC population was 0.9413 (95% CI: 0.8913- 0.9808). The analysis for migration rate (m) was low, 0.15 from GARRC to TRRC and 0.035 from TRRC to GARRC.

Population demography and Bottleneck

The demographic pattern of the studied *B. dhongoka* was inferred from neutrality and mismatch distribution analysis. The mismatch distribution analysis showed a multimodal distribution-shaped graph, which might result from a relatively stable population size over a long period. Results of Tajima's D and Fu's Fs tests were used to explain the population history of both populations. In overall samples, the values of Tajima's D and Fu's FS were 1.56 and -1.864, respectively, but non-significant values indicated a stable population size. Moreover, effective population sizes and demographic trends were also estimated by the Bayesian skyline plot (BSP) analysis. The Bayesian Skyline Plot indicated historical stability followed by growth in the effective population size, with a recent reduction over the past 2000 years.

The values of the G-W index test (TRRC = 0.31±0.07 and GARRC = 0.32 ±0.11) were lower than the critical value MC = 0.68, indicating the sign of a genetic bottleneck in both the population of *B. dhongoka*. In contrast, BOTTLENECK analysis showed that no significant heterozygosity excess was found in either population under either TPM (TRRC *P* = 0.72; GARRC *P* = 0.90) or SMM (TRRC *P* = 0.21; GARRC *P* = 0.24). The mode-shift test demonstrated no distortion of the allelic frequency, and a normal L-shaped distribution was observed.

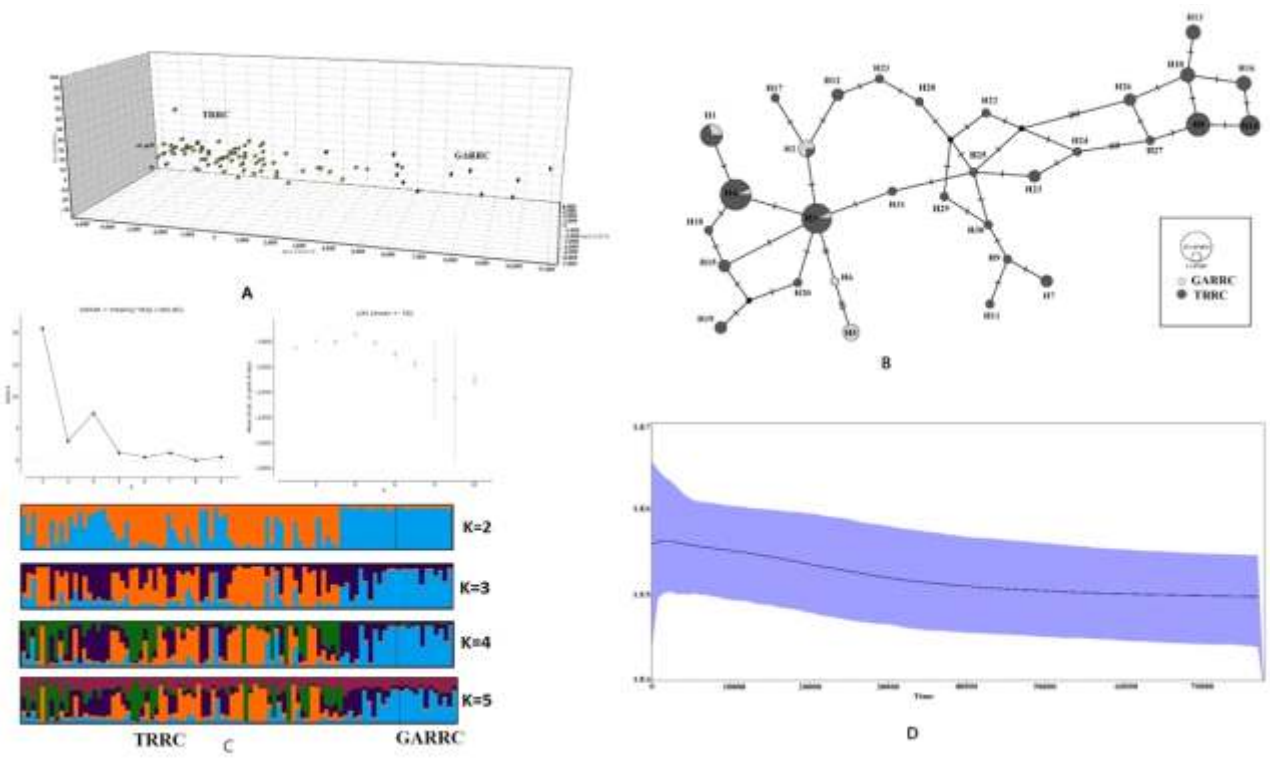


Figure 11.9 (A) Factorial correspondence analysis (FCA), (B) Median-joining network inferred from *Batagur dhongoka* mitochondrial DNA haplotypes, (C) Genetic structure plot derived from Bayesian-based cluster analysis, (D) Bayesian skyline plots representing historical demographic trends

II. Genetics of *Lissemys*

We generated the mtDNA cyt b dataset comprised of 1133bp, two nuDNA datasets Cmos of 602bp, and R35 of 985bp from 69 samples of *L. p. andersoni* from seven sites of the Ganga River (Figure 11.10). In addition, we included 55 cyt b sequences from GenBank, which consisted of *L. p. andersoni* (11), *L. p. punctata* (9), *L. p. vittata* (24), *L. ceylonensis* (5), and *L. scutata* (6). Among the 124 cyt b sequences, we observed 229 variable sites; of these, 29 polymorphic sites were singletons, and 200 were parsimony informative. These sequences were grouped into 38 haplotypes (H), and there were different numbers of individuals in each haplotype. Of these, 12 haplotypes (H1 to H12) were observed in Ganga, and two haplotypes (H1 and H6) were observed in other populations of *L. p. andersoni*. H1 and H6 are the core haplotypes, where H1 is shared with the sequences of Ganga and other northern groups, and H6 is more common in the north-to-southeast populations. Fourteen haplotypes (H13 to H26) were detected in *L. p. vittata*, four (H27 to H30) were observed in *L.p. punctata*, four (H31 to H34) were found in the Sri Lankan population, *L. ceylonensis*, and four (Hap 35 to 38) were detected from Myanmar lineages, *L. scutate*. The haplotypes (hd) and nucleotide diversity (π) of *L. punctata* are varied, and the values range from hd=0.327 ± 0.053 and π=0.0002 ± 0.0001 in *L. p. andersoni* group II to hd=0.906 ± 0.046 and π=0.013 ± 0.001 in *L. p. vittata*. The HD and π of the Ganga population were 0.694 ± 0.054 and 0.0009 ± 0.0001, respectively. The gene diversity of the overall *L. p. andersoni* population was high and estimated as hd=0.732 ± 0.036 and π=0.00095 ±0.00009 (Table 11.9).



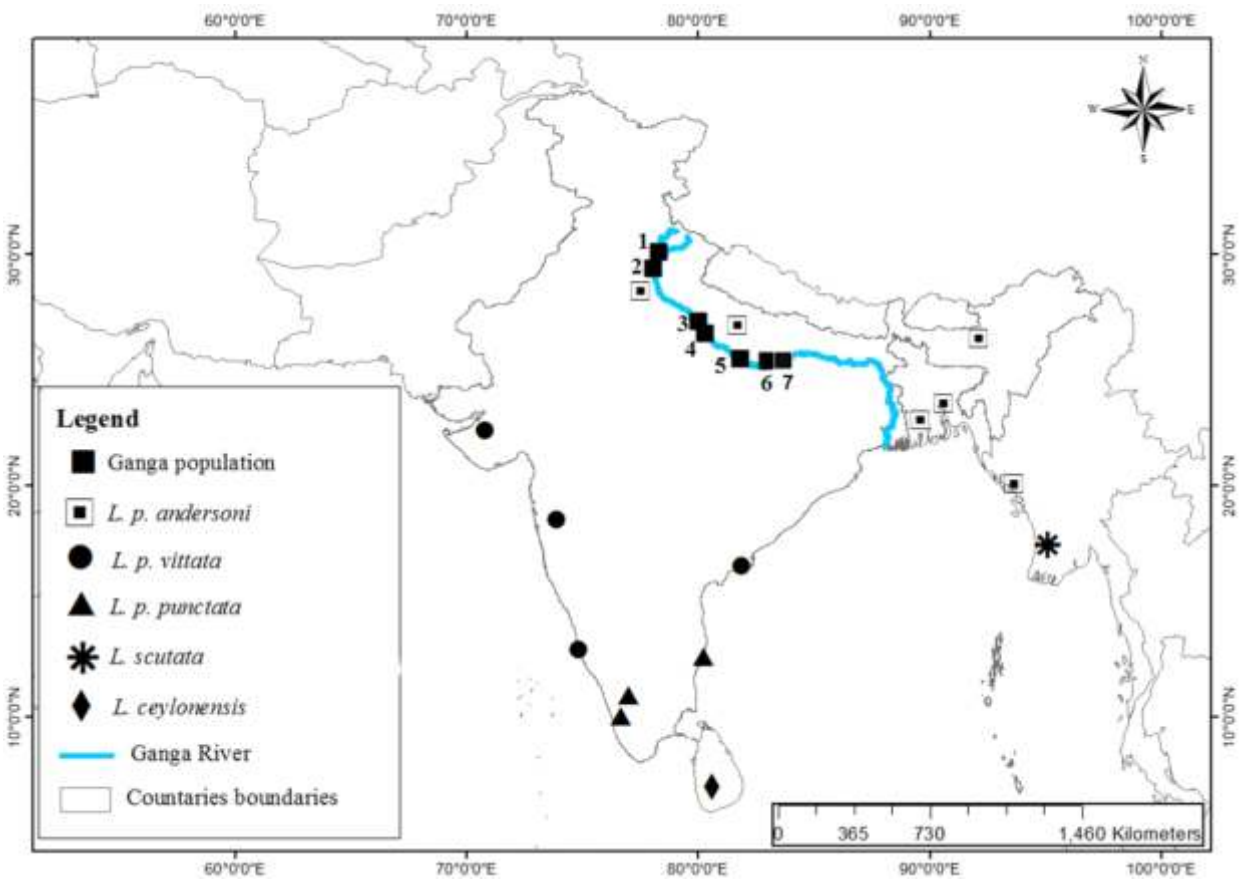


Figure 11.10 Map showing the sample collection sites of Lissemys and sequences used from type localities.

Table 11.9 Sample size (n), number of haplotypes (H), haplotype diversity (h), nucleotide diversity (p), Fu's Fs, Tajima's D, mismatch distribution test (SSD) and raggedness index (r) in *Lissemys* populations.

	L. p. andersoni	*L. p. punctata*	*L. p. vittata*	*L. ceylonensis*	*L. scutata*	
	Group I	**Group II**				
N	69	11	9	24	5	6
H	12	2	4	14	4	4
S	10	1	9	60	7	7
hd (±SD)	0.694 (0.054)	0.327 (0.053)	0.750 (0.112)	0.906 (0.047)	0.900 (0.161)	0.867 (0.129)
π (±SD)	0.0009 (0.0001)	0.0002 (0.0001)	0.003 (0.0005)	0.013 (0.001)	0.0030 (0.0008)	0.0028 (0.00067)
Ts/Tv	7/3	1/0	6/3	37/25	6/1	6/1
Neutrality tests						
Tajima's D (P)	-1.310 (0.05)	-1.100 (0.25)	0.957 (0.83)	-0.190 (0.46)	0.082 (0.52)	0.128 (0.47)
Fu's Fs (P)	-6.84 (0.00)	0.356 (0.35)	2.00 (0.83)	0.909 (0.646)	-0.12801 (0.368)	0.31383 (0.548)
Mismatch analysis						
SSD (P)	0.003 (0.35)	0.002 (0.35)	0.181 (0.05)	0.030 (0.03)	0.05 (0.46)	0.315 (0.62)
Rd	0.063 (0.44)	0.226 (0.39)	0.523 (0.02)	0.042 (0.03)	0.130 (0.83)	0.115 (0.68)

Note: n, sample size; h, number of haplotypes; S, number of polymorphic sites; hd, haplotype diversity; π, nucleotide diversity; Ts, transition sites; Tv, transversion sites; sum of squared deviations (SSD), and the raggedness index (r); SD, standard deviation; P, probability value.

Phylogenetic and network relationship

The tree represented the five distinct clusters with significant bootstrap support values (>57%). Clade *I* consisted of twelve haplotypes (H1 to H12) that represented the sequences of Ganga clustered with other andersoni populations (Figure 11.11). Clade-*II*, representing the haplotype of *L. p. vittata*, forms the sister group with Clade-*I*, with bootstrap support of ~71%. Clade-*III* comprised the haplotypes belong to *L. p. punctata*, whereas Clade-*IV* and Clade-*V* represented the sequences of *L. ceylonensis* from Sri Lanka and *L. scutata* from Myanmar, respectively. The distribution and connectivity of AFT haplotypes were inferred from the median-joining network. The results of the network analysis were consistent with those of the phylogenetic analyses, illustrating five clustered clades. Two haplotypes, H1 and H6, shared a majority of genepool from Ganga sites as well as the sequences belonging to other localities of Uttar Pradesh, Assam, Haryana (Yamuna River), Bangladesh and Myanmar. No clear structuring was observed in seven sites of the Ganga River.

Divergence dating and demographic history

The divergence time between Trionychidae and Carettochelyidae was estimated at 146 MA (95% high posterior density [HPD] = 126-173). On this basis, we estimated that the genus *Lissemys* split earlier from the other listed softshell genus during the Cretaceous, around 116.32 MA (95% HPD = 94.66-139.59). Within *Lissemys*, the diversification events mainly occurred in two periods, namely Oligocene and Miocene. The *L. scutata* split first around 29.96 MA (95% HPD = 22.72-37.70), then *L. ceylonensis* is about 23.21 MA (95% HPD = 17.74-29.71). The molecular divergence between lineages of *L. punctata* suggests a divergence date of approximately 9.38 MA (95% HPD = 6.67-12.33). Bayesian skyline plot (BSP) analyses also supported the hypothesis of population expansion in Andersoni populations, and a long phase of demographic stability was observed in the rest of the AFT from the late Pleistocene onwards (Figure 11.12).

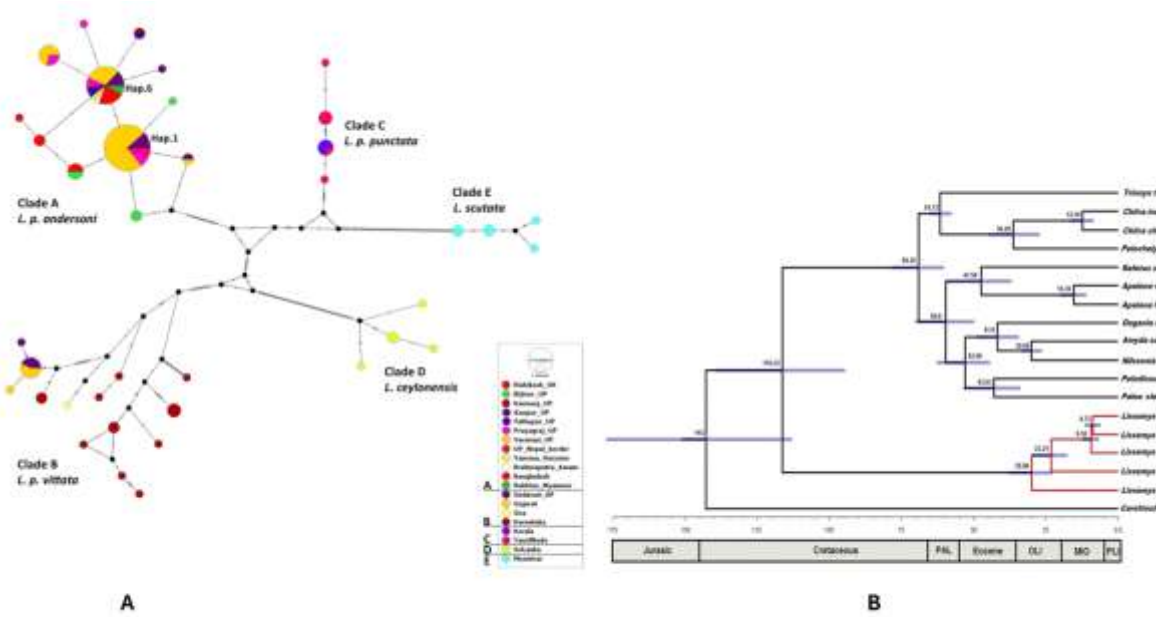


Figure 11.11 (A) Median Joining network showing the distribution of haplotypes among Lissemys, (B) Divergence times estimation

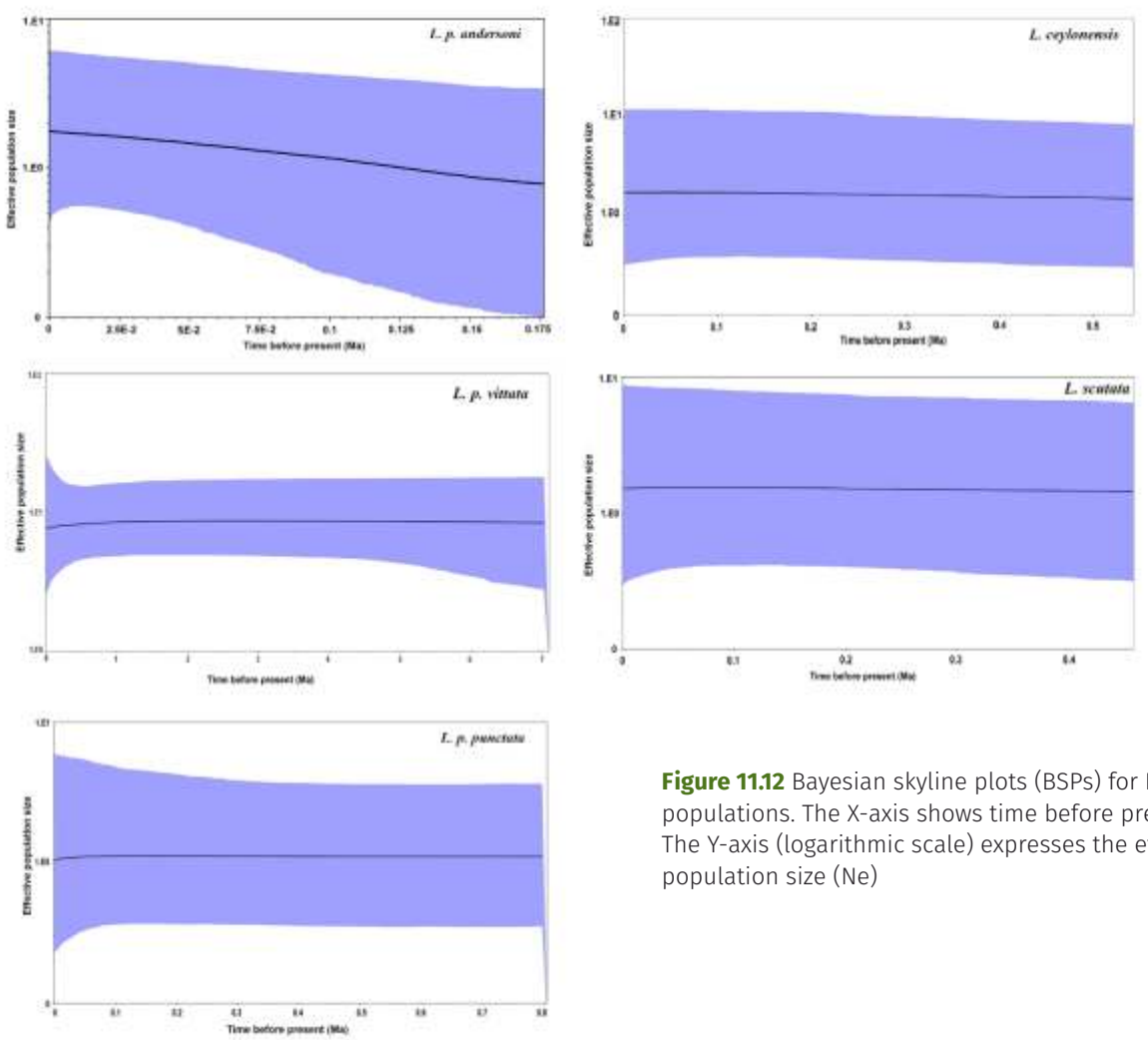


Figure 11.12 Bayesian skyline plots (BSPs) for Lissemys populations. The X-axis shows time before present (Ma). The Y-axis (logarithmic scale) expresses the effective population size (Ne)

III. Genetics of *Batagur baska*

The current population size of *B. baska* in captivity (Figure 11.13), which has been recovered from the founder stock, underscores the critical need for conservation efforts (Mallick et al., 2021). Genetic analysis using 24mtDNA sequences revealed only 5 haplotypes in *B. baska*. The haplotype pattern suggests that most haplotypes were closely linked and only three mutation sites were present on location number nt15646, nt16014 and nt16233. The median-joining network showed that most haplotypes appeared to be related and differed by only a single mutation site. Overall, only 3 variable sites were observed in the sequences. In nucleotide positions nt15646, nt16014 and nt16233, accounting for a very low number of nucleotide changes per site.



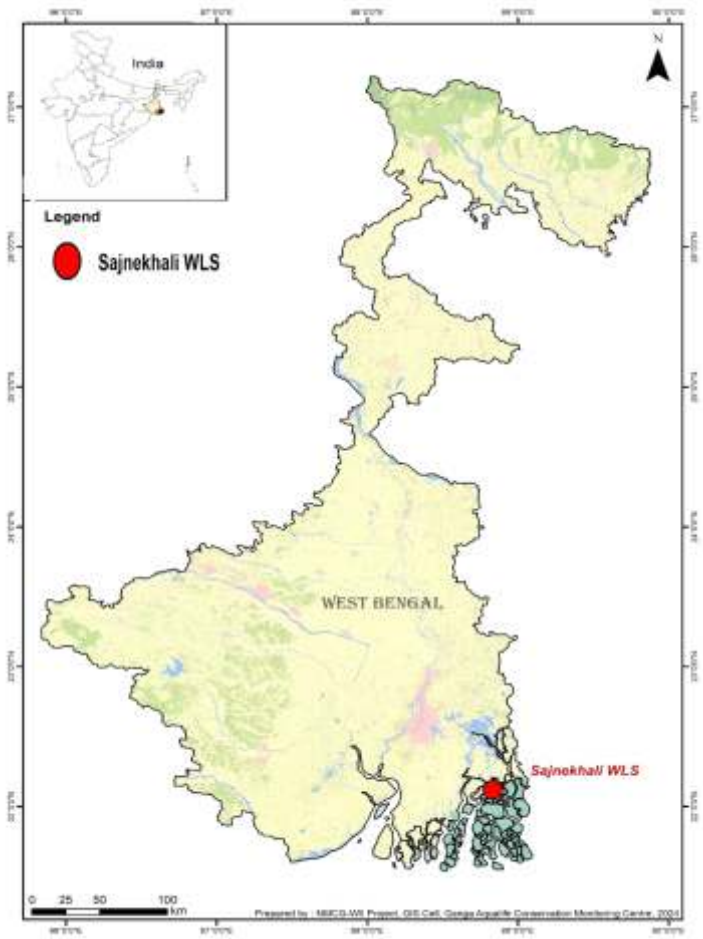


Figure 11.13 Location of Sajnekhali Wildlife Sanctuary, Sundarban Tiger Reserve

Genetic diversity

The genetic diversity of *B. baska* was assessed using haplotype diversity (hD) and nucleotide diversity (π) calculations. The observed haplotype diversity was moderate, 0.782 ± 0.042, within the population. Nucleotide diversity, however, was very low, 0.00125 ± 0.0005, suggesting limited nucleotide variation in the population (Table 11.10). This could be due to factors such as population bottlenecks, genetic drift, or selective pressures that have reduced the overall genetic diversity at the nucleotide level. Understanding these genetic parameters is crucial for the conservation and management of *B. baska* populations, as it provides insights into their evolutionary history, population dynamics, and potential response to environmental changes.

For comparison, the genetic diversity of other *Batagur* species was analysed. *B. baska* exhibited 5 haplotypes among the total 24 samples, with Hd and π calculated at 0.782 and 0.0012, respectively. In contrast, *B. dhongoka* showed higher genetic diversity, with 92 mtDNA sequences resulting in 31 haplotypes, and Hd and π values of 0.94 and 0.002, respectively. Conversely, *B. borneoensis* displayed lower genetic diversity, with 90 mtDNA sequences yielding only four haplotypes, and Hd and π values of 0.405 and 0.00076, respectively. Similarly, *B. affinis* showed low genetic diversity, with 120 mtDNA sequences resulting in six haplotypes, and Hd and π values of 0.285 and 0.0044, respectively.

Table 11.10 Comparison of genetic diversity in other species of *Batagur* based on mtDNA

Species	N	H	Hd	π	Location	References
Batagur baska	24	5	0.782	0.0012	Sunderban Tiger Reserve, India	Present study
Batagur dhongoka	92	31	0.94	0.002	Ganga River, India	Kumar et al., 2024
Batagur borneoensis	90	4	0.405	0.00076	Ujung Aceh Tamiang, Indonesia	Guntoro et al., 2020
Batagur affinis	120	6	0.285	0.0044	Peninsula Malaysia	Salleh et al., 2023

The results indicate varying levels of genetic diversity among the Batagur species. *B. dhongoka* exhibited the highest genetic diversity, with a large number of haplotypes and high values of haplotype diversity, suggesting a robust genetic structure possibly due to a large population size and/or historical demographic factors. In contrast, *B. borneoensis* and *B. affinis* displayed lower genetic diversity, indicated by fewer haplotypes and lower values of haplotype diversity and nucleotide diversity, possibly due to smaller population sizes, genetic bottlenecks, or founder effects. Considering this, *B. baska* also exhibited low genetic diversity as reported in *B. borneoensis* and *B. affinis* species, suggesting a low level of nucleotide variation among the analysed mtDNA sequences, which could be attributed to a founder effect.

Demographic history

The demographic history of the studied *B. baska* was inferred from neutrality analysis. Results of Tajima's D and Fu's Fs tests were used to explain the population history of both populations. In overall samples, the values of Tajima's D and Fu's FS were 0.676 and -1.041, respectively, but non-significant values indicated a stable population size. Moreover, effective population sizes and demographic trends were also estimated by the Bayesian skyline plot (BSP) analysis. The Bayesian Skyline Plot indicated a declining trend in the effective population size of *B. baska* from around 25 kya during the late Pleistocene. Oscillations in tidal zones, alterations in estuarine salinity levels due to climate change, and intensified human activities, including overexploitation, are critical factors leading to the significant population decline of *B. baska* (Mallick et al., 2021).

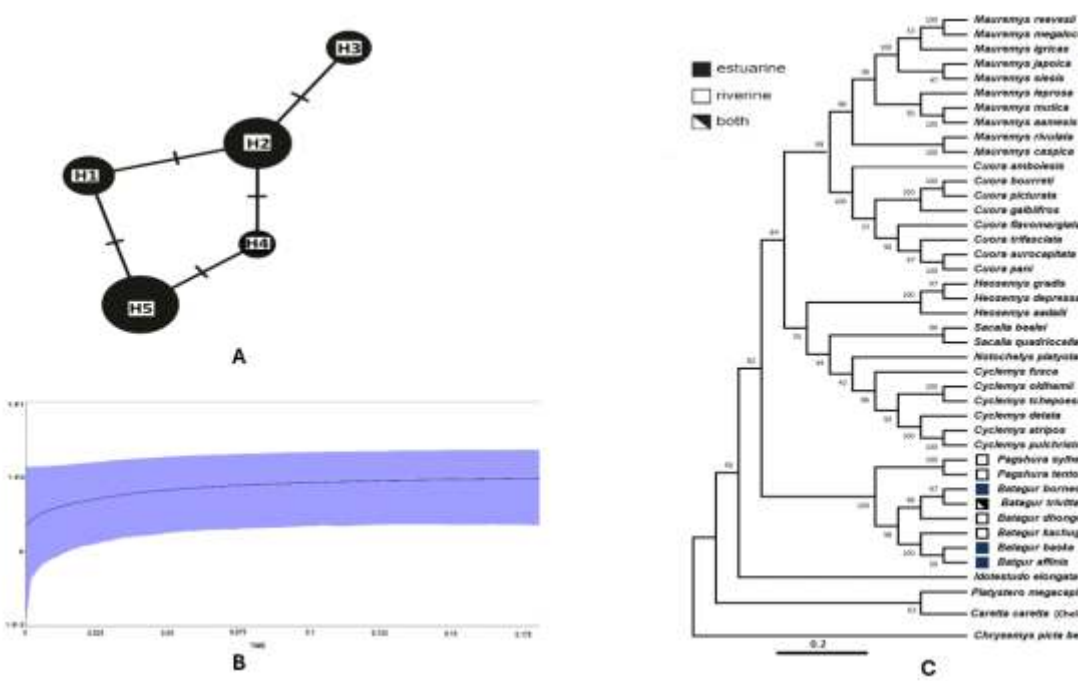


Figure 11.14 (A) Median-joining network inferred from Batagur baska mitochondrial DNA, (B) Bayesian Skyline plot to visualise the demographic changes in effective population size (Ne) over time (x-axis), (C) Phylogenetic relationship of *Batagur baska*.

Phylogenetic relationships

A total of 42 species of Testudines were included in our phylogenetic analysis, focusing on the cyt b gene (Figure 11.14). This dataset comprised 6 species from the Batagur genus, 32 from the Geoemydinae subfamily, and 4 from other families within Testudines. In our Maximum Likelihood phylogenetic tree (ML analysis), both the Batagur and Pangshura genera were positioned basally to all other Geoemydids in the ingroup, with high bootstrap support (>80%). Regarding the Batagur genus, our analyses strongly support the riverine B. kachuga as basal to a terminal clade that includes the estuarine species B. baska and B. affinis. This clade is sister to another clade comprising the remaining three Batagur species, namely B. dhongoka, B. borneoensis, and B. trivittata. Our phylogeny, based on the cyt b gene, is consistent with the general topology of the phylogeny previously reported by Le et al. (2007) and Praschag et al. (2009). Furthermore, our analysis reveals that the genus Cuora is closely related to Mauremys, while Cyclemys, Sacalia, Heosemys, and Notochelys form a distinct cluster with significant posterior probability support.

IV. Genetic diversity in Pangshura

Within *P. smithii*, 58 sequences were organised into 15 haplotypes, while *P. tentoria* exhibited 10 haplotypes among its 38 sequences, and *P. tecta* displayed 9 haplotypes with its 21 sequences. The gene diversity for *P. smithii* was relatively low, with Hd=0.592 and π=0.0029, in contrast to *P. tentoria*, which showed higher gene diversity (Hd=0.814 and π=0.00323), and *P. tecta*, with a gene diversity of Hd=0.852 and π=0.00171, respectively (Table 11.11).



Table 11.11 Sample size (N), number of haplotypes (H), haplotype diversity (Hd), nucleotide diversity (Pi), Fu's Fs, and Tajima's D in Pangshura populations

Species	N	H	Hd	Pi	Tajima's D*	Fu's Fs
P. smithii	58	15	0.592	0.0029	-2.79*	-3.54
P. tentoria	38	10	0.814	0.00323	-0.015	-0.470
P. tecta	21	9	0.852	0.00171	-1.25	-3.67

Genetic differentiation in Pangshura

The analyses unequivocally confirmed significant genetic differentiation among all *Pangshura* species. The within-group mean distance was notably high in *P. smithii* and *P. tentoria*, while it exhibited a lower value in *P. tecta*. The genetic differentiation percentages further revealed distinctions: 5.9% between *P. smithii* and *P. tentoria*, 6.4% between *P. tecta* and *P. tentoria*, and 7.2% between *P. smithii* and *P. tecta*. Based on these estimates of genetic differentiation, it is evident that *P. smithii* and *P. tentoria* are more closely related than *P. tecta.*

Population demography

The neutrality test analysis, Tajima's D, and Fu's Fs tests were employed to infer the demographic history of all Pangshura populations. The high significant negative Tajima's D value was observed in *P. smithii*, whereas it was a non-significant negative value for *P. tentoria* and *P. tecta*. No statistical significance values for Fu's Fs were observed in all *Pangshura* populations, but shows high negative values. The significant negative values observed for both Tajima's D and Fu's Fs in the Pangshura population within the Ganga River system suggest the presence of rare nucleotide site variants. These findings serve as evidence of deviation resulting from sudden population growth or selection pressures. In support of this, Bayesian skyline plot (BSP) analyses were conducted, further substantiating the hypothesis of population expansion in *P. smithii* and *P. tentoria* populations after a sharp decline. *P. tecta* showed a prolonged phase of demographic stability. This anomaly may be attributed to either a limited sample size or a close genetic relationship among individuals of *P. tecta*.

Geneflow and haplotype linkage

A median-joining network was constructed to elucidate genetic relationships among all haplotypes belonging to *Pangshura* populations. In the case of *P. smithii*, 15 haplotypes were identified, and core haplotypes were notably present in the Ganga River, sharing genes with the Ghaghra and Chambal rivers, as well as samples from unidentified locations in Uttar Pradesh rivers (Figure 11.15). Additionally, some haplotypes were shared between the Ghaghra and Brahmaputra rivers, as well as between the Ganga and unknown locations in Uttar Pradesh. A star-like network pattern emerged in *P. smithii*, aligning with and supporting the results of the neutrality test and Bayesian skyline plot (BSP) analysis, suggesting population expansion within the Indian river system. The absence of distinct river-wise clustering in the studied population suggests a significant level of maternal gene flow within *P. smithii* across diverse river systems.

In the case of *P. tentoria*, 10 haplotypes were identified, and three core haplotypes were observed, indicating evolution of different maternal lines in *P. tentoria*. Sharing of genes was observed in the Ganga, Gomti, Chambal, Ghaghra and Brahmaputra rivers constitute the core haplotype. Sharing of haplotypes was also between Gomti, unknown localities of Uttar Pradesh, Chambal and the Bangladesh population. The absence of distinct river-wise clustering in the *P. tentoria* suggests a significant level of maternal gene flow across diverse river systems.

In *P. tecta*, 9 haplotypes were identified, and sharing of genes was observed in Ganga, Chambal, and unknown localities of Uttar Pradesh. The absence of distinct river-wise clustering in the *P. tecta* suggests a significant level of maternal gene flow across diverse river systems and a stable population size.

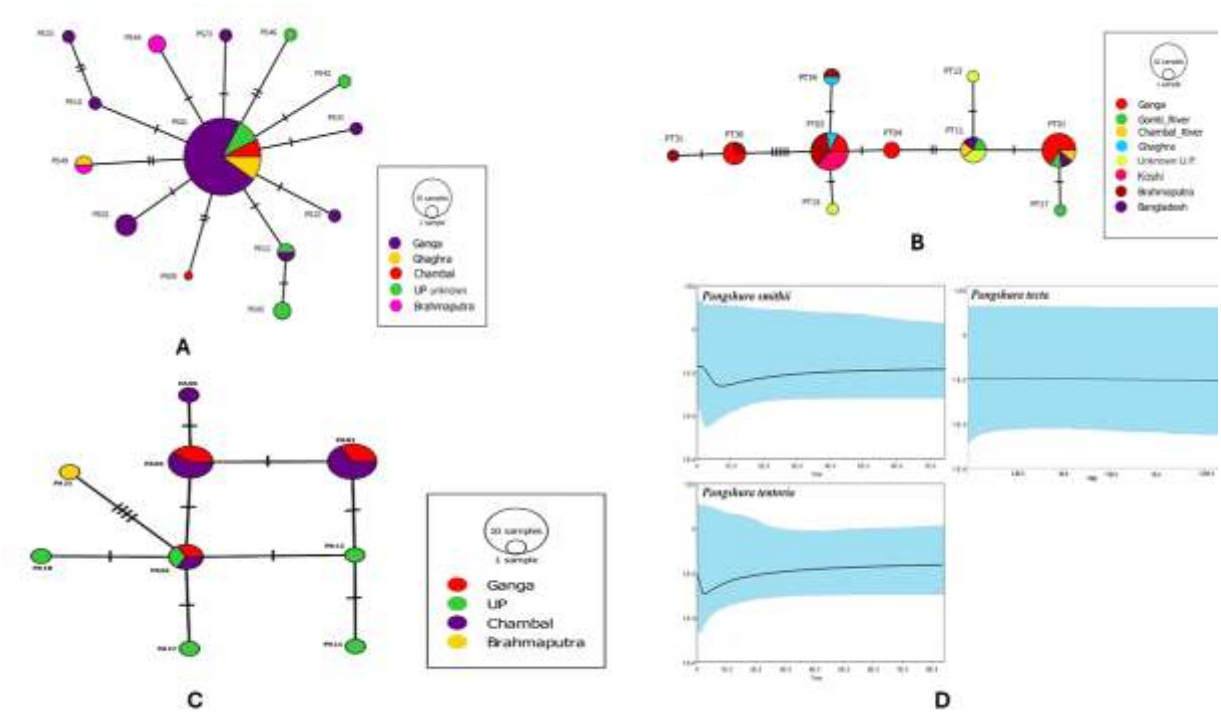


Figure 11.15 (A) Median-joining network of Pangshura smithii, (B) Median-joining network of *Pangshura tentoria*, (C) Median-joining network of *Pangshura tecta*, (D) Bayesian skyline plots (BSPs) estimated by BEAST for *Pangshura* populations in the X-axis shows time before present (Ma). The Y-axis (logarithmic scale) expresses the effective population size (Ne)

11.3.3 Gangetic Dolphin

I. Mitogenome features and organization

We obtained a 16319 bp complete circular mitochondrial genome of the Gangetic dolphin and deposited it in GenBank with accession no. MN896020-MN896023 and MT668915, MT668916 (Figure 11.16). The mitogenome is encoded by two rRNA genes, 22 tRNA genes, one origin of replication (OL), 13 PCGs, and a non-coding CR. Among these, 28 genes (2rRNA, 14 tRNA, and 12 PCGs) were located on the heavy strand (H-strand), except the ND6 gene and eight tRNA genes (*tRNA^{Gln}*, *tRNA^{Ala}*, *tRNA^{Asn}*, *tRNA^{Cys}*, *tRNATyr*, *tRNA^{Ser}*, *tRNA^{Glu}*, *tRNA^{Pro}*) and OL located on the light strand (L -L-strand) (Figure 11.17). The distribution and arrangement of mitogenes were like those of other mammalian species (Kumar et al., 2019; Singh et al., 2019; Boore, 1999). The nine pairs of overlapping regions in the mitogenome were observed among *tRNA^{Ile}*/*tRNA^{Gln}*, *ND2*/*tRNA^{Trp}*, *OL*/*tRNA^{Cys}*, *ATP8*/*ATP6*, *ATP6*/*COIII*, *COIII*/*tRNA^{Gly}*, *ND4L*/*ND4*, *ND5*/*ND6*, and *tRNA^{Thr}*/*tRNA^{Pro}*. The overlapping regions ranged from -1 to -39 bp. The longest overlapping was located between *ATP8* and *ATP6* (39bp), and the smallest between *ATP6*/*COIII*, *COIII*/*tRNA^{Gly}*, and *tRNA^{Thr}*/*tRNA^{Pro}* (1 bp). The OL sequence was 35 bp in length and was located between the tRNA^{Asn} and *tRNA^{Cys}*; this region played an important role in the initiation of DNA synthesis by recognising the start site of DNA polymerase (Wong and Clayton, 1985). The non-coding CR region was located between *tRNA^{Pro}* and *tRNA^{Phe}*. In addition, 14 intergenic spacers were observed between the mitochondrial regions, ranging from 1 to 32 bp in length; the longest intergenic region was present between *tRNA^{Asn}* and *tRNA^{Cys}* (Table 11.12).

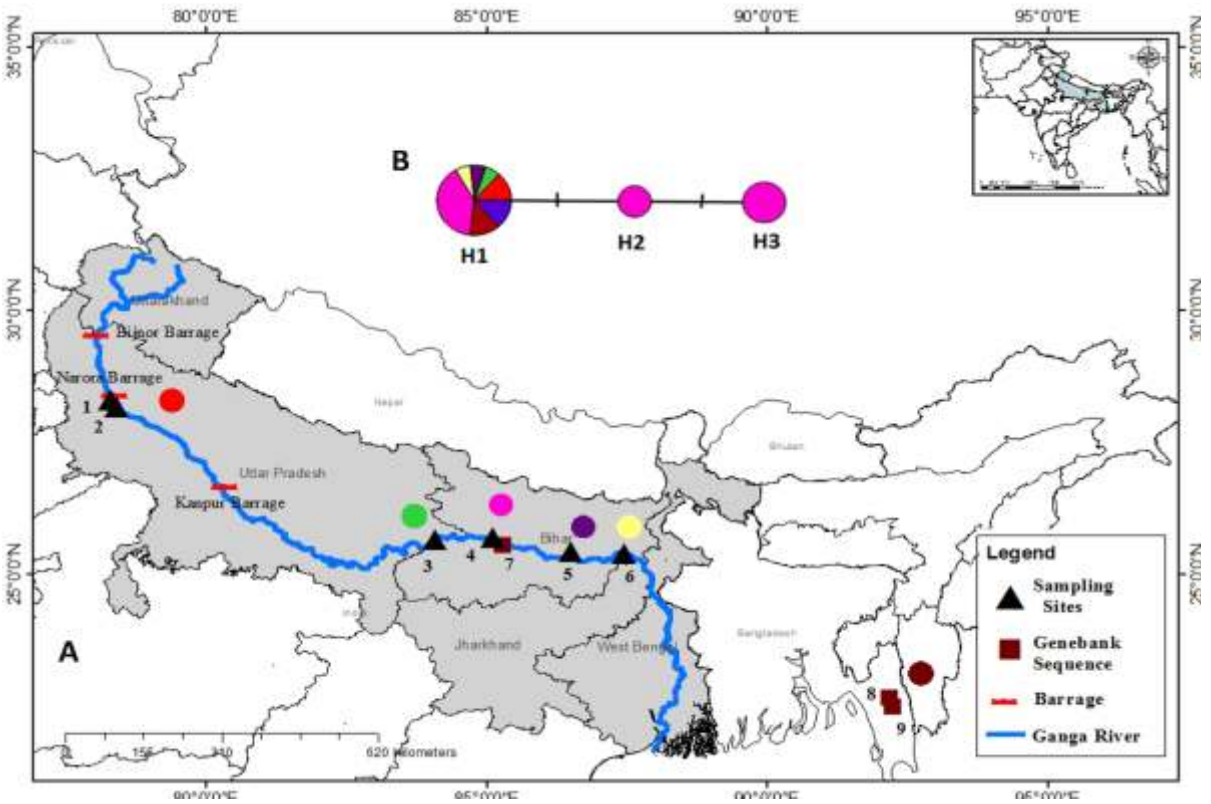


Figure 11.16 (A) The geographic origin of the samples used in this study. (B) mtDNA control region-based haplotype sharing; the colour of each circle represents the geographic origin.

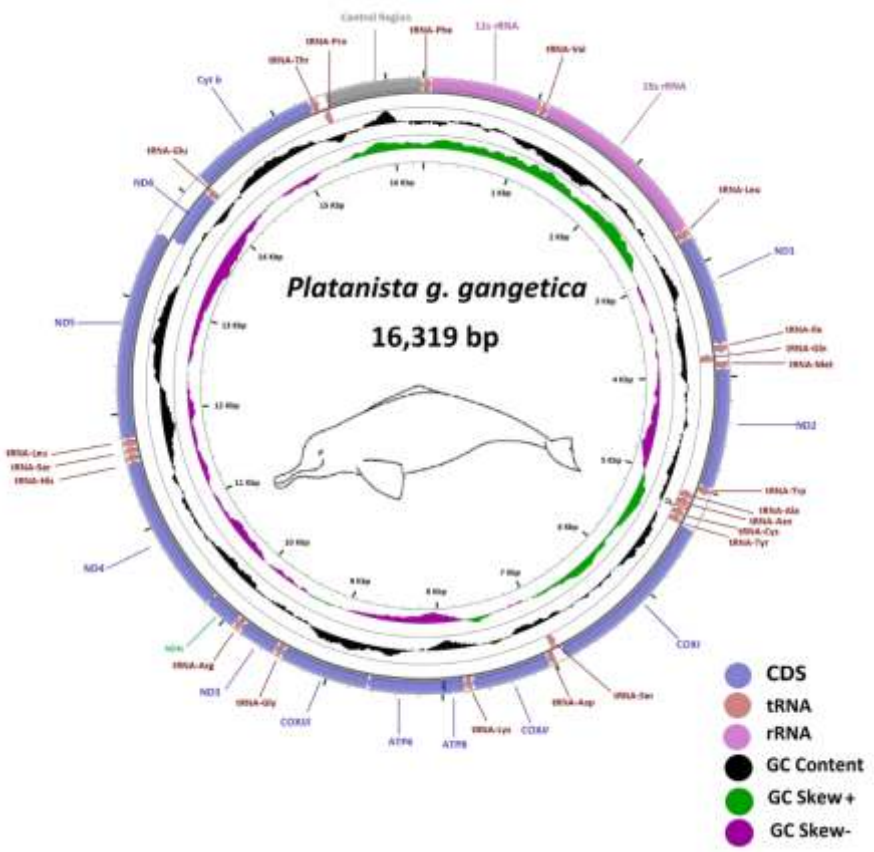


Figure 11.17 The complete mitochondrial genome organisation of the Gangetic dolphin (*P. g gangetica*). 12S rRNA and 16S rRNA refer to ribosomal RNAs; *COXI*, *COXII* and *COXIII* refer to subunits of cytochrome c oxidase; *Cyt b* denotes to cytochrome b; *ND1-ND6* refer to components of NADH dehydrogenase; *ATPase 6* and *ATPase 8* refers to classes of ATP synthase; Transfer RNAs (tRNA) are labeled with their corresponding amino acids; CDS represent the coding region and are shown in blue.

Table 11.12 The organisation and characterisation of the complete mitochondrial genome of the Gangetic dolphin (*P. g. gangetica*).

Gene	Start position	End position	Length (bp)	Initiation codons	Termination codons	Anti-codon	Strand	Space /overlap
tRNA-Phe	1	73	73	-	-	GAA	H	0
12S ribosomal RNA	74	1044	971	-	-	-	H	0
tRNA-Val	1045	1111	67	-	-	TAC	H	0
16S ribosomal RNA	1112	2688	1577	-	-	-	H	0
tRNA-Leu	2689	2763	75	-	-	TAA	H	0
ND1	2766	3722	957	ATG	TAA	-	H	+2
tRNA-Ile	3728	3796	69	-	-	GAT	H	+5
tRNA-Gln	3794	3866	73	-	-	TTG	L	-3
tRNA-Met	3868	3936	69	-	-	CAT	H	+1
ND2	3937	4980	1044	ATA	TAG	-	H	0
tRNA-Trp	4979	5046	68	-	-	TCA	H	-2
tRNA-Ala	5052	5120	69	-	-	TGC	L	+5
tRNA-Asn	5122	5195	74	-	-	GTT	L	+1
rep origin-OL	5196	5230	35	-	-	-	L	0
tRNA-Cys	5228	5294	67	-	-	GCA	L	-3
tRNA-Tyr	5295	5360	66	-	-	GTA	L	0
COXI	5362	6906	1545	ATG	TAA	-	H	+1
tRNA-Ser	6908	6976	69	-	-	TGA	L	+1
tRNA-Asp	6984	7051	68	-	-	GTC	H	+7
COXII	7052	7735	684	ATG	TAA	-	H	0
tRNA-Lys	7739	7805	68	-	-	TTT	H	+3
ATP8	7807	8007	201	ATG	TAG	-	H	+4
ATP6	7968	8648	681	ATG	TAA	-	H	-39
COXIII	8648	9433	786	ATG	TAG	-	H	-1
tRNA-Gly	9433	9501	69	-	-	TCC	H	-1
ND3	9502	9848	346	ATA	TA-	-	H	0
tRNA-Arg	9849	9918	70	-	-	TCG	H	+1
ND4L	9919	10215	297	GTG	TAA	-	H	0
ND4	10209	11586	1378	ATG	T--	-	H	-7
tRNA-His	11587	11655	69	-	-	GTG	H	0
tRNA-Ser	11656	11715	60	-	-	GCT	H	0
tRNA-Leu	11717	11786	70	-	-	TAG	H	+1
ND5	11787	13607	1821	ATA	T--	-	H	0
ND6	13593	14112	520	ATG	T--	-	L	-14
tRNA-Glu	14113	14181	69	-	-	TTC	L	0
CYT b	14186	15325	1140	ATG	AGA	-	H	+4
tRNA-Thr	15326	15396	71	-	-	TGT	H	0
tRNA-Pro	15396	15462	67	-	-	TGG	L	-1
Control region	15463	16319	857	-	-	-	H	0

II. Base composition and AT/GC-skew

The total nucleotide composition of the Gangetic dolphin mitochondrial genome was A (32.9%), T (26.7%), C (27.9%), and G (12.4%), and it was biased towards A+T (59.6%) (Table 11.13). The total length of all 13 PCGs was 11400 bp; however, 1519 bp were for tRNAs and 2548 bp for rRNA genes. The A+T composition of PCGs, tRNAs, rRNAs, and CR was 58.9%, 63.5%, 60.7%, and 60.5%, respectively. The AT skewness was 0.104, and the GC skewness was -0.384 in the complete mitogenome. The AT-skew was positive for PCGs, tRNAs, and rRNAs, whereas the GC-skew was negative except for tRNAs in the Gangetic dolphin. We estimated base skews between all the freshwater river dolphins to understand the nucleotide distribution in PCGs. The trend of AT-skew and GC-skew values in all 13 PCGs of the Gangetic dolphin (Figure 11.18). The average AT and GC skew values for the Gangetic dolphin in PCGs were 0.045 and -0.412, respectively. In all studied river dolphins, AT skewness was positive, indicating that the adenine base occurs more frequently than thymine, whereas GC skewness was negative, indicating that the cytosine base is more common than the guanine base in PCGs.

The length of CR in the Gangetic dolphin was 857 bp and was located between $tRNA^{Pro}$ and $tRNA^{Phe}$, which is shorter than that of many cetaceans. The AT content was higher than the GC content. In particular, an 18 bp repeat consensus (AATACTAATAACAAAAAC) was found within 14062-14101 bp with a copy number of 2.2 of CR. However, no repeat sequence was detected in the mitogenome of *P. g. minor*, *Inia geoffrensis*, *Pontoporia blainvillei*, and *Lipotes vexillifer*. Duplicated CRs have also been found in the mitogenomes of deer (Gupta et al., 2015; Kumar et al., 2017), birds (Abbott et al., 2005), and fishes (Shi et al., 2014).

Table 11.13 Nucleotide composition and skewness in the Gangetic dolphin (*P. g. gangetica*) mitochondrial genome.

Platanista gangetica gangetica	Size (bp)	A%	T%	AT-skew	G%	C%	GC-skew
Whole mitogenome	16319	32.9	26.7	0.104	12.4	27.9	-0.384
PCGs	11400	30.8	28.1	0.045	12.1	29.1	-0.412
tRNAs	1519	33.3	30.2	0.048	19.0	17.4	0.439
rRNAs	2548	37.2	23.5	0.225	17.0	22.3	-0.134

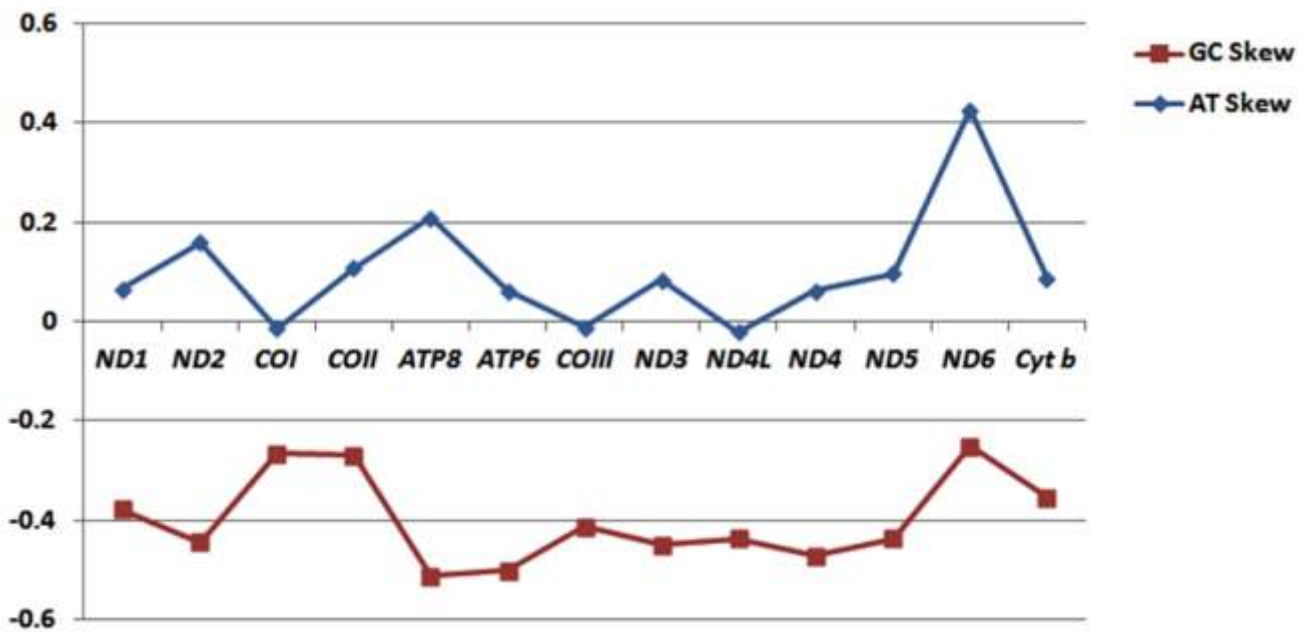


Figure 11.18 Graphical representation of AT- and GC-skew in all the 13 protein-coding genes of the Gangetic dolphin (*P. g. gangetica*) mitogenome. Values of AT- and GC-skew are plotted on the x-axis.

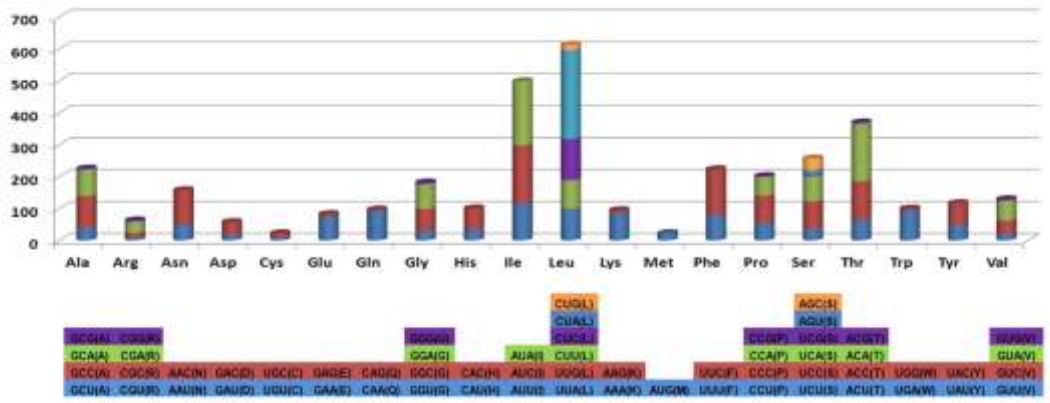


Figure 11.19 Relative synonymous codon usage (RSCU) of the mitochondrial protein-coding genes of the Gangetic River dolphin. Codon count numbers are provided on the X-axis.

III. Genetic diversity, geospatial genetic structuring, and demography

We used 23 sequences of mtDNA CR region (857 bp) for the estimation of genetic diversity in the Ganga River covering a wide geographic range, i.e., Narora (Uttar Pradesh) in India to Bangladesh. Among the 23 CR sequences, we observed only two parsimony informative sites at nucleotide positions 15574 and 16136 (corresponding to the complete mitogenome) of the Gangetic dolphin (GenBank no. MN896020). These sequences were grouped into 3 haplotypes (hap), where hap1 was the core haplotype shared between the sequences from Narora (India) to Bangladesh. Hap2 and Hap3 consisted of 3 and 5 sequences from Patna (Bihar). The haplotypes (*hd*) and nucleotide diversity (π) of the Gangetic dolphin were *hd*=0.534 ± 0.097 and π=0.00097 ± 0.00018. The population of the Gangetic dolphin showed a low level of genetic variation, and most sequences from the Ganga to the Karnaphuli River in eastern Bangladesh were clustered in a single haplotype, which indicated a high genetic homogeneity across their distribution ranges. The low genetic diversity may be a result of the founder's effect due to historically low population size (Braulik et al., 2014). Low genetic variability indicated that the population of the Gangetic dolphin might have historically suffered from inbreeding, which could have affected the fitness and local adaptation of the species. Remarkably low genetic diversity was also observed in common bottlenose dolphins in the Southwestern Atlantic Ocean (Fruet et al., 2014), Panama (Barragán-Barrera et al., 2017), the Western North Pacific Ocean (Chen et al., 2017), and Australian humpback dolphins (Parra et al., 2018).

IV. Genetic differentiation and phylogenetic analysis

The mean pairwise genetic distance based on Kimura's 2-parameter model was estimated for 2 rRNA, 13 PCGs, CR, and the complete mitogenome between Platanistidae and ten families of cetaceans. We found that Platanistidae was genetically closer to the Mysticeti, followed by Ziphiidae. However, few genes, such as 12s and ND1, showed an equal genetic distance from Platanistidae to Kogiidae/Mysticeti (0.126) and Ziphiidae/Mysticeti (0.202), respectively. The COXII showed a low genetic distance with Delphinidae, ND2 showed a lower value with Ziphiidae, whereas ND4l and CR showed a close affinity with Monodontidae. The genetic differentiation revealed that the genus Platanistidae is closer to the Baleen and Beaked whales' group than the other river dolphins, namely *Lipotes*, *Inia*, and *Pontoporia*. A similar genetic character of Platanistidae with whales indicated the South Asian River dolphin followed a different evolutionary line. In this light, the choice of a short fragment-based approach for molecular studies within and among cetaceans would affect the accuracy and reliability of the genetic analysis. Hence, long coverage of mtDNA or multigene alignment provides better insight into phylogenetic information than short or single-gene analysis and might give a more accurate taxonomic status (Kumar et al., 2019).

Our analysis indicated that river dolphins are polyphyletic, and the placement of *Platanista* is more basal and has no affinity with other river dolphins. Based on this, it is clear that *Platanista* had a diverse lineage that has been widely accepted. Based on the partial mitochondrial Cyt b and nuclear interphotoreceptor retinoid-binding protein (IRBP) gene sequences, a sister genetic relationship between Platanistidae and Mysticeti was suggested (Verma et al., 2004). This result was consistent with our mean pairwise genetic distance data, where comparatively low distance values were observed between Platanista/Mysticeti than any other group of cetaceans (Figure 11.20). The method used by Verma et al. (2004) was a conventional neighbour-joining analysis, which was a clustering algorithm that clusters groups based on genetic distance. Therefore, to construct the phylogenetic tree for such highly diverse species, model-based approaches, ML and BI, and choosing the best-fit model provide better insight. The high fragility in the phylogenetic position of *Platanista* within cetaceans may be partly because the lineages of the South Asian River dolphin, sperm whale, beaked whale, and baleen whale appear to have been produced through a very rapid split

event during the Oligocene-Miocene (Cassens et al., 2000; Nikaido et al., 2001). The previous studies using only the cytochrome b sequence suggested the split between the Indus River dolphin and Gangetic dolphin was around 0.55 million years ago (95% HPD=0.13 - 1.05) (Braulik et al., 2014), and 0.51 million years ago (95% HPD=0.14-1.02) (McGowen et al., 2009). This split age was possibly associated with the formation of the Himalayan Mountains driven by tectonic forces, which in turn might have altered the drainage pattern of the western Himalayan Mountain system in the recent geologic past (Clift and Blusztajn, 2005). Based on these events, we hypothesise that after the loss of potential connectivity between these rivers, the South Asian River dolphins later colonised and then were genetically isolated at around 1.03 million years ago (95% HPD = 0.84-1.18).

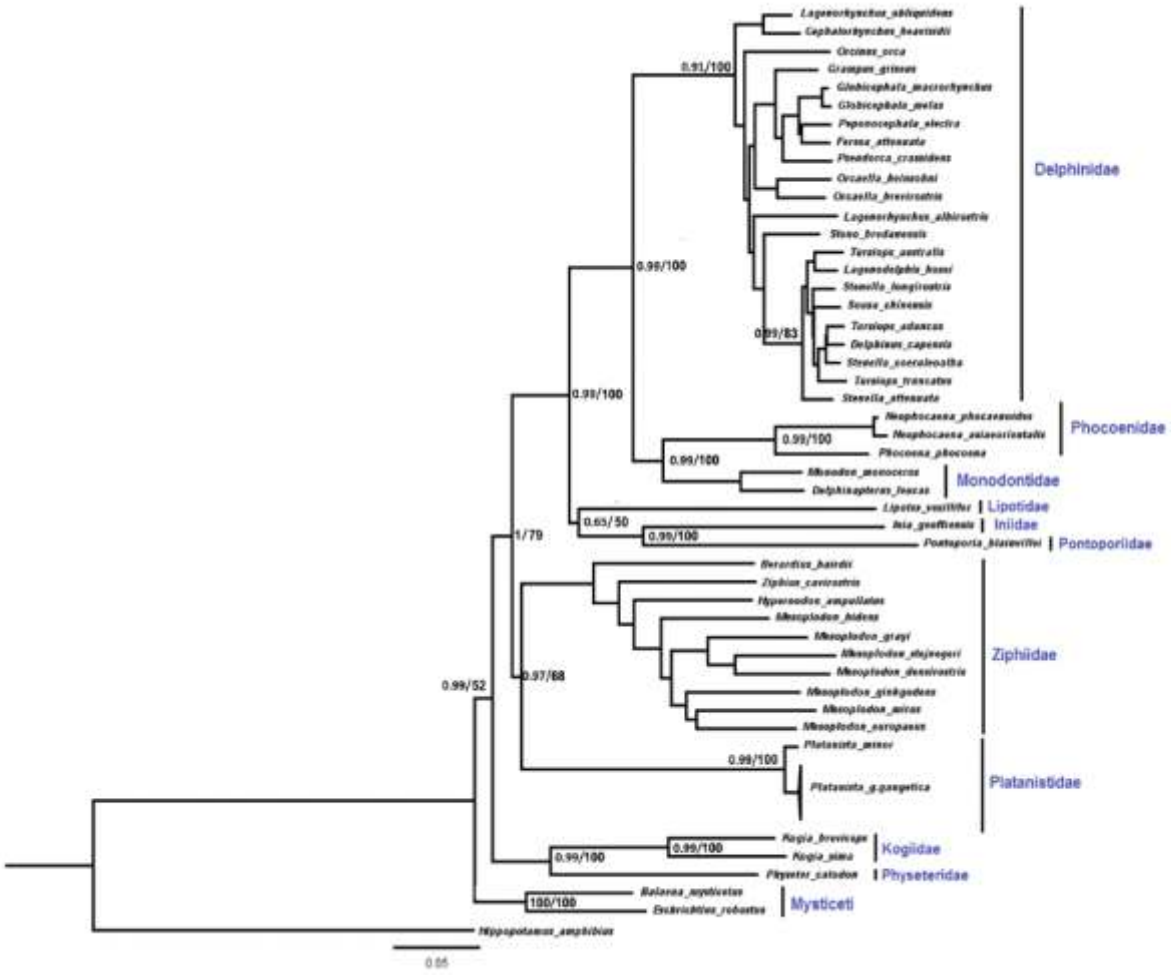


Figure 11.20 Phylogenetic tree inferred from maximum likelihood (ML) (raxmlGUI 2.0 beta) and Bayesian inference (BI) analyses using 12 concatenated protein-encoding genes. Bootstrap support and Bayesian posterior probability values (≥ 50% BS) are shown at the node of the tree

11.4 DISCUSSION

11.4.1 Fish

The genetic structure and diversity analysis of any species that is under high threat gives us vital information for its development and effective management (Kumar et al., 2017; Gupta et al., 2018). The Ganga River is a vital biodiversity hotspot where anthropogenic pressures make understanding the population dynamics of species like *W. attu* essential for conservation. This study provides the first detailed genetic insight into the species within the GRS, revealing high haplotype diversity but low nucleotide diversity. This signature suggests a historical bottleneck followed by rapid expansion, allowing for the accumulation of unique mutations without a corresponding increase in overall sequence divergence. While analyses identified three distinct genetic clades, they do not align with specific river geography, indicating that W. attu is undergoing basin-wide diversification driven by varying selective pressures rather than physical isolation.

Furthermore, genetic variation primarily occurs within populations, with low overall differentiation despite

increasing distance between tributaries. This connectivity is likely maintained by high gene flow and a lack of physical barriers, facilitating genetic exchange across the basin. Historically, most populations have remained stable, though the Ganga population specifically shows significant signals of expansion. Bayesian Skyline Plot analysis dates this major growth spurt to approximately 0.04 million years ago during the late Pleistocene. This period was marked by dramatic glacial-interglacial fluctuations and cycles of shifting water levels that likely dictated the evolutionary trajectory and current distribution of the species.

Ultimately, these findings suggest that higher genetic variation increases the likelihood of individuals possessing advantageous traits suited for their changing environments. This adaptive advantage leads to the prolonged survival of specific lineages, contributing to the ongoing diversification of *W. attu* into distinct genetic groups. Because these results underscore the species' high adaptive potential and complex population structure, further exploration of other Indian river systems is warranted to develop more comprehensive, large-scale conservation and management strategies.

For the conservation and to maintain the pure genetic stock, knowledge about the existing lineages is essential. Present chapter also provides the first molecular data of *S. aor* and compared it with other existing populations of *Sperata* spp. Our data revealed a high haplotype diversity (>0.71) in *Sperata* species found in three Indian rivers including the Ganga River. The pairwise genetic distance, phylogenetic, and AMOVA analysis indicated population structuring in *Sperata* spp. The phylogenetic relationship and network revealed the presence of two mtDNA lineages (clade IA and IB) of the *S. seenghala* from the Ganga River. Clade IA is widely distributed throughout the Ganga, whereas Clade IB is confined to the lower stretch of the Ganga, i.e, Munger district, Bihar. Interestingly, when we compared the data with Kumari et al. (2017), the two sequences (accession no. KT022220 and KT306656) from the Brahmaputra were merging with the Ganga haplotype (Hap.3). In contrast, three sequences (accession no. KT022199, KT022220, and KT022201) from Mahanadi (Hap. 69) were clustered with *S. aor* of the Ganga River. It indicated that the Brahmaputra River also sustains the gene pool of the Ganga River. The possible explanation for the existence of the Brahmaputra lineage in the Ganga is that both rivers merge at the Sunderbans area of Bangladesh and provide the potential route for migration. Besides, the presence of a similar gene pool to the Ganga. Therefore, the genetic differentiation was estimated between the different identified lineages observed in the study. Considering two known species, *S. seenghala* and *S. aor*, as a reference, we observed a higher genetic differentiation value (17.5%) than the newly identified lineage of *seenghala* from Ganga (4.8%). Interestingly, the genetic differentiation between Ganga-Brahmaputra was much higher (25.3%) than the values observed from *S. seenghala* and *S. aor.* This result indicated the presence of highly diverse lineages in the Brahmaputra than the *S. seenghala*, which needs to be confirmed based on their detailed morphological characteristics. The study on stock discrimination using microsatellite markers from the middle to lower stretch of the river Ganga, i.e, Narora-Kanpur, Varanasi, and Bhagalpur, revealed three different stocks of *S. aor* (Nazir and Khan, 2017). However, this result was contradictory with our mtDNA-based study, where we did not find any significant barrier to gene flow and structuring in *S. aor* across the sampling sites of the Ganga River.

Moreover, the existence of two distinct lineages of *S. seenghala*, which is more diverse than the *S. aor*, indicates the presence of multiple clades of *Sperata*. In the stretch of Varanasi to Sahebganj of the Ganga River, a large number of tributaries, such as Gomti, Ghaghara, Gandak, Son, Kiul, and Kosi, merge with the Ganga, which might have resulted in the migration and confinement of the different gene pools of these rivers to a particular habitat (Nazir and Khan, 2017).

The genetic diversity analysis of 40 sequences of *Bagarius bagarius* across six major river systems, including the Ganga River, revealed a notably low and uneven pattern of mitochondrial variation, highlighting the species' threatened status. Despite its wide distribution, *B. bagarius* populations exhibit limited genetic diversity, likely due to habitat fragmentation, overfishing, and environmental degradation. The observed heterogeneity among rivers reflects localised demographic histories and ecological pressures, indicating that each river system is influencing the genetic makeup of populations differently. The observed haplotype diversity and nucleotide diversity based on COI sequences, indicating extremely low genetic variation within *B. bagarius* populations across the sampled river systems. This overall low diversity is possibly resulting from recent population bottlenecks, habitat fragmentation, or ongoing anthropogenic pressures. Analysis using Cyt b sequences revealed comparatively higher genetic variation, with haplotype diversity (Hd) of 0.588 ± 0.062 and nucleotide diversity (Pi) of 0.00142 ± 0.00034. This moderate level of mitochondrial diversity suggests that it retains some genetic differentiation across populations, possibly reflecting historical connectivity and localised adaptation. Nagarajan et al. (2016) sequenced fragments of the mitochondrial COI and cytochrome b genes from individuals in the Ganges and Brahmaputra basins. They detected no significant differentiation in COI, but notable divergence in cyt b, indicating gene flow in COI but population structuring in cyt b. Moreover, COI and cyt b reliably distinguished *B. bagarius* from *B. yarrelli*.

By using Cyt b sequences, the median-joining network revealed a total of 5 haplotypes (Hap_1 - Hap_5) across the river systems. Hap_1 was the central haplotype, shared among the Ganga, Yamuna, and Ghaghra rivers, suggesting an ancestral or ongoing distribution across other river systems. Hap_2 was found to be the most widely distributed haplotype among all the rivers. It was shared between five of the six rivers, including the Ganga

River. This implies a general interrelatedness between the populations from mainstem Ganga and other tributaries and a stable genetic exchange through hydrological connectivity among the different river systems. Meanwhile, Hap_3 and Hap_4 were unique to the Ganga River and arose from three mutational events, whereas Hap_5 was a common haplotype shared by the Gomti and Girwa rivers, possibly reflecting regional genetic connectivity.

The ML phylogenetic tree establishes *B. bagarius* as a monophyletic lineage across South Asia, as defined by the core cluster of haplotypes from the Ganga and other rivers. The intermingling of these samples and the minimal internal branch length suggests robust historical gene flow and relatively recent expansion throughout the Indo-Gangetic and Brahmaputra basins.

The study provided clear insights into the genetic structure and connectivity within the studied freshwater system. Although there are some levels of connectivity among all the rivers, the overall diversity and health of *B. bagarius* appear to be in decline. The genetic assessment using the COI gene showed extremely low genetic diversity, while the Cyt b gene revealed low to moderate genetic variation. This could be a warning sign of reduced adaptive potential, emphasizing the need for close monitoring and habitat protection to prevent further loss of genetic variation.

11.4.2 Turtles

To date, genetic studies of *B. dhongoka* have been limited. Our findings reveal new genetic insight about *B. dhongoka* and thus play an important role in freshwater turtle conservation. This study uses mitochondrial and microsatellite markers to investigate the pattern of genetic diversity, population structure and demography of critically endangered *B. dhongoka* from two turtle rescue and rehabilitation centres, TRRC and GARRC. The analysis of mtDNA revealed high haplotype diversity in concurrence with low nucleotide diversity, indicating that haplotypes were closely related. The possible explanation for turtles' low nucleotide diversity is their slow mitochondrial evolutionary rate (King, 2004). It was also evident from the haplotype network, which shows mostly single-nucleotide differences between haplotypes. Similarly, high haplotype diversity has been reported in loggerhead sea turtle (*Caretta caretta*) (Baltazar-Soares et al., 2020), whereas lower haplotype diversity in turtle species, e.g., in leatherback turtles (*Dermochelys coriacea*) (Wongfu, 2022) and Bog turtle (*Glyptemys muhlenbergii*) (Rosenbaum et al., 2007). Our data show that low nucleotide diversity with high haplotype diversity, which can be a signature of population expansion from a small effective population size (Rogers et al., 1992). The clustering of sequences showed that four haplotypes of TRRC were similar to those found in GARRC, indicating



close genetic relationships and having common genetic ancestry. Furthermore, microsatellite analysis revealed a moderate level of genetic diversity for both *B. dhongoka* populations. Microsatellite-based structure analysis revealed weak genetic clusters between the TRRC and GARRC populations. The results support the ongoing conservation practices under the National Mission for Clean Ganga Project, where most of the *B. dhongoka* individuals in TRRC belong to the source population of the Chambal River and a few rescued individuals from seizures near the Ganga River. Hence, two different stocks are observed in TRRC. In contrast, individuals in GARRC are only the rescue cases recovered from the local areas.

The BayesAss analysis indicated recent migration from GARRC to TRRC (m=0.15), which may be attributed to human interference and the mixing of individuals in TRRC (Ganga and Chambal rivers). The rate of self-assemblage was higher in both GARRC and TRRC, which may be due to limited gene flow and low population size. In the current study, our sample size from GARRC is limited. Although *B. dhongoka* has experienced a severe reduction in population size due to anthropogenic disturbance, the mtDNA-based demographic history analyses ruled out any significant past contraction in both the studied populations. It was also in accordance with the estimates of the BOTTLENECK analysis with respect to recent bottlenecks.

In contrast, the G-W index test did not give a consistent result with bottlenecks and mtDNA analysis, suggesting a genetic bottleneck in both populations. It may be accounted for by the G-W index's sensitivity in detecting population bottlenecks, in which the number of alleles is typically reduced more than the range due to a decline in population size. As indicated by the Bayesian Skyline Plot, there was a period of historical stability followed by an expansion in the effective population size, but more recently, a slight decline has been observed from ~2 thousand years ago.

The primary factors contributing to reduced genetic diversity are small population sizes, which are intricately connected to the fitness and health of individuals, along with limited population growth capacity (Spielman et al., 2004). Therefore, robust rehabilitation and relocation strategies are needed to support small and declining populations, which include scientifically based releases into natural environments. Finding reliable origin information is often challenging, and releasing rescued individuals of unknown sources into the wild is sometimes associated with the mortality of individuals (Villemey et al., 2013). Additionally, while reintroduction starts with a small population, genetic monitoring is essential to comprehend current genetic diversity and relatedness for management and conservation considerations. As a result of the recent trend of population decline amidst persistent pressures, long-term evidence-based conservation and management interventions are required for the long-term survival of *B. dhongoka*.

The pattern of genetic diversity varies within the AFT lineages found in different geographic ranges. The major Andersoni populations of the Ganga River exhibited a moderate level of genetic diversity in the mtDNA *cyt b* region and *CMOS*, whereas it was high in the R35 region. In contrast, a relatively very low level of genetic diversity was observed in the andersoni group II, where widely distributed samples belonging to three different localities of India, Bangladesh and Myanmar were clustered within two haplotypes. Interestingly, sharing of sequences within Ganga and other andersoni populations indicates high gene flow, possibly due to high contemporary migration between Pakistan, northern India, Nepal, Bangladesh and Rakhine State of western Myanmar. We did not detect any significant barrier of geneflow within Andersoni populations. The comparatively high levels of genetic diversity were observed in *L. p. vittata* from central to peninsular India and *L. ceylonensis*, which is only restricted to Sri Lanka.

The phylogenetic and network analysis also revealed the five distinct mtDNA lineages of AFT from its distribution ranges. The distribution ranges of AFT, both the spotted and unspotted groups, sometimes overlap. These species are quite different in morphological features such as pattern of head, neck, carapace shape and colour (Smith 1931; Webb and RG 1980; Webb 1982; Ernst and Barbour 1989; Ernst et al. 2000; Praschag et al. 2011). Despite the clear morphological character between spotted subspecies *L. p. andersoni* and unspotted *L. p. vittata*, intergradations between these subspecies were recorded in a few localities of Odisha, an Indian state (Praschag et al. 2011). The identification of hybrid individuals is sometimes challenging because of morphological similarity; establishing a genetic barcode for molecular tracking can help guide adequate conservation strategies.

The significant pairwise genetic differentiation was detected between five extant AFT lineages, due to their specific habitat, dispersal ability and reproductive isolation. Praschag et al. (2011) reported the high sequence divergence based on uncorrected p distances between *L. p. andersoni* and *L. p. vittata* than the *L. p. punctata*, whereas in our study, we observed its vice-versa (high PD value between *L. p. andersoni* and *L. p. punctata*). This high genetic divergence between these two lineages might be the result of the amalgamation of hybrid origin (*L. p. andersoni* × *L. p. vittata*) samples from Odisha, an Indian state. In comparison to *L. p. andersoni*, the complete *cyt b* shows variations from ~4.9% for L. p. vittata to 12.9% for *L. scutata*. These sequences were used to estimate the divergence time along with that of other extant softshell turtles. The evolution of the Asian softshell turtle is still uncertain, and it has been validated thoroughly in previous studies (Le et al. 2014; Li et al. 2017). *Carettochelys insculpta* is the only extant member of the family Carettochelyidae; it is native to northern Australia and southern New Guinea (Li et al. 2017). We estimated divergence time between Trionychidae and Carettochelyidae to be around 143 MA

(HPD=113.26-177.4) for this node. The last common ancestor of extant AFT existed in Southeast Asia and split at around 116.32 MA (HPD=94.66-139.59) during the Cretaceous (Joyce et al. 2013; Le et al. 2014; Li et al. 2017). Due to climate change, *L. ceylonensis* of Sri Lanka diverged from *L. scutata* of Myanmar at around 30 MA (HPD=22.72-37.70), followed by *L. punctata* at around 23.21 MA (HPD=17.74-29.71). During this period, a Palaeogene biogeographic link was maintained between South-East Asia and India. The northward drifting of the Indian plate towards Asia occupied the north-east corner of the subcontinent, encountering Sumatra and Burma at around 57 MA ago (early Eocene), which was followed by a hard collision at around 35 MA (early Oligocene) with Asia (Ali & Aitchison 2008, Beck et al. 1995).

The results from BSP, neutrality and mismatch distribution strongly indicate population expansion of *L. p. andersoni* in the Ganga River and other northern populations from the ~1.25 MA in the late Pleistocene. The scenario in the *L. p. vittata*, *L. p. punctata*, *L. ceylonensis* and *L. scutata* indicate a stable demographic situation in the effective population size with no sign of population expansion. This result was consistent with previous findings of Hawksbill turtle (Vargas et al. 2016), leatherback turtles (Molfetti et al. 2013), *Schizothorax o'connori* from the Yarlung Tsangpo River (Guo et al. 2016), and *Schizothorax nukiangensis* from the Nujiang River (Chen et al. 2015), where climatic fluctuations during the Holocene and Pleistocene play a major role in dramatic demographic changes over species growth. The sea-level fluctuation in the Pleistocene period greatly influences the environment, alternation of land, river dimension and existence of natural sources (Simanjuntak 2006). These changing conditions call for adaptation processes and play a significant role in influencing the activity and mobility of species over time. However, in our analysis, low sample size in a few AFT populations is likely to reduce the power for estimating the demographic history (Ho and Shapiro 2011). Hence, assumptions involved in BSP analysis suggest that this should be interpreted cautiously (Grant 2015).

11.4.3 Gangetic dolphin

Endangered species are typically categorised by a low effective population size, which leads to low genetic diversity and may result in inbreeding. The present study indicated low genetic diversity at the mitochondrial genome with high homogeneity across its distribution range (India and Bangladesh). While, loss of genetic diversity in small and isolated populations, is associated with higher risk of extinction (Gilpin and Soule, 1986), the more immediate threat to Gangetic dolphin is anthropogenic pressure, which continues to impede population growth. According to our analysis, river dolphins are polyphyletic, and Platanista is placed at the base and has no relationship with other river dolphins. It is evident that Platanista had a varied lineage that was widely accepted. The phylogenetic position of this species is important, as it is evolutionarily linked to the whale group rather than to other river dolphins (*I. geoffrensis*, *P. blainvillei*, and *L. vexillifer*). This distinction makes the molecular characterisation of its complete mitogenome - spanning 16,319 bp - a landmark comparative study, representing one of the first of its kind for the Gangetic dolphin.



CONCLUSIONS

Fishes

Gaining insights into the genetic diversity and population structure holds the potential to enhance both the management of fisheries and the conservation efforts aimed at preserving vulnerable freshwater fish species. As an economically important species, *W. attu* holds a widespread presence across the Indian subcontinent and other regions of Southeast Asia. This study's revelation of high genetic diversity, coupled with moderate genetic differentiation between populations, indicates the initiation of divergence within the *W. attu* species found in the GRS. The outcomes of this research furnish comprehensive details about the population genetics and historical demographics of *W. attu*. Furthermore, these findings lay the groundwork for the assessment and effective resource management for this species. The implications of these results offer crucial insights for sustainable utilisation, prudent fishery management, and enduring conservation strategies applicable to the species.

The present study provides the reference database for the identification and genetic differentiation of *S. aor* and *S. seenghala* from the Ganga River. The study highlighted the presence of two distinct lineages of *S. seenghala* from the Ganga River. Also, it indicated that the Brahmaputra population is more diverse. Therefore, the present study highlights that the Brahmaputra giant river catfish is a highly diverse lineage that genetically qualifies the status of a distinct species. However, it requires a detailed morphological study from more locations for the identification of multiple lineages existing in the Indian River that can formulate the appropriate conservation and management plans. This study indicated the presence of multiple lineages of *Sperata* from Ganga, Mahanadi, and Brahmaputra that are considered as a distinct Evolutionary Significant Unit (ESUs). These findings will help us understand fish biology and implement the proper conservation and management plan for the development of catfish. However, detailed comparative morphological evidence with support of molecular data is required to be able to support their consideration as separate species.



Turtles

This study presented a pioneering genetic analysis of *B. dhongoka*. These results expand our genetic knowledge of the Critically Endangered *B. dhongoka* and are significant for supporting and developing management strategies to safeguard its genetic diversity in the future. The conservation management of *B. dhongoka* should focus on protecting its core habitats and breeding grounds while tackling illegal poaching and hunting. Its habitat should be monitored and maintained continuously without disturbance, and reconnected across its range to maintain a relatively large and healthy effective population size and enhance its chances of successful survival and adaptation. If implemented, these measures will conserve not only the *B. dhongoka* but also many threatened sympatric turtle species throughout the Ganga River basin.

Assessments of genetic diversity, gene flow, and population demography are competent aspects for conservation programs. Maintaining a high level of genetic diversity is assumed to be essential for the conservation of viable populations (Reed et al. 2002). Despite low nucleotide diversity, the Ganga population shows signs of expansion in effective population size, whereas the rest of the AFT population showed a stable phase. It necessitates urgent targeted conservation efforts to augment the diversity and maintain gene flow of the species. The resolution power in delimiting taxa, especially in cases when hybridisations are now occurring, and extant lineages are morphologically very similar, guiding adequate conservation strategies for any lineages, is a difficult task. Therefore, the signature of mtDNA and nuclear genes can play a pivotal role in wildlife forensics to track the origin of poached species. However, due to limited sampling under the current study, more research is required to compare and resolve the genetic story of the species with other tributaries of the Ganga. To save these jewels of evolution, all stakeholders must come together and act to know more about the turtle populations and their demographic history to better understand the threats and how to combat them. Specialised administration strategies to conserve and maintain safe habitats for these ancient creatures stand as the need of the hour.

Examining the genetic structure and diversity of a species facing significant threats provides crucial insights for its development and effective management (Kumar et al., 2017; Gupta et al., 2018). This study presents, for the first time, detailed genetic data to estimate the level of genetic diversity, gene flow, and demography of all three species of Pangshura, namely *P. smithii*, *P. tentoria*, and *P. tecta*, in different river systems of India. Our data

revealed high haplotype diversity (>0.80) in *P. tentoria* and *P. tecta*, whereas it was comparatively low in *P. smithii*. Interestingly, recent population expansion is observed in *P. smithii*, indicating that the population is genetically fit but requires proper habitat management for long-term conservation. Network analysis revealed the presence of highly diverse lineages of *P. tentoria* in the Ganga River system. All Pangshura species are maternally well-connected within their respective species and exhibit genetic fitness. Molecular genetic analysis emphasises the dire need for further sampling in other river tributaries to develop effective conservation strategies. The present data also aid in the restoration of rescued individuals to their natural habitat.

Gangetic dolphin

The conservation and management of the closely related subspecies are challenging to practice due to minimal physical variation. This study provides the baseline information for adaptive evolution, spatial distribution, and evolutionary relationships of *Platanista*. Taking into consideration low genetic diversity and genetic bottleneck, continuous population monitoring and strong conservation efforts are needed to focus on restricting the mortality rate that causes due to illegal human activities.

Implications for Conservation Management

These insights are critical for informing conservation and management strategies, particularly in light of increasing habitat fragmentation and anthropogenic pressures within the Ganga River system. For fishes, establishing baseline genetic data for future large-scale monitoring and conservation plans is required. Further, preventing interstock mixing during ranching or release to prevent inbreeding is also required. Identification the source population among the Ganga River System is also needed. Mitigation measures should be streamlined to avoid overfishing and genetic loss to reduce the risk of genetic drift. The Ganga River basin should be treated as a single cohesive conservation unit. Considering future challenges, monitoring climate and habitat disturbances around major populations should also be planned. Establishing baseline genetic data for future large-scale monitoring and conservation plans should also be considered.

In terms of turtles, establishing long-term genetic baseline data for future conservation prospects should be prioritised. There is need to expand Pangshura habitat and genetically restoring the population in accordance with its haplotype in the rivers. Further, managing the different populations as an interconnected unit. Identification of the Evolutionary Significant Units (ESUs) should be considered rather than a single widespread species of turtles. Implementation of transboundary conservation within different states should be considered for long-term persistent of turtles. Identification and monitoring of more susceptible populations across the riverine ecosystem should also be prioritised. Due to the very low number and diversity in *Batagur* genus, in captivity, it should be treated as founder stock, and measures should be taken to increase its healthy population number. Haplotype identification and subsequent breeding plans should be developed. Mitigation of Estuarine Environmental Stress should also be focused. At facilities, managing the distinct river stocks from the TRRC should be done separately. Addressing the risk of inbreeding within the same population should also be focused. Establishing mediums to ensure proper gene flow among the populations to reduce the risk of isolation.

Due to its unique evolutionary history, it must be managed as a high-priority ESU of the Gangetic dolphin. Maintaining river connectivity through bypassing physical barriers, preventing further population fragmentation is key to conservation. Further, mitigation of inbreeding risks should also be assessed. Utilisation of non-invasive eDNA surveys for high-resolution monitoring should be considered. Eventually, restricting human-induced



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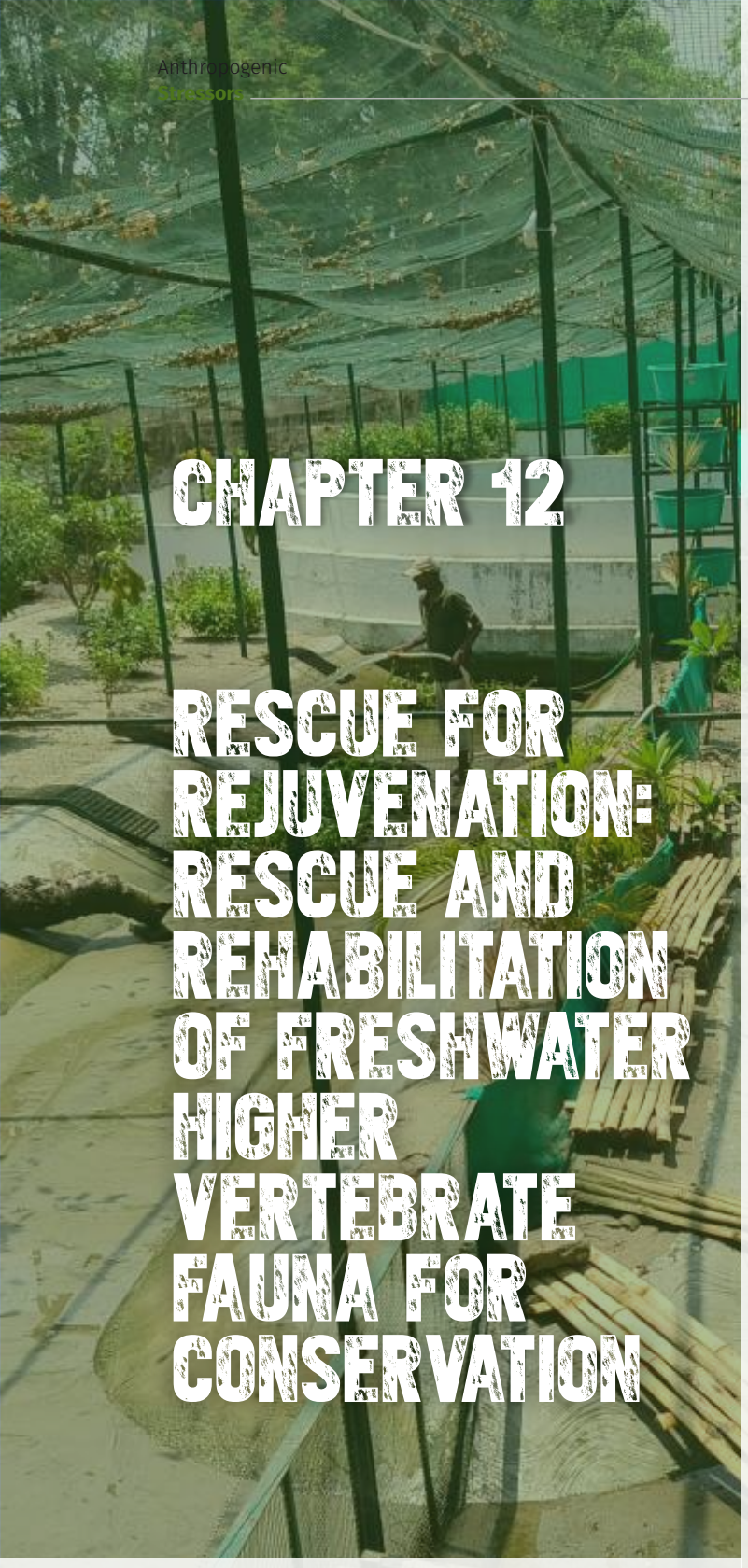
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CHAPTER 12

RESCUE FOR REJUVENATION: RESCUE AND REHABILITATION OF FRESHWATER HIGHER VERTEBRATE FAUNA FOR CONSERVATION

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SUMMARY

This chapter outlines a strategic framework for the rescue and rehabilitation of freshwater higher vertebrate fauna in the Ganga River, with a focus on strengthening population recovery and ecosystem resilience. The Ganga River supports a highly diverse assemblage of threatened species, including turtles, crocodilians, otters, and the Gangetic dolphin. However, increasing anthropogenic pressures such as habitat degradation, pollution, illegal wildlife trade, and hydrological alterations have significantly reduced and fragmented populations. Conventional conservation approaches based on protected areas are insufficient, as only about 4% of the river length falls within such networks, necessitating basin-scale conservation strategies. Rescue and rehabilitation are critical conservation tools aimed at restoring injured or displaced individuals and reintroducing them into suitable habitats to support population supplementation and re-establishment. The approach integrates ecological planning, veterinary science, and community participation. Integrating species recovery with ecosystem management and community engagement contributes to long-term biodiversity conservation. This approach aligns with the One Health perspective by linking animal health, ecosystem integrity, and human well-being-reducing disease risks, restoring ecological functions, and promoting sustainable coexistence in the Ganga River. Thus, the objectives were to establish rescue and rehabilitation centers at strategic locations, build a trained network of local communities and officials for rapid response, and enhance institutional capacity for wildlife management.

The methodology involved prioritizing species based on conservation status (IUCN, Wild Life Protection Act, and CITES), identifying suitable sites using ecological and logistical criteria, and developing science-based husbandry and health management protocols. Twelve priority sites across four states (Uttar Pradesh, Bihar, Jharkhand, and West Bengal) were identified, with four facilities established or upgraded to operationalize rescue and rehabilitation efforts. These centres have collectively handled large volumes of rescue cases, particularly for freshwater turtles, achieving substantial release success (over 9,200 individuals released out of more than 10,700 rescued or managed).

A major contribution of the initiative is the standardization of husbandry and veterinary protocols, including quarantine, disease management, nutrition, and pre-release conditioning, adapted from global best practices to local ecological contexts. The integration of scientific monitoring tools, such as digital morphometric techniques, has strengthened evidence-based management. Planned release strategies, aligned with ecological suitability and seasonal considerations, further enhance post-release survival and adaptation.

Capacity building emerged as a central pillar of the rescue and rehabilitation activities. Extensive training and sensitization efforts were conducted for local communities, forest officials, and veterinarians, recognizing their roles as first responders and conservation enablers. Over 1,500 stakeholders received targeted training, and broader awareness programmes reached nearly 1,900 participants, reinforcing participatory conservation.

12.1 INTRODUCTION

The Ganga River, one of the largest rivers in Asia, traverses three major biogeographic zones, the Himalayas, the Gangetic Plains, and the Coasts, in India (Rodgers & Panwar, 1988). The Ganga River supports a unique and diverse assemblage of biodiversity across its three stretches: the upper stretch (Gomukh to Haridwar), the middle stretch (Haridwar to Varanasi), and the lower stretch (Varanasi to Gangasagar). The upper stretch supports species such as the Near Threatened Eurasian otter (*Lutra lutra*) and the Vulnerable smooth-coated otter (*Lutrogale perspicillata*) (Hussain, 2002; Nawab & Hussain, 2012). The middle stretch represents a critical zone for aquatic biodiversity and includes several species of high conservation importance. Among mammals, the Endangered Gangetic dolphin (*Platanista gangetica*) is a flagship species of this zone. Reptilian fauna includes the Critically Endangered gharial (*Gavialis gangeticus*), Vulnerable marsh crocodile (*Crocodylus palustris*), and several freshwater turtles such as the red-crowned roofed turtle (*Batagur kachuga*), three-striped roofed turtle (*Batagur dhongoka*), Indian narrow-headed softshell turtle (*Chitra indica*), Indian softshell turtle (*Nilssonia gangetica*), Indian peacock softshell turtle (*Nilssonia hurum*), crowned river turtle (*Hardella thurjii*), and spotted pond turtle (*Geoclemys hamiltonii*) under various threat categories in the IUCN Red List of Threatened Species. Avifaunal diversity includes key species such as the Vulnerable sarus crane (*Grus antigone*) and the Vulnerable Indian skimmer (*Rynchops albicollis*) (Sundar et al., 2000; Sundar, 2004; Sundar, 2011). The lower stretch, particularly in the Coasts, provides habitat for species such as the Critically Endangered northern river terrapin (*Batagur baska*). All the species mentioned above are placed in Schedule I of the Wild life (Protection) Act of 1972 to ensure that they receive the maximum possible legal protection for their conservation.

With a human population density exceeding 700 individuals per km², the Ganga River is heavily relied upon for livelihood, economic activity, and religious and cultural traditions. The growing population has put this ecological resource under severe pressure, which undermines the sustained availability of riverine goods and services. Unsustainable resource extraction, habitat degradation, pollution, illegal wildlife trade, and climate change (Figure 12.1) have fragmented and diminished populations of several conservation-dependent species.

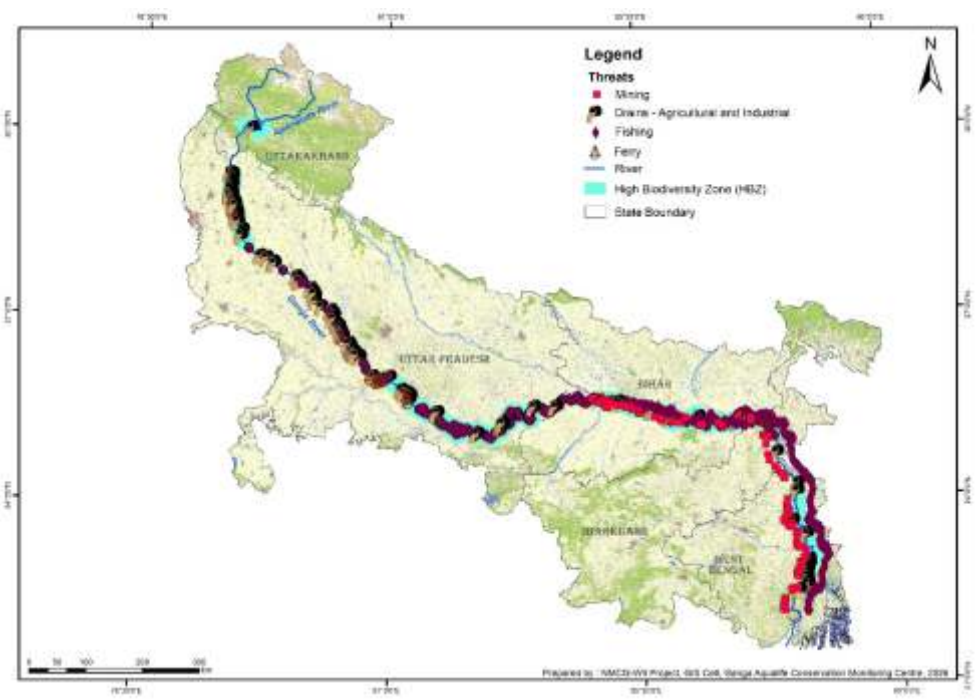


Figure 12.1 Spatial distribution of major anthropogenic threats along the mainstem Ganga

Unlike conventional conservation strategies that rely primarily on Protected Area (PA) networks, conserving the Ganga River's biodiversity requires a more inclusive and landscape-level approach, as much of the River's biodiversity exists outside PA network. About 4% of the Ganga River gets incidental protection through PA network, whereas the home ranges of the conservation-dependent species are beyond the 4% stretch of the Ganga River (Hussain et al., 2020). This necessitates protection of the conservation dependent species and their home range through collaboration among multiple stakeholders, including forest departments (for legal and enforcement support), veterinary professionals (for animal health management), and local communities (for monitoring, reporting, and first-response actions). Incidents of accidental/intentional capture in the fishing net, stranding in the canals, boat collision, and poaching are common across the Ganga River (Badola et al., 2025).

These challenges necessitate targeted conservation interventions aimed at establishing multiple self-sustaining populations within suitable habitats in the river. In this context, rescue, rehabilitation, and release programs have emerged as one of the important conservation strategies. It involves the use of rescued animals restored to fitness for the supplementation of declining populations and reintroduction for the establishment of new populations in suitable habitats. Additionally, such programs contribute to conservation awareness by highlighting the impacts of illegal wildlife trade and other anthropogenic stressors operating on natural habitats, besides promoting community engagement.

In view of the mentioned emergent situations, establishing a network of rescue and rehabilitation centers, and a trained rapid response network, supported by regional veterinary facilities, would be critical for designing targeted mitigation strategies. Thus, the activities were undertaken to fulfill the following objectives

1. To establish aquatic species, rescue and rehabilitation centres at strategic locations for the higher vertebrate fauna of the Ganga River in distress.
2. To develop a trained network of riverside communities sensitive and motivated to report and assist in addressing emergent conditions of the higher vertebrate fauna of the Ganga River.
3. To develop a pool of officials of the forest and animal husbandry departments, and other line and enforcement agencies, sensitive and motivated to address emergent conditions of higher vertebrate fauna of the Ganga River.

12.2 METHODOLOGY

Rescue and rehabilitation of freshwater higher vertebrate fauna is a challenging task involving multiple stakeholders and skillsets. Targeted interventions for identified species in river stretches where protection after release can be ensured need to be prioritized. In continuation of the above, the first step in the process was to identify species that are conservation dependent and for whom interventions could result in positive conservation outcomes. An additional cause of concern is the limited protected area coverage of riverine habitats essential for the conservation of freshwater fauna. Addressing the concern requires identification of stretches with suitable habitats that fall within the protected area network or can offer a desired level of protection. After completion of these two preliminary tasks, the establishment of rehabilitation facilities at identified sites was initiated.



12.2.1 Identification of species of conservation concern for rescue and rehabilitation

Limited resources in terms of space and infrastructure are available for managing the rehabilitation of rescued animals. It was therefore decided to prioritize the species for rescue and rehabilitation based on their conservation needs. The criteria used for prioritization were based on field observations and information collated from available literature, including the IUCN Red List of Threatened Species and listing under various schedules of the Wild life (Protection) Act 1972 and the Convention on International Trade in Endangered Species (CITES).

12.2.2 Identification of potential sites

Potential sites along the Ganga River for the establishment/ upgradation of rescue and rehabilitation facilities along the Ganga River were identified based on the following criteria:

12.2.2.a Spatial Considerations - Distribution Range of the Species of Concern

The sites identified for the establishment of rescue and rehabilitation facilities should be a part of the distribution range of the species. This would facilitate the selection of sites for the release of animals after rehabilitation.

12.2.2.b Proximity to Area with Rescue and Rehabilitation Needs

The identified site should be in proximity to the area from which frequent incidents are reported, to facilitate timely rescue and rehabilitation interventions. For this, the records of incidents such as animal stranding, net entanglement, displacement from natural habitat, and poaching reported for the last twenty years were collected and segregated area-wise. This was undertaken by reviewing media reports available online. Based on this information, heat maps that indicate the landscapes necessitating rescue efforts were generated.

12.2.2.c Proximity to secure release sites

The sites were in proximity to the rehabilitation facilities and were part of the protected area network to provide suitable habitats for the release of rehabilitated animals that afforded the animals maximum protection on release.

12.2.2.d Administrative control and infrastructure

The sites of choice were those that were under the control of State Forest Departments and had some infrastructure available that could be renovated or upgraded to provide the necessary infrastructure for the speedy rehabilitation of rescued animals.

12.2.3 Science-Based Husbandry

Extensive gaps in knowledge on freshwater higher vertebrate fauna exist due to various challenges that exist in studying them. These gaps extend into their captive husbandry and management. Attempts were made to bridge these gaps in knowledge through an extensive review of the literature for similar species globally on their husbandry and health management in captivity. Additionally, efforts were put into documenting the outcomes of husbandry practices in an attempt to standardize these practices.

12.2.4 Capacity enhancement for conservation

Effective rescue and rehabilitation for achieving conservation goals is a knowledge-driven participatory process involving multiple stakeholders. However, the stakeholders often have limited exposure to the technical skills required for successful efforts. Three key stakeholder groups identified as critical to the successful rescue and rehabilitation of freshwater higher vertebrate fauna along the Ganga River were local communities inhabiting riverfront areas, frontline forest officials of state forest departments, and field veterinarians from animal husbandry departments. To strengthen their capacities, targeted training programmes with a defined curriculum were designed and implemented to equip these stakeholders with the necessary skills for effective rescue and rehabilitation.

12.3 OUTCOME

12.3.1 Identification of species of conservation concern for rescue and rehabilitation

The species of conservation concern are listed in Table 12.1, while their distribution in the Ganga River is presented in Figure 12.2. These have been prepared based on field observations and information collated from available literature, including the IUCN Red List of Threatened Species and listing under various schedules of the Wild Life (Protection) Act, 1972 and the Convention on International Trade in Endangered Species (CITES).

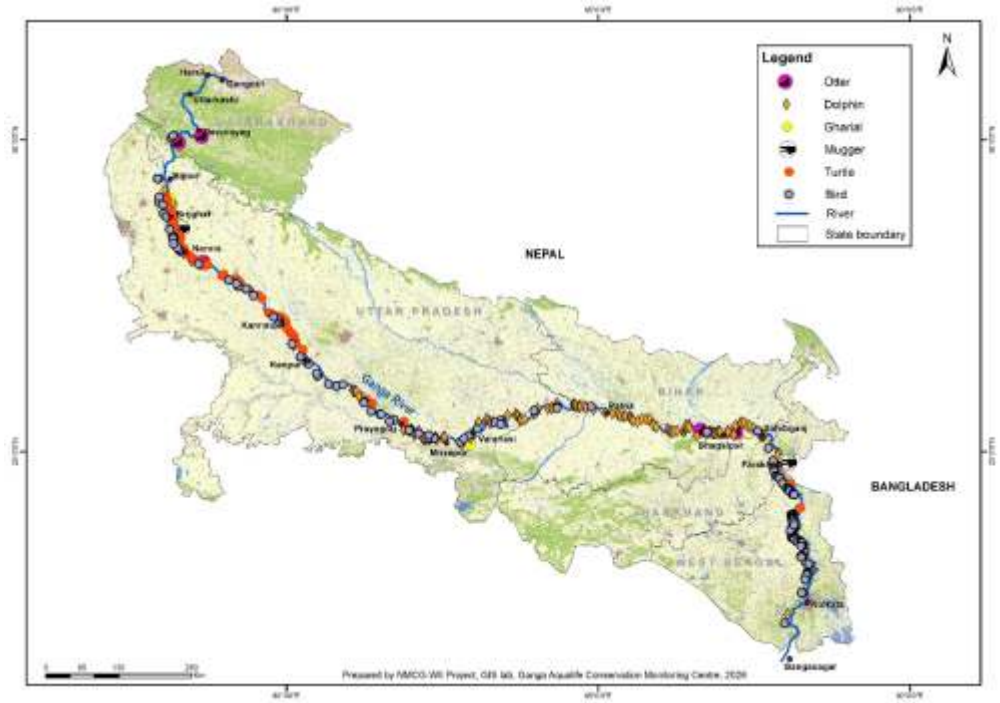


Figure 12.2
Multispecies Occurrence map of different taxa along the mainstem Ganga River

Table 12.1 Species identified for rescue and rehabilitation in the Ganga River

S.No	Species	WPAStatus	IUCNRed List	CITES
1.	Red-crowned roofed turtle (*Batagur kachuga*)	Schedule I	Critically Endangered	Appendix I
2.	Three-striped roofed turtle (*Batagur dhongoka*)	Schedule I	Critically Endangered	Appendix II
3.	Northern river terrapin (*Batagur baska*)	Schedule I	Critically Endangered	Appendix I
4.	Black spotted turtle (*Geoclemys hamiltonii*)	Schedule I	Endangered	Appendix I
5.	Indian tent turtle (*Pangshura tentoria*)	Schedule I	Least Concern	Appendix II
6.	Brown roofed turtle (*Pangshura smithii*)	Schedule II	Near Threatened	Appendix II
7.	Indian roofed turtle (*Pangshura tecta*)	Schedule I	Vulnerable	Appendix I
8.	Crowned river turtle (*Hardella thurjii*)	Schedule I	Endangered	Appendix II
9.	Indian black turtle (*Melanochelys trijuga*)	Schedule II	Least Concern	Appendix II
10.	Tricarinate hill turtle (*Melanochelys tricarinata*)	Schedule I	Endangered	Appendix I
11.	Indian eyed turtle (*Morenia petersi*)	Schedule I	Endangered	Appendix II
12.	Indian narrow-headed softshell turtle (*Chitra indica*)	Schedule I	Endangered	Appendix II
13.	Indian peacock softshell turtle (*Nilssonia hurum*)	Schedule I	Endangered	Appendix I
14.	Indian softshell turtle (*Nilssonia gangetica*)	Schedule I	Endangered	Appendix I
45.	Indian flapshell turtle (*Lissemys punctata*)	Schedule I	Vulnerable	Appendix II
16.	Gharial (*Gavialis gangeticus*)	Schedule I	Critically Endangered	Appendix I
17.	Marsh crocodile (*Crocodylus palustris*)	Schedule I	Vulnerable	Appendix I
18.	Smooth-coated otter (*Lutrogale perspicillata*)	Schedule I	Vulnerable	Appendix I
19.	Oriental small-clawed otter (*Aonyx cinereus*)	Schedule I	Vulnerable	Appendix I
20.	Eurasian otter (*Lutra lutra*)	Schedule I	Near Threatened	Appendix I
21.	Gangetic dolphin (*Platanista gangetica*)	Schedule I	Endangered	Appendix I



Remarks
Habitat loss, low recruitment rate, exploitation for trade, and existence in a single habitat (the Chambal River)
Habitat loss, low recruitment rate, and existence in a single habitat (the Chambal River)
Habitat loss, exploitation of eggs and adults, and a small remaining population size are major threats. It is included in the list of the 25 most threatened turtle species globally.
Reduction in available habitat and extensive illegal trade makes it one of the most threatened turtle species.
Illegal trade and reduced habitat are major threats that undermine populations of the species.
Impacted by illegal trade and habitat alteration.
Impacted by illegal trade for use as pets and in traditional medicine, and habitat loss.
Illegal consumptive trade and pollution from agricultural runoffs are major threats that the species faces.
Consumptive use, illegal trade, and net entanglement are the major threats facing the species.
Habitat loss, local consumption, the pet trade, and the use of body parts for making handicrafts threaten the species.
Consumptive collection, illegal trade, and habitat destruction are major causes that undermine populations of this species.
Illegal consumptive trade, habitat loss, and pollution are believed to be responsible for the decline of the species.
Extensive consumptive collection, illegal trade, net entanglement, pollution, and habitat loss threaten the survival of the species.
Consumptive collection, habitat destruction and persecution by Fishermen are a threat that the species faces.
Consumptive exploitation and trade, habitat loss and pollution have impacted populations of the species.
Habitat fragmentation caused by water diversion structures, loss of nesting and basking areas, water extraction, net entanglement, sand mining, and invasive exotic species in their habitats undermines gharial populations.
Depredation of eggs, fish net entanglement and poaching undermine populations of the species.
Poaching, habitat degradation, fragmentation and conversion of wetland ecosystems to terrestrial ecosystems threaten the survival of the species.
Habitat degradation and loss along with poaching threaten the species' survival.
Habitat loss and degradation, poaching and pollution are major threats to the survival of the species.
Fragmentation of habitat has resulted in fragmented populations, disturbance from increased boat traffic, stranding in water diversion structures, and entanglements in fishing nets are major threats that the species faces.

12.3.2 Potential sites and establishment/ Upgradation of Rescue and Rehabilitation facilities

The sites identified for the establishment of rehabilitation facilities as discussed above were based on the distribution range of the species of concern, proximity to the areas with rescue and rehabilitation needs, and proximity to secure release sites. Figure 12.3 illustrates the stretches of the Ganga River with high biodiversity that fall within existing Protected Areas (PAs). These stretches provide suitable habitats for the species of conservation concern listed in Table 12.1. The Protected Area (PA) network, comprising National Parks, Wildlife Sanctuaries, and Community Reserves, offers secure habitats for these priority species and supports dedicated personnel with the expertise required to manage emergent situations arising from wildlife straying beyond their natural habitats. These PAs also serve as safe release sites for rehabilitated wildlife and facilitate population establishment through assisted colonization. The PA network in the Ganga River is presented in Figure 12.4, while the sites identified for the establishment of rescue and rehabilitation centres are shown in Figure 12.5.

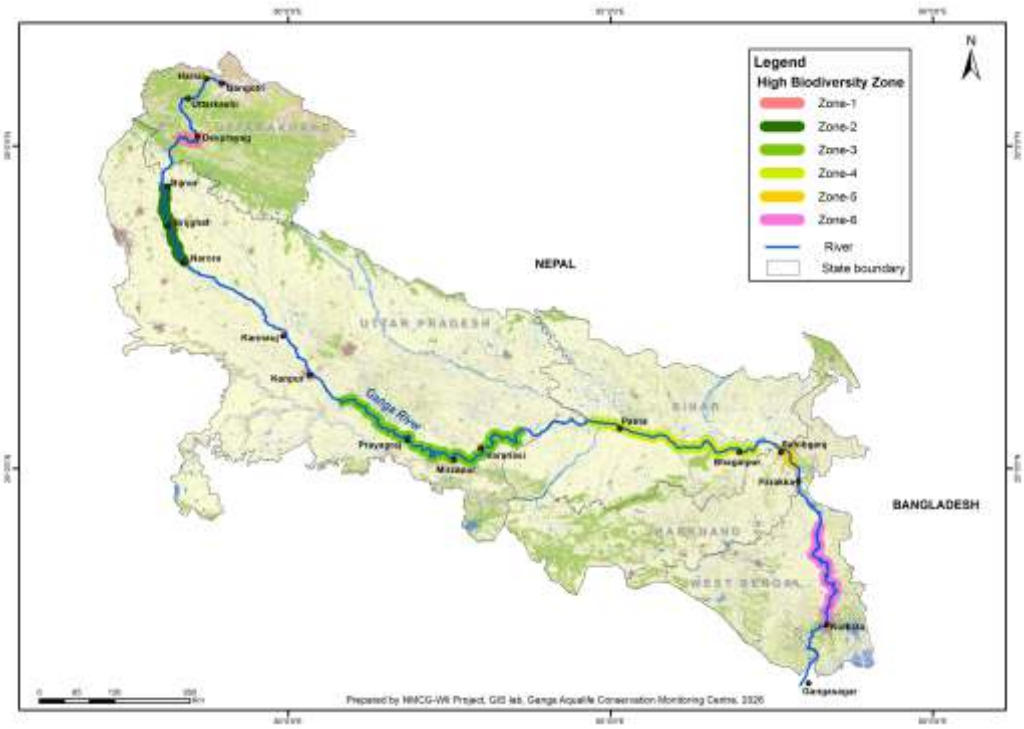


Figure 12.3 High Biodiversity Zones (HBZ) along the mainstem Ganga

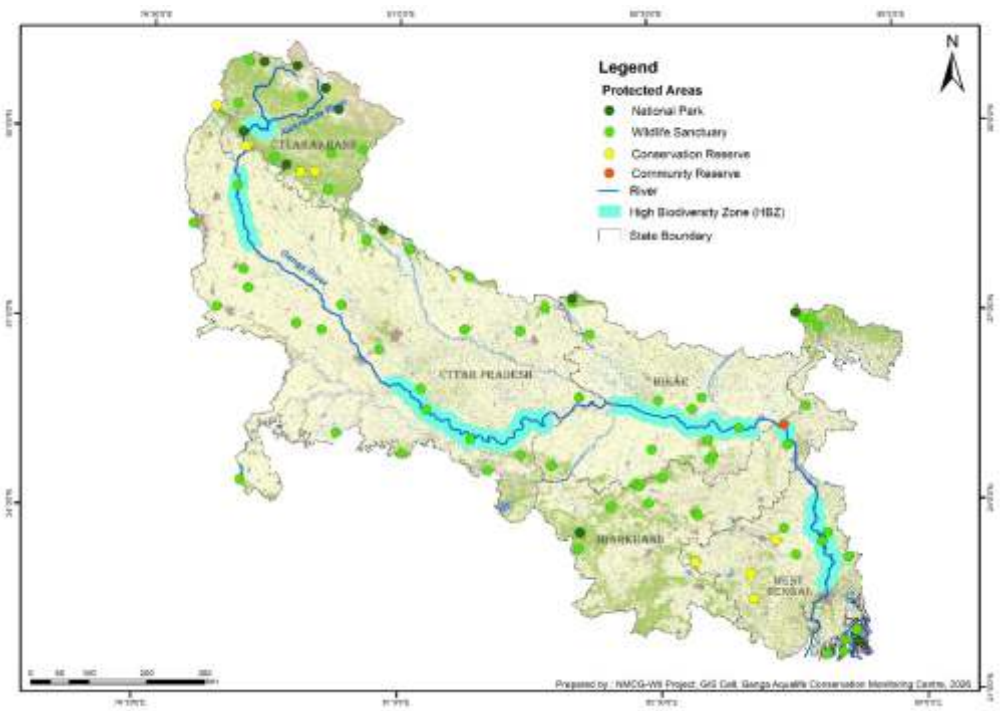


Figure 12.4 Spatial distribution of protected areas along the Ganga River overlaid with the river network and identified High Biodiversity Zones

12.3.3 Identified Sites

Discussions with officials of the state forest departments and field visits led to the identification of 12 key locations across four Ganga River states (Table 12.2.). Uttar Pradesh had five potential sites, followed by West Bengal with four potential sites, Bihar had two potential sites, while Jharkhand had only one potential site (Figure 12.5). These sites will play a pivotal role in strengthening conservation efforts by addressing key threats such as poaching, fishing net entanglement, habitat degradation, and encroachment. The effectiveness of these initiatives will depend on robust conservation planning, active community participation, and strong collaboration among stakeholders.

Table 12.2 Identified sites for establishment and upgradation of rescue and rehabilitation centres in the Ganga River states

State	Potential Sites
Uttar Pradesh	Hastinapur Wildlife Sanctuary
	Turtle Breeding Centre (Narora)
	Kanpur Zoo (Kanpur)
	Turtle Sanctuary (Prayagraj)
	Turtle Breeding Centre (Sarnath Varanasi)
Bihar	Sanjay Gandhi Biological Park (Patna)
	Vikramshila Dolphin Sanctuary (Bhagalpur)
Jharkhand	Sahibganj
West Bengal	Adina Deer Park (Malda)
	Barrackpore (North 24 Parganas)
	Garchumuk Deer Park (Srirampur)
	Alipore Zoological Garden (Kolkata)



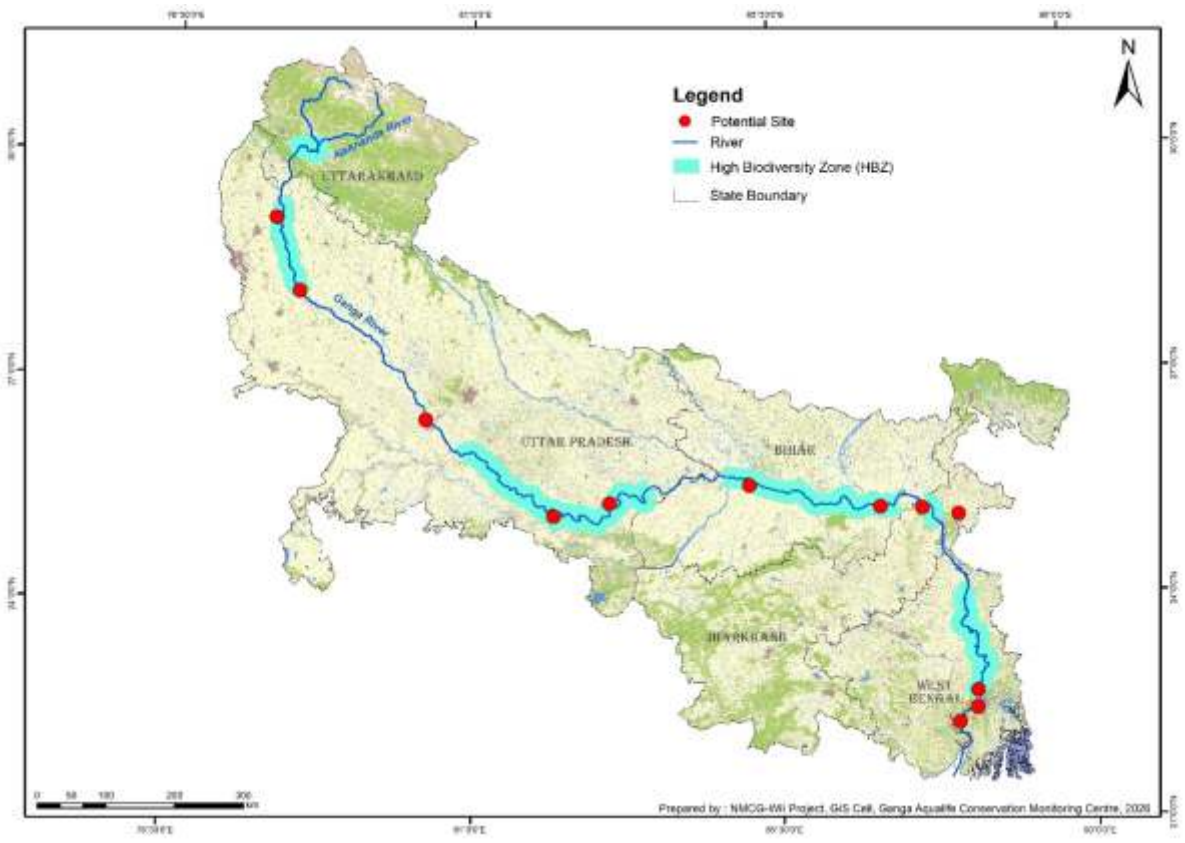


Figure 12.5 Identification of potential for establishment of rescue and rehabilitation facilities for higher vertebrate fauna along the Ganga River mainstem

12.3.4 Establishment of Rescue and Rehabilitation Facilities

Four facilities were established for strengthening of rescue and rehabilitation capacities along the Ganga River. These include the head-starting centre for turtles established by the Nuclear Power Corporation of India Limited (NPCIL) at Narora, the Turtle Breeding Facility at Sarnath, Varanasi operated by the Uttar Pradesh Forest Department (Figure 12.6). The facilities in Uttar Pradesh at Narora and at Sarnath in Varanasi are being managed for the rescue and rehabilitation of freshwater higher vertebrate fauna in the Ganga River. Two additional facilities; one at Bhagalpur, Bihar and the second at Barrackpore, West Bengal in partnership with respective forest departments were also developed. The former included technical inputs from the project team and is currently being managed by the Bihar Forest Department. While the latter was developed under the project.



Figure 12.6 Rescue and rehabilitation centres established along the Ganga River

Detailed assessments of the Sarnath and Narora centres were conducted, and based on these evaluations, retrofitting and refurbishment of the facilities were carried out, keeping in mind the requirements of the species to be housed while ensuring cost-effectiveness. This included the repair and modification of enclosures, installation of water purification systems, and development of enriched environments that cater to species-specific needs in captivity while minimizing human imprinting. Additionally, the project contributed significantly to the standardization of husbandry practices for freshwater turtles in rescue facilities. These practices include protocols for nutrition, housing, and environmental enrichment. As a result of these efforts, both centres are now fully functional and regularly receive rescued animals (Figure 12.7). These animals are managed intensively to restore their fitness, after which they are released back into nearby natural habitats or to the locations from where they were originally rescued. The current stock and detailed records of animals rescued, rehabilitated, and successfully released from the Sarnath and Narora facilities are presented in Tables 12.3, 12.4 and Figure 12.8.

Table 12.3 Current Stock of Freshwater Turtles at Rescue and Rehabilitation Centres under WII-NMCG

Centre	Date of Establishment	Present Stock					Total
		Batagur dhongoka	*Batagur kachuga*	*Nilssonia gangetica*	*Lissemys punctata*	*Geoclemys hamiltonii*	
Turtle Rehabilitation Centre, Narora, Uttar Pradesh	27-Oct-16	18	0	0	0	0	18
Turtle Rescue and Rehabilitation Centre, Sarnath, Uttar Pradesh	27-Oct-16	1074	62	61	343	0	1540
				Total			**1558**



Table 12.4 Details of animals rescued, rehabilitated, and successfully released from the Sarnath and Narora facilities

Common name	Scientific name	Sarnath		
		Phase I		
		Headstart	Rescued	Released
Red-crowned roofed turtle	*Batagur kachuga*	0	0	89
Three-striped roofed turtle	*Batagur dhongoka*	0	315	690
Indian narrow-headed softshell turtle	*Chitra indica*	0	0	0
Indian flapshell turtle	*Lissemys punctata*	0	1772	1860
Indian/Ganges softshell turtle	*Nilssonia gangetica*	0	6	4
Indian peacock softshell turtle	*Nilssonia hurum*	0	0	0
Black pond turtle	*Geoclemys hamiltonii*	0	0	14
Indian black turtle	*Melanochelys trijuga*	0	0	0
Indian roofed turtle	*Pangshura tecta*	0	0	0
Indian tent turtle	*Pangshura tentoria*	0	16	16
Brown roofed turtle	*Pangshura smithii*	0	0	0
Brahminy river turtle	*Hardella thurjii*	0	0	0
Gharial	*Gavialis gangeticus*	0	0	0
Mugger	*Crocodylus palustris*	0	0	0
Mixed turtle species	....	1802	1959 (from Dec 2016)	1959 (from Dec 2016)
	Total	**1802**	**4068**	**5870**

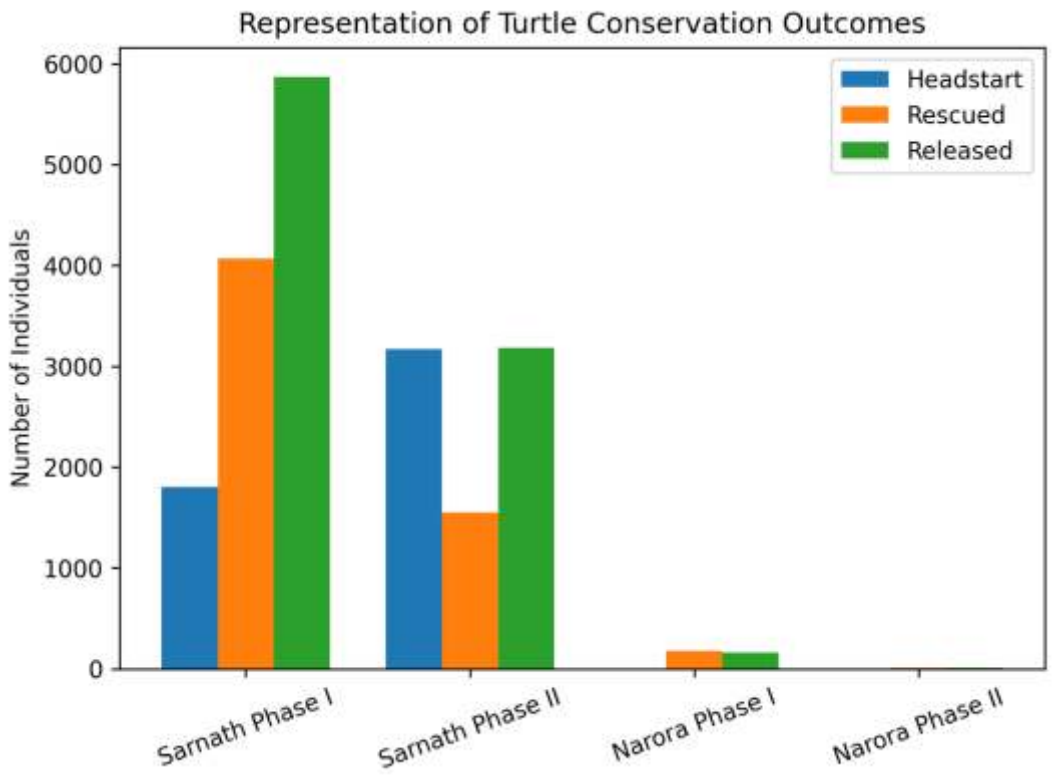


Figure 12.7 Phase-wise Conservation Outcomes of Turtle Rescue and Head starting Programme

Sarnath			Narora					
	Phase II			Phase I			Phase II	
Headstart	Rescued	Released	Headstart	Rescued	Released	Headstart	Rescued	Released
179	35	152	0	0	0	0	0	0
2882	5	1813	0	23	5	0	0	0
0	0	0	0	1	1	0	0	0
0	1425	1082	0	12	12	0	4	4
109	77	125	0	9	9	0	0	0
0	0	0	0	3	3	0	0	0
0	7	6	0	21	21	0	0	0
0	0	0	0	4	4	0	0	0
0	1	1	0	89	89	0	0	0
0	0	0	0	7	7	0	0	0
0	2	2	0	4	4	0	0	0
0	1	1	0	3	3	0	0	0
0	0	0	0	1	1	0	1	1
0	0	0	0	2	2	0	3	3
0	0	0	0	0	0	0	0	0
3170	**1553**	**3182**	**0**	**179**	**161**	**0**	**8**	**8**

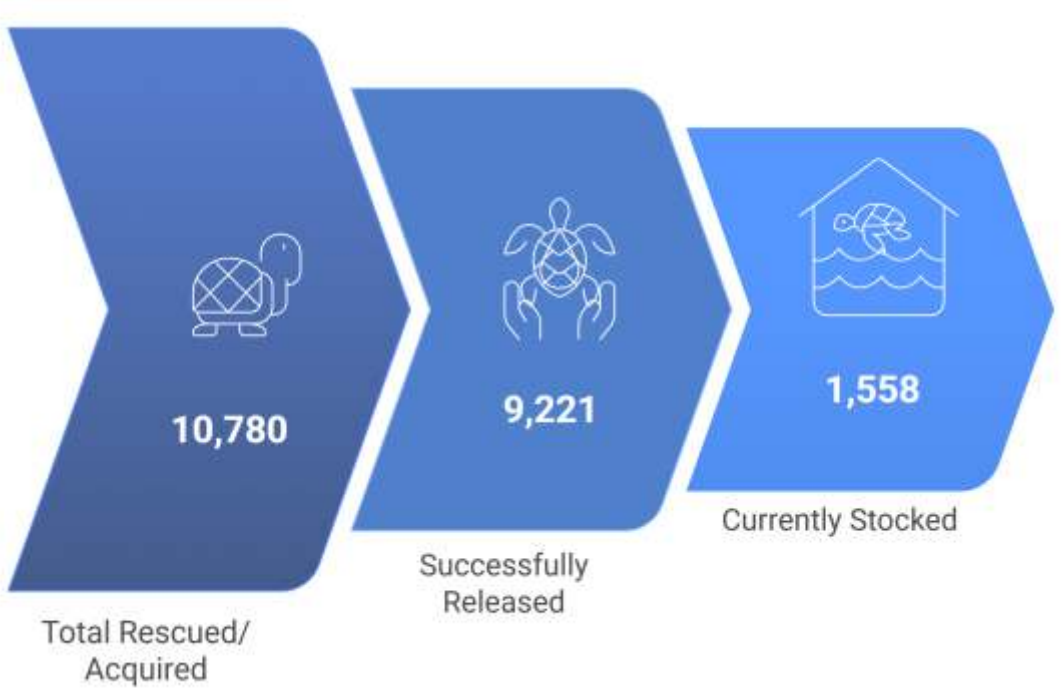


Figure 12.8 Details of total individuals rescued, successfully released and in stock at the Sarnath and Narora facilities

12.3.5 Science-Based Husbandry

Rescue and rehabilitation are a knowledge driven activity that draws information from the natural history of the species being managed, stressors that are undermining populations and diseases that impact it. The information forms the basis for developing effective husbandry practices, managing the health of rescued animals during rehabilitation and developing effective release strategies. Significant knowledge gaps for managing emergent conditions of freshwater higher vertebrate fauna of Ganga River were present. Attempts to bridge these gaps through standardisation and scientific protocol development were made. Best practices have been standardised for quarantine management, health screening, disease management, hatchling care, and pre-release conditioning. These practices, based on global best practices, were adapted to local conditions to provide a replicable model for rescue and rehabilitation initiatives across India. This was undertaken by meticulous monitoring of growth patterns of animals under our care through morphometric measurements (Figure 12.9). A seminal contribution of the project in this direction has been the development of a digital morphometric technique (Panda et al 2025).


PLOS ONE

Digital image processing: A new tool for morphological measurements of freshwater turtles under rehabilitation

Abstract

Introduction

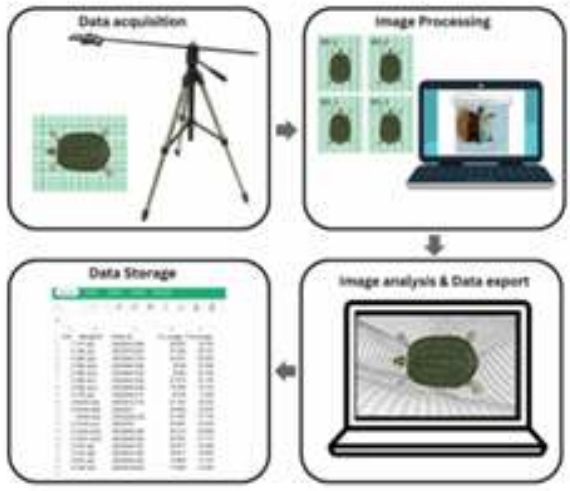


Figure 12.9 Digital image processing approach for morphometric measurements of freshwater turtles under rehabilitation

The rehabilitation facilities faced space constraints that limited their ability to fully meet the ecological and behavioural needs of the species they house. To address this, enriched environments based on the natural history of the species being managed were provided as an attempt to replicate the natural habitats of the species. The action also facilitates the training of animals to adapt to their natural environments on release. Further scientifically designed husbandry protocols have been implemented to ensure appropriate nutrition and care for all individuals, while accounting for species-specific and age-specific requirements. For herbivorous species, aquatic macrophytes are provided, while carnivorous species are offered fish fingerlings and crustaceans (Figure 12.10). These feeding strategies serve as enrichment measures that help retain natural foraging behaviors and feeding patterns. As chelonians are ectothermic (cold-blooded) animals, the provision of a mosaic of sunlit and shaded areas is essential for effective thermoregulation. This is achieved throut and the inclusion of aquatic and terrestrial macrophytes, which create thermal gradients within both land and water components of the enclosure, thereby facilitating natural thermoregulatory behavior.








Figure 12.10 Science-based captive care husbandry practices

12.3.6 Effective Health Management

Veterinary interventions and disease surveillance are a pillar of rehabilitation strategy. Animals entering rescue and rehabilitation facilities are often injured, sick, or both, and therefore require intensive veterinary care. All newly admitted individuals are first maintained in quarantine facilities, where detailed assessments of their health and fitness are conducted prior to their introduction to existing populations of conspecifics (Figure 12.11). This ensures disease prevention and safeguards the health of resident animals. Necessary veterinary interventions, including triage and treatment, are provided to individual animals from the time of their entry until their release, ensuring their overall well-being. The quarantine period also allows for close monitoring and helps alleviate stress experienced by the animals during rescue and transport. Preventive healthcare measures include restricting visitor access to minimize the risk of pathogen transmission between humans and animals, as well as maintaining optimal water quality to reduce the incidence of disease. This is particularly important as turtles are aquatic animals and are often maintained at higher densities in captivity than in natural conditions.

Regular health assessments, based on visual assessments and pathological investigations, were carried out. Necropsy examinations of animals dying in the facility or arriving dead at the facility were carried out to understand the diseases present in the rescued individuals to develop appropriate interventions. Standardised body condition scoring methods and species-specific feeding schedules were developed to ensure optimal nutrition and fitness. The establishment of on-site veterinary laboratories in facilities such as Sarnath facilitated rapid diagnostics and treatment, minimising morbidity and mortality during rehabilitation.





Figure 12.11 Veterinary interventions for effective health management

12.3.7 Planned Release for Scientific Conservation

Efforts are made to ensure that animals, once deemed fit, are repatriated to their natural habitats at the earliest possible time. Fitness evaluations were conducted based on comprehensive health assessments and the animal's ability to adapt to the conditions of the intended release site (Figure 12.12). When confiscated animals lacked verifiable information about their origin, they were released into appropriate habitats within the species' natural geographic range. The success of release programs is also influenced by environmental conditions. Therefore, releases are carefully planned to avoid extreme weather, ensuring higher survival and adaptation rates post-release.



Figure 12.12 Release of rehabilitated freshwater turtles into a suitable natural habitat

12.3.8 Capacity enhancement for conservation

Effective rescue and rehabilitation for achieving conservation goals is a participatory process involving multiple stakeholders. However, it is inherently a knowledge-driven activity, and many stakeholders often have limited exposure to the technical skills required. Three key stakeholder groups were identified as critical to the successful rescue and rehabilitation of aquatic macro-fauna, viz., local communities inhabiting riverfront areas, frontline forest officials of state forest departments, and field veterinarians from animal husbandry departments (Table 12.5). To strengthen their capacities, targeted training programmes were designed and implemented to equip these stakeholders with the necessary skills for effective rescue and rehabilitation (Figure 12.12)



Table 12.5 State-wise Participation of Key Stakeholders in Capacity Building and Training Programmes under the WII–NMCG

States	Stakeholders				
	Forest Official	Veterinarian	Local Community	Academicians/ researchers	Miscellaneous
Uttarakhand	287	36	15	6	-
Uttar Pradesh	455	31	352	1498	269
Bihar	197	11	35	80	3
Jharkhand	31	-	33	-	-
West Bengal	55	1	36	-	-
Total	**1025**	**79**	**471**	**1584**	**272**

Local communities serve as first responders during rescue events and play a crucial role in safeguarding species at release sites. Essential skills for their effective participation include species identification and the scientific and humane handling of rescued animals. Accordingly, capacity-building programmes were conducted for riverine communities with a curriculum specifically tailored to their role in conservation. A total of 471 participants were trained across five Ganga River states: Uttarakhand (15), Uttar Pradesh (352), Bihar (35), Jharkhand (33), and West Bengal (36). Frontline forest officials and field veterinarians are central to the rescue and rehabilitation process. Specialized training curricula were developed to address the distinct roles and requirements of these groups. Capacity-building programmes for forest officials focused on field identification, handling techniques, and legal aspects related to wildlife conservation. A total of 1,025 forest officials were trained from Uttarakhand (287), Uttar Pradesh (455), Bihar (197), Jharkhand (31), and West Bengal (55). In addition, 79 veterinary professionals were trained from Uttarakhand (36), Uttar Pradesh (31), Bihar (11), and West Bengal (1) (Table 12.5). These programmes emphasized species identification and effective veterinary management of aquatic macro-fauna during rescue and rehabilitation (Figure 12.13).

Furthermore, sensitization programmes were conducted for a broader group of stakeholders, including teachers, professors, school, college and university students, researchers, and other concerned individuals. These programmes aimed to enhance awareness and promote conservation-oriented attitudes toward aquatic biodiversity. A total of 3,431 participants were sensitized through these outreach initiatives (Table 12.5).



Figure 12.13 Capacity enhancement of different stakeholders for conservation

CONCLUSION

The Ganga River supports a rich diversity of aquatic species, many of which are endangered and face multiple threats, including habitat degradation, poaching, pollution, and climate change. Rapid infrastructure development and increasing anthropogenic pressures are further exacerbating the vulnerability of these ecosystems. Interventions such as translocation, population supplementation, and reintroduction of rescued individuals into their natural habitats are recognized as effective measures to counter population declines (Turtle Conservation Fund, 2002). The success of rescue and rehabilitation programmes depends on several key factors, including early intervention, well-planned infrastructure, availability of skilled personnel, and strong administrative and legal support. Additionally, public empathy, awareness, and education campaigns play a vital role in ensuring long-term conservation success (Dudgeon, 2019).

The ongoing Namami Gange Programme under the Government of India focuses on pollution abatement, conservation, and rejuvenation of the Ganga River. The programme adopts keystone, umbrella, and flagship species approaches for targeted conservation (Sinha, 2015). Within this framework, rescue and rehabilitation efforts have emerged as a critical conservation strategy to address threats such as entanglement, poaching, injury and mortality. Rescue and rehabilitation of aquatic species also aligns well with the One Health framework, which recognizes the interconnected health of ecosystems, animals, and humans. Rescue operations, followed by scientific rehabilitation protocols in controlled facilities, allow for treatment of trauma and injury, implementation of quarantine to prevent pathogen spread, and eventual reintroduction of healthy individuals into suitable habitats. From a One Health point of view, these efforts reduce the risk of zoonotic disease transmission and improve ecosystem functioning by restoring species. Rescue and rehabilitation of aquatic species, by integrating veterinary science, environmental monitoring, and community awareness, ensures that conservation is not done in isolation but as part of a broader, systemic approach to sustaining riverine health and public health outcomes.





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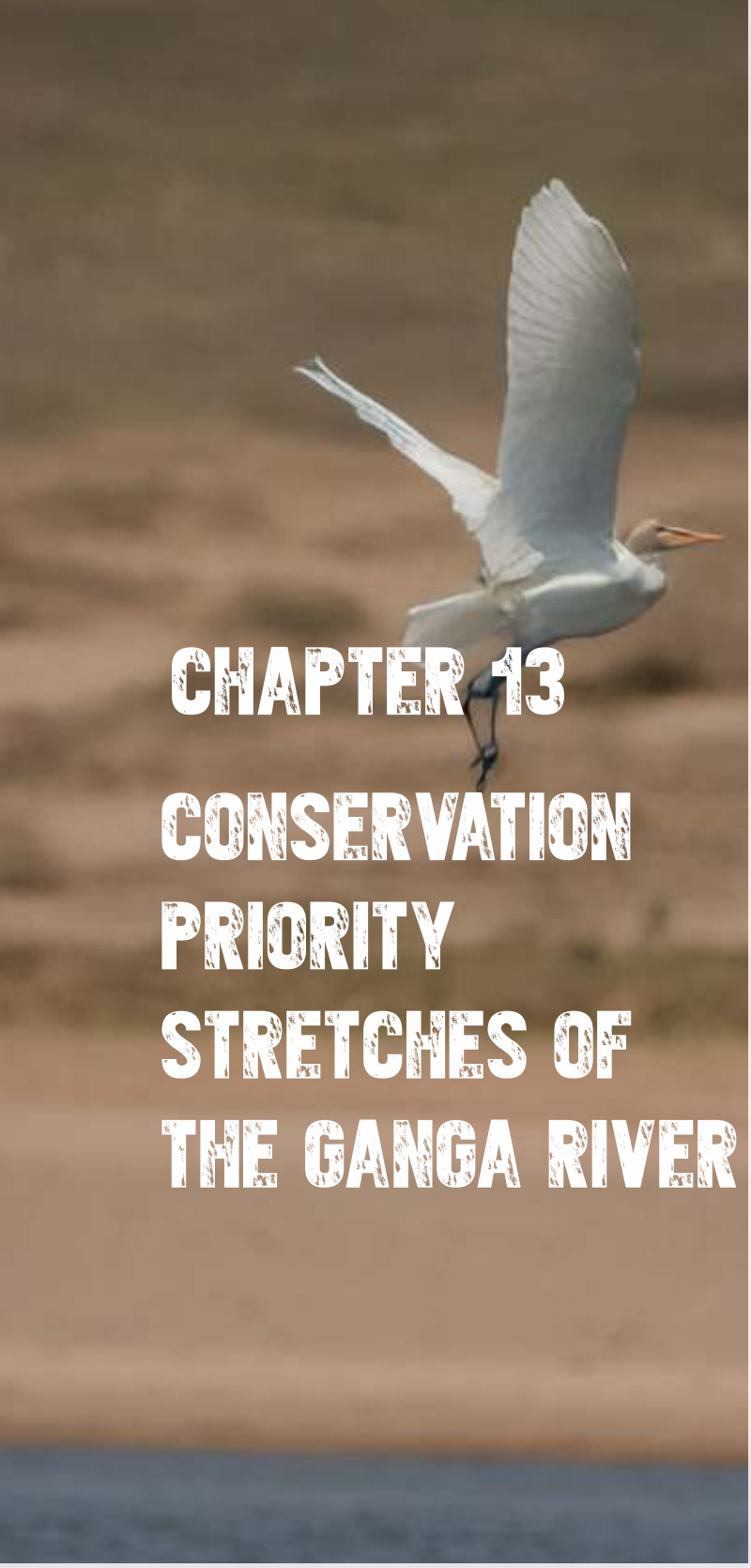
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CHAPTER 13

CONSERVATION PRIORITY STRETCHES OF THE GANGA RIVER

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SUMMARY

Freshwater ecosystems are increasingly threatened by anthropogenic pressures, including habitat fragmentation, pollution, and climate change, resulting in substantial biodiversity loss. This study presents a systematic, multispecies framework for the spatial delineation of Conservation Priority Stretches (CPS) along the 2,145 km mainstem of the Ganga River, spanning Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal. A species distribution modelling approach based on Maximum Entropy (MaxEnt) was applied using 2,654 occurrence records of six indicator taxa-the Gangetic dolphin (*Platanista gangetica*), gharial (*Gavialis gangeticus*), black-bellied tern (*Sterna acuticauda*), Indian skimmer (*Rynchops albicollis*), river lapwing (*Vanellus duvaucelii*), and river tern (*Sterna aurantia*)-in conjunction with sixteen ecologically relevant bioclimatic, hydro-morphological, and anthropogenic variables. Field data were collected through boat-based visual encounter surveys (2020-2021) and analysed using 5 km Biodiversity Evaluation Units (BEUs).

Predicted habitat suitability was classified into three conservation priority categories (CPS I: ≥0.70; CPS II: 0.61-0.70; CPS III: 0.51-0.60) and Restoration Zones (RZ: <0.50). No river segments met the threshold for CPS I, indicating widespread habitat degradation and fragmentation along the river corridor. Approximately 635 km (29.6%) and 1,105 km (51.5%) of the river were categorized as CPS II and CPS III, respectively, while 405 km (18.9%) were identified as restoration zones. Spatial patterns show that CPS II stretches are concentrated in the middle reaches, particularly in Uttar Pradesh, whereas CPS III stretches are more broadly distributed. In contrast, downstream sections, especially in West Bengal, are dominated by restoration zones, reflecting cumulative anthropogenic pressures.

These findings underscore the role of large river systems as dynamic ecological corridors, where habitat suitability varies along hydrological, geomorphological, and anthropogenic gradients. In the Ganga River, these interacting drivers have resulted in the predominance of moderately and low suitable habitats, with highly suitable stretches largely absent or fragmented. Relatively higher suitability in the middle reaches contrasts with substantial restoration needs in both upstream regulated and downstream heavily modified sections, consistent with patterns observed in large river systems globally.

A discrepancy between identified CPS and the existing protected area network highlights critical gaps in current conservation frameworks. Notably, even moderately suitable stretches (CPS II and CPS III) may function as important ecological corridors, supporting species movement and metapopulation connectivity for riverine taxa.

Overall, this study provides a robust, spatially explicit

basis for prioritizing conservation and restoration interventions along the Ganga River. It emphasizes the need for integrated river basin management, targeted habitat restoration, and strengthened policy measures to enhance ecological integrity and biodiversity conservation, while aligning with global frameworks such as the Kunming-Montreal Global Biodiversity Framework and the Freshwater Challenge.

13.1 INTRODUCTION

Freshwater ecosystems are among the most imperiled ecosystems worldwide, experiencing intense pressures from interconnected drivers which range from pollution, overexploitation of resources, and climate change (Reid et al., 2019; Schneider et al., 2013). Altered natural flow regimes, species range reduction, change in water quality, loss of aquatic habitats are some of the impacts of the drivers (Dudgeon, 2006; Grimm et al., 2008; Echols et al., 2009). Climate change further compounds these impacts by modifying water temperature, flow patterns, and precipitation, thereby affecting species distributions and ecosystem resilience. The combined influence of these stressors has resulted in widespread declines in freshwater biodiversity. As a consequence, many freshwater species are now threatened with extinction. In context of the Ganga River, the Gangetic dolphin *(Platanista gangetica)*, gharial *(Gavialis gangeticus)*, smooth-coated otter *(Lutrogale perspicillata)*, and riparian birds including black-bellied tern *(Sterna acuticauda)* and Indian skimmer *(Rynchops albicollis)* are particularly vulnerable to these environmental changes. Their decline signals a broader crisis threatening freshwater biodiversity and ecosystem integrity (Dudgeon, 2006; Strayer & Dudgeon, 2010; Reid et al., 2019; IUCN, 2023).

In response to the global decline in freshwater ecosystems, six priority actions were identified to bend the curve of freshwater biodiversity decline (Tickner et al., 2020). Among those priorities, protecting and restorating critical habitats, managing exploitation of riverine species and aggregates, preventing and controling invasive species, and safeguarding and restoring freshwater connectivity translate into identifying Conservation Priority Stretches (CPS) -ecologically significant regions requiring urgent action (Margules et al., 2002; Bonn & Gaston, 2005). Conservation prioritization helps identify the crucial areas (spawning grounds, refugia, headwaters, connectivity), allocate limited resources where conservation could yield maximum ecological return and trade-offs could be managed, to align with human well-being (Howard et al., 2018; Reid et al., 2019).

A systematic conservation prioritization framework integrates spatial modeling tools, species distribution data, and connectivity assessments (Moilanen et al., 2009; Nel et al., 2009). Approaches such as MaxEnt (Maximum Entropy Modeling), AHP (Analytical Hierarchy Process), and WOA (Weighted Overlay Analysis) provide a robust basis for identifying high-priority conservation areas and guiding sustainable river basin management (Balmford, 2002; Albuquerque & Beier, 2015; Howard et al., 2018). Species distribution modeling (SDM) links occurrence records with environmental variables to predict suitable habitats (Ma & Sun, 2018). MaxEnt, particularly suited to presence-only data, is especially useful in freshwater systems where absence data are limited (Elith et al., 2006; Beery et al., 2021). Since identifying conservation priority stretches is a complex task (Knight et al., 2011; Tambosi et al., 2014; Perring et al., 2015), species distribution and habitat conditions are valuable for determining high-biodiversity stretches (Darwall & Vié, 2005).

In context of the Ganga River, which provides habitat to some of the globally endangered species, conservation prioritization enables the identification of habitats for indicator species such as the Gangetic dolphin, gharial, and freshwater breeding birds including the black-bellied tern, Indian skimmer, river lapwing *(Vanellus duvaucelii)*, and river tern *(Sterna aurantia)*. This chapter focuses on the prioritization of stretches along the Ganga River. Establishing CPS can enhance gene flow, seasonal migration, and stabilize populations of threatened species (Kumar, 2021). Using a multispecies framework and advanced conservation planning tools, we identified CPS to strengthen biodiversity conservation and ecosystem services. Delineating and managing these priority areas aligns with national and global conservation targets, which would help curb biodiversity loss and enhance ecological sustainability (Strassburg et al., 2020). By mapping the key habitats of multiple indicator species, this study provides a robust scientific basis for identifying conservation priority areas and implementing targeted management interventions necessary to maintain the ecological integrity of the mainstem Ganga River.



13.1.1 Indicator species

Indicator species are widely applied in environmental science to detect ecological change and evaluate conservation effectiveness (Siddig et al., 2016). In the face of escalating pressures-including climate change, habitat degradation, pollution, emerging diseases, and invasive species-biological monitoring serves as a cost-effective and scientifically robust basis for environmental decision-making (Landres et al., 1988; Spellerberg, 2005). The concept is grounded in the premise that certain taxa reliably reflect environmental conditions; accordingly, indicator species are defined as organisms whose presence, abundance, or reproductive performance can serve as proxies for environmental attributes that are otherwise difficult or costly to measure (Landres et al., 1988; McGeoch, 1998; Carignan & Villard, 2002). The rigorous selection of indicator species requires clearly articulated monitoring objectives and a comprehensive understanding of ecosystem structure and function (Carignan & Villard, 2002). Effective indicators are typically characterized by well-understood ecological traits and consistent responses to environmental variability (Hilty & Merenlender, 2000). Single-species approaches may not fully capture the complexity of riverine ecosystems, whereas the use of multiple indicator species allows for a broader representation of habitat conditions (Lindenmayer et al., 2000). Collectively, a robust indicator-species framework must generate reliable evidence of whether ecological integrity is improving or deteriorating (Carignan & Villard, 2002). Integrating multiple indicators across levels of biological organization further strengthens interpretive capacity by enabling cross-scale assessments of ecological responses to environmental change.

This framework is particularly relevant in the Indian subcontinent, where several riverine taxa function as indicators of freshwater ecosystem integrity (Siddig et al., 2016; WII-GACMC, 2017). The Gangetic dolphin, an endemic apex predator of the Ganga-Brahmaputra river system, reflects river health through its sensitivity to pollution, altered flow regimes, and habitat fragmentation (Choudhary et al., 2006; Braulik et al., 2014; Sinha & Kannan, 2014). Similarly, the critically endangered gharial, owing to its specialized habitat requirements, indicates relatively undisturbed riverine conditions (Behera et al., 2013; IUCN, 2023). River-dependent birds-including the Indian skimmer, black-bellied tern, river tern, and river lapwing-also respond sensitively to changes in habitat quality, hydrological regimes, and anthropogenic pressures. Monitoring these taxa provides empirical insights into the status of riverine biodiversity and the functional integrity of freshwater ecosystems. In this study, the MaxEnt modelling framework integrates occurrence data across multiple taxa with environmental gradients to generate spatial patterns of habitat suitability along the Ganga River. These patterns are subsequently used to delineate CPS, enabling the identification of river segments with relatively higher conservation value. By emphasizing spatial patterns of habitat suitability across taxa, the approach provides a spatially explicit, river-scale perspective for prioritizing conservation efforts along the mainstem of the Ganga River.



13.2 METHODOLOGY

13.2.1 Data collection

We conducted a boat-based visual encounter survey to assess the ecological conditions of the Ganga River by examining the presence of key indicator species between 2020 and 2021. The surveyed river stretch was divided into 5 km segments referred to as the Biodiversity Evaluation Unit (BEUs) using ArcGIS 10.2 (ESRI, Redlands, USA). Bioclimatic, hydro-morphological, and anthropogenic variables were compiled across the current and historical ranges of these species to predict potential habitat suitability and identify priority areas within the basin. Information on hydro-morphological and anthropogenic variables was collected at 1 km intervals and averaged for each BEU. Climatic variables were downloaded from WorldClim version 2 at a spatial resolution of 2.5 arc minutes (~4.5 km^2) (Fick & Hijmans, 2017) and resampled at 5 km2 to have a uniform spatial resolution. A total of 29 environmental variables initially taken were based on published literature for species distribution modelling using MaxEnt (e.g. Kelkar et al., 2010; Choudhary et al., 2006; Paudel et al., 2015).

Surveys were conducted during the post-monsoon season (November-February). Field surveys were carried out during daylight between 8:00 hrs to 12:00 hrs and 15:00 to 17:00 hrs using an inflatable rubber (25 hp)/country boat following thalweg (the deepest part of the river channel) (Oliveira et al., 2017). The boat speed was kept constant at

6-8 km h^{-1} to minimize the chances of missing sightings of surfacing dolphins.

Hydro-morphological parameters recorded within each BEU included channel width (m), channel depth (m), water flow (m^3 s^{-1}), river slope (degree), and channel morphology. Field observations were made using binoculars (NIKON 8×42), GPS (GARMIN e-Trex 30), depth sounder (HONDEX PS7), range finder (HAWKE Endurance LRF-1000). Additional variables such as number of meanders (me), fishing intensity (fn), sand mining intensity (mining boats/BEU), and other anthropogenic factors were also recorded.

13.2.2 Data Analysis

We used MaxEnt models to predict the potential distribution and identify priority stretches for conservation of indicator species. MaxEnt is based on the principle of maximum entropy and is extensively used to model species distributions using presence-only occurrence data and environmental variables (Phillips et al., 2006; Clements et al., 2012; Kramer-Schadt et al., 2013). The approach is widely recognized as an effective method, particularly where absence data are lacking (Elith et al., 2006), and for identifying areas of high habitat suitability that can be used to delineate conservation priority stretches.

Species distribution modelling using MaxEnt was conducted for six key indicator species: Gangetic dolphin *(Platanista gangetica)*, gharial *(Gavialis gangeticus)*, black-bellied tern *(Sterna acuticauda)*, Indian skimmer *(Rynchops albicollis)*, river lapwing *(Vanellus duvaucelii)*, river tern *(Sterna aurantia)*. The analysis was conducted along the length of the Ganga River covering a total length of 2145 km. It must be noted that since the distribution of the priority species is not found in the state of Uttarakhand, hence stretch above Haridwar was excluded, while a short segment downstream of Haridwar was retained. The total 2,654 species occurrence records were used in analysis, including black-bellied tern (n = 97), Indian skimmer (n = 41), river lapwing (n = 613), river tern (n =96), gharial (n =1049), and Gangetic dolphin (n =758).

Bioclimatic, hydro-morphological, and anthropogenic variables were checked for multicollinearity, and highly correlated (Pearson correlation ≥0.70) variables with low ecological influences were removed from the modelling (Zuur et al., 2009). Presence records of six indicator species, together with 16 ecologically meaningful and uncorrelated variables (bioclimatic =7, hydro-morphological =5, and anthropogenic=4) were used to predict the suitable habitat of the species in MaxEnt software v3.4.4 (Phillips et al., 2017).

The predicted probability outputs generated by MaxEnt were exported as ASCII raster files, imported into ArcGIS 10.6, and reclassified to generate habitat suitability maps. River stretches with probability values greater than 0.50 were identified as potential distribution areas. This midpoint threshold was applied to distinguish suitable from unsuitable habitats and to convert the continuous probability surface into a binary habitat suitability map for spatial analysis. These stretches were further categorized into three CPS classes: ≥ 0.70 CPS I (High Conservation Priority), 0.61-0.70 CPS II (Moderate Conservation Priority), and 0.51-0.60 CPS III (Low Conservation Priority). River stretches with suitability scores below 0.50 were classified as Restoration Zones (RZ).

13.3. RESULTS

The MaxEnt model classified river stretches into different CPS categories based on habitat suitability scores. No segment of the Ganga River met the threshold for CPS I (≥0.70). The Ganga River was found to be distributed across CPS II (0.61-0.70) and CPS III (0.51-0.60) (Table 13.1; Fig. 13.1). Overall, the spatial distribution of CPS varied across the Ganga River. CPS II segments were largely concentrated in the middle reaches, particularly within Uttar Pradesh, whereas CPS III stretches were more broadly distributed across four states and interstate segments. In contrast, restoration zones were primarily located in the lower reaches, with substantial extents observed in West Bengal. These patterns collectively reflect differences in habitat suitability and conservation priority along the river corridor.

State-wise patterns further highlight differences in conservation priority among river stretches. Uttarakhand comprises 10 km of river stretch, which is entirely classified under CPS III. The Uttarakhand-Uttar Pradesh stretch comprised 45 km entirely under CPS III. Uttar Pradesh contained the largest extent of CPS, with 570 km (57%) under CPS II and 425 km (42.5%) under CPS III, whereas only 5 km (0.5%) was identified as a restoration zone. In Bihar, 205 km (78.8%) of the Ganga River was classified as CPS III, 10 km (3.8%) as CPS II and 45 km (17.3%) as restoration zone. In West Bengal, restoration zones dominated (335 km; 64.4%), followed by CPS III (170 km; 32.7%) and CPS II (15 km; 2.9%). CPS III stretches were more widely distributed across the river, whereas CPS II segments were primarily concentrated in Uttar Pradesh and adjacent interstate reaches. Interstate segments also showed distinct patterns. The Bihar-Uttar Pradesh stretch was largely CPS III (200 km; 93%) with a smaller stretch as CPS II (15 km; 7%). About 25 km (62.5%) of the Jharkhand-Bihar stretch was classified as CPS II, and 15 km (37.5%) as CPS III. About 35 km (63.6%) of the Jharkhand-West Bengal stretch was classified as CPS III and the remaining 20 km (36.4%) was classified as the restoration zone (Figure 13.1).



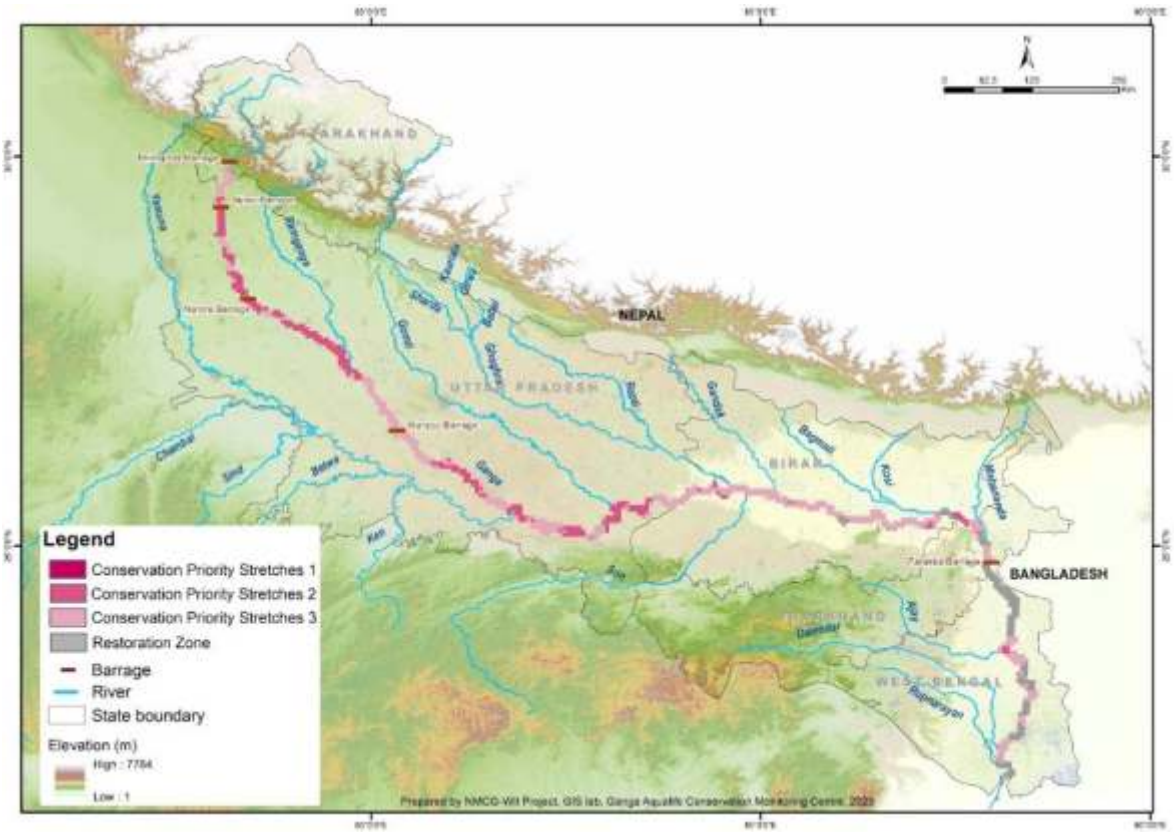


Figure 13.1 Conservation Priority Stretches along the Ganga River

Table 13.1 Length of Conservation Priority Stretches in different states along the Ganga River

State / River Stretch	CPS I (km)	CPS II (km)	CPS III (km)	RZ (km)	Total (km)
Uttarakhand	0	0	10	0	10
Uttarakhand-Uttar Pradesh	0	0	45	0	45
Uttar Pradesh	0	570	425	5	1000
Bihar	0	10	205	45	260
Bihar-Uttar Pradesh	0	15	200	0	215
Jharkhand-Bihar	0	25	15	0	40
Jharkhand-West Bengal	0	0	35	20	55
West Bengal	0	15	170	335	520
Total	**0**	**635**	**1105**	**405**	**2145**



13.3.1. State-wise distribution of conservation priority stretches

To ease the management related decision-making, identified CPS were further segregated at the state level.

1. Uttarakhand

In Uttarakhand, CPS III stretches accounted for 10 km (3.3%) of the river length along the segment between Haridwar and Kishanpur Jhara Ahat (Figure 13.2). This stretch hosts good assemblage of waterbirds.

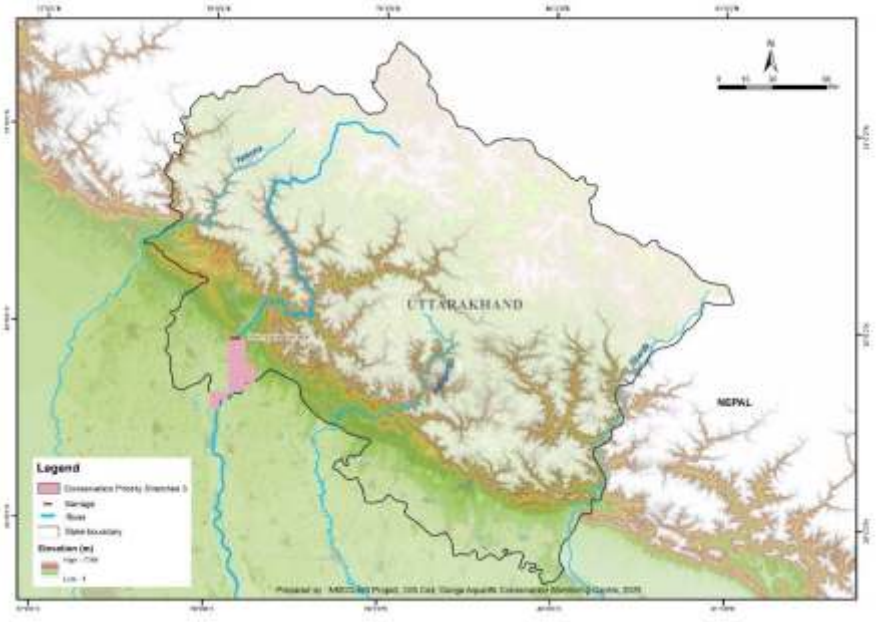


Figure 13.2 Conservation Priority Stretches in Ganga River in Uttarakhand

2. Uttar Pradesh

Uttar Pradesh has the largest extent of conservation priority stretches along the Ganga River. Approximately 570 km (57%) of the river length falls under CPS II, while 425 km (42.5%) is classified as CPS III, indicating extensive river segments requiring conservation management. In comparison, only 5 km (0.5%) has been identified as a restoration zone. Overall, nearly 99.5% of the river length within the state falls under conservation priority stretches, representing the highest proportion among all assessed states (Figure 13.3). The entire length of the Ganga River in Uttar Pradesh hosts varied assemblages of all the indicator species.

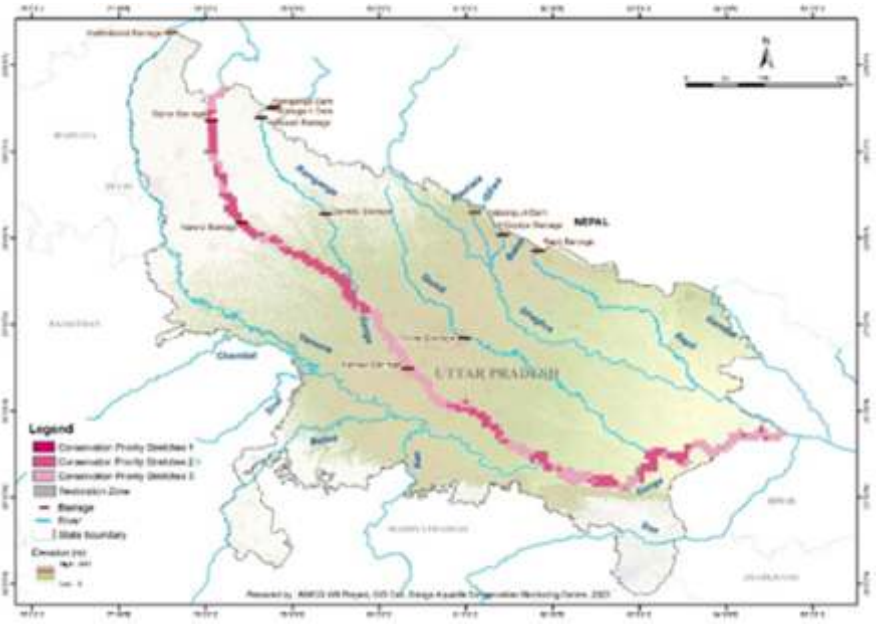


Figure 13.3 Conservation Priority Stretches in Ganga River in Uttar Pradesh

3. Bihar

In Bihar, 10 km (3.8%) of the Ganga River is classified under CPS II, while 205 km (78.8%) falls within CPS III, indicating a predominance of stretches requiring moderate conservation attention. Additionally, 45 km (17.3%) has been designated as restoration zones, highlighting river segments where ecological rehabilitation is necessary to restore habitat functionality and enhance riverine ecosystem integrity (Figure 13.4).

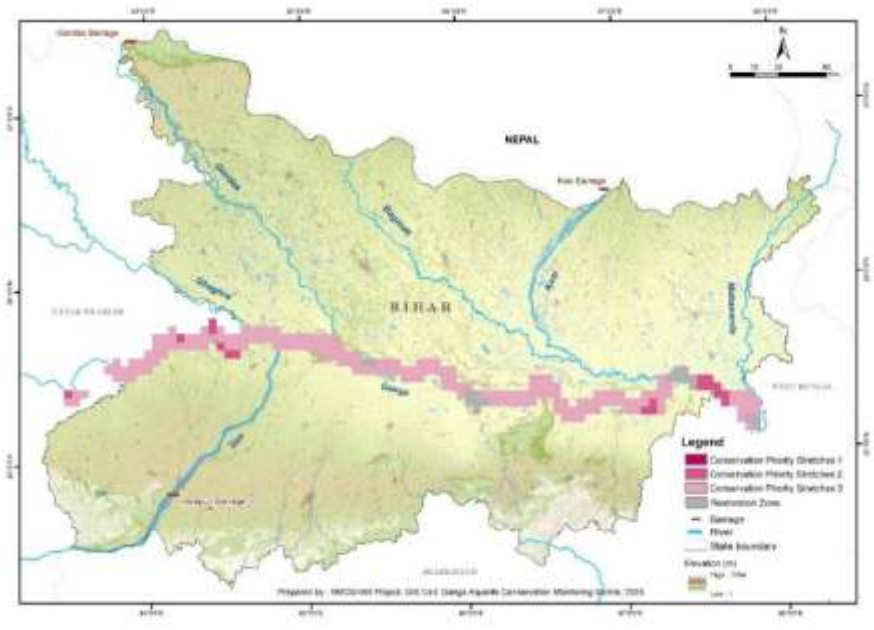


Figure 13.4 Conservation Priority Stretches in Ganga River in Bihar

4. Jharkhand

Within Jharkhand and its adjoining interstate stretches, the Ganga River exhibits a relatively limited distribution of conservation priority segments. Portions of the river along the Jharkhand-Bihar and Jharkhand-West Bengal boundaries include segments categorized under CPS II, CPS III, and restoration zones. These transitional stretches reflect localized conservation priorities and restoration needs along the interstate river corridor (Figure 13.5). These CPS host good assemblages of the Gangetic dolphin.

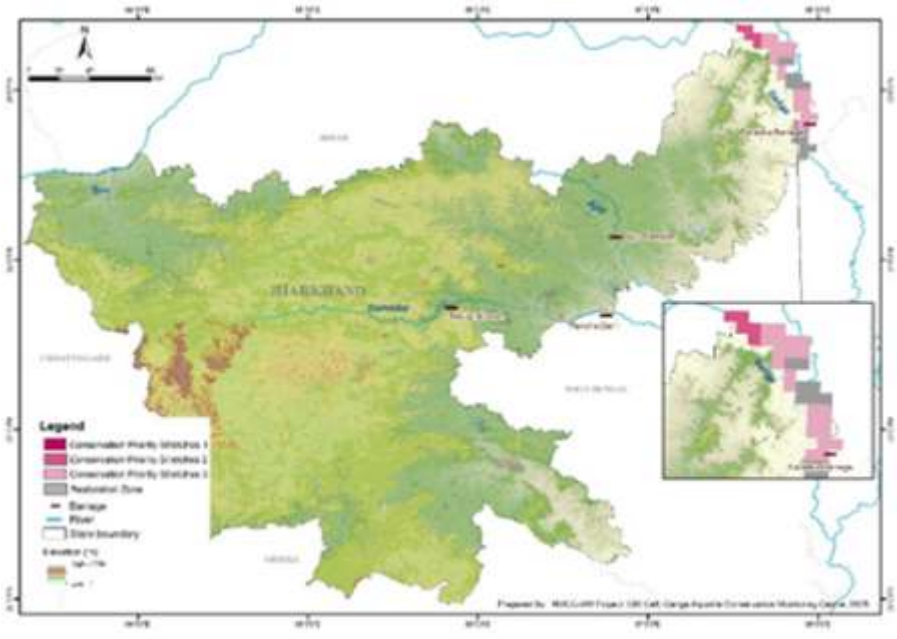


Figure 13.5 Conservation Priority Stretches in Ganga River in Jharkhand

5. West Bengal

In West Bengal, 335 km (64.4%) of the Ganga River has been designated as a restoration zone, representing the largest extent of restoration stretches among the assessed states. In addition, 170 km (32.7%) is classified under CPS III and 15 km (2.9%) under CPS II, indicating notable conservation requirements in the lower reaches of the river (Figure 13.6).

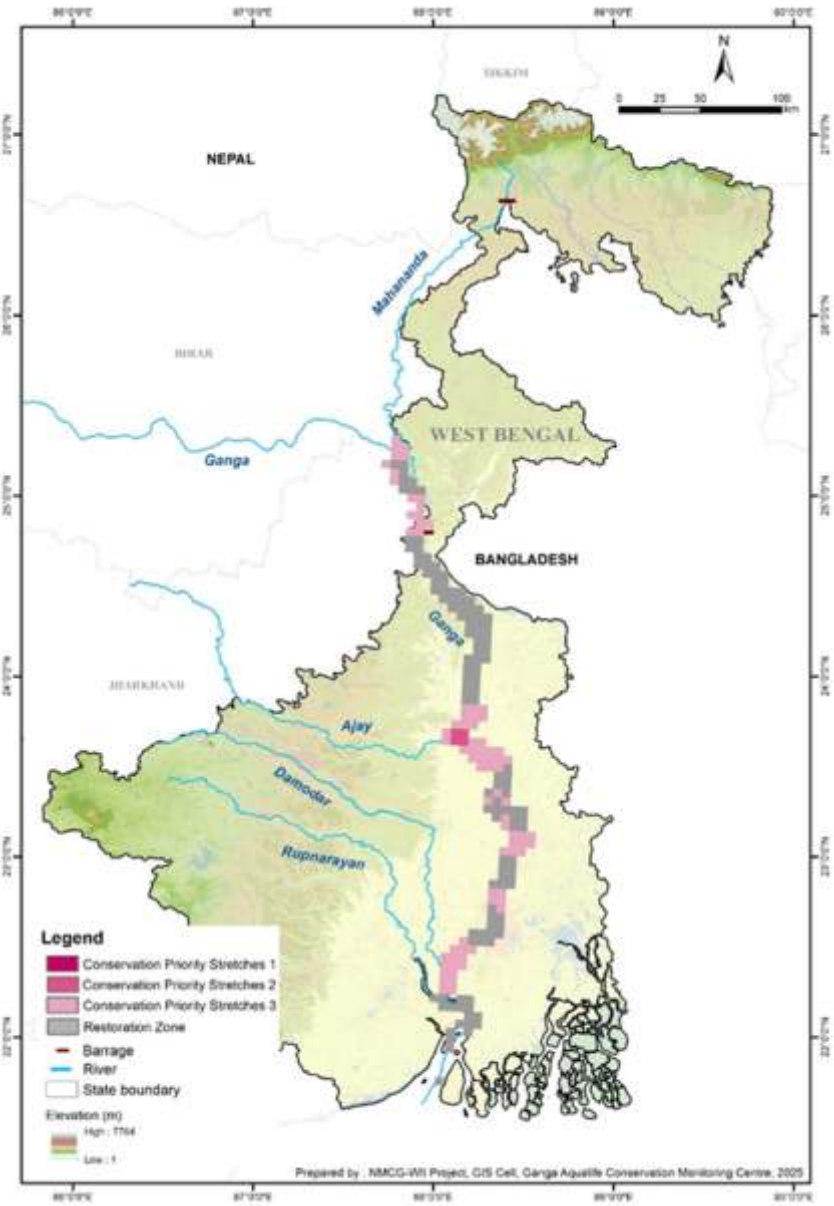


Figure 13.6 Conservation Priority Stretches in Ganga River in West Bengal



Table 13.2 Details of the CPS locations

State -1	State- 2	No. of BEUs	Start Location	Start Longitude	Start Latitude
Uttarakhand	Uttarakhand	57	Gomukh	79.0807	30.9257
		2	Haridwar	78.1637	29.9434
		1	Kishanpur Jhara Ahat	78.1628	29.8556
Uttarakhand	Uttar Pradesh	9	Bhogpur	78.1764	29.8127
Uttar Pradesh	Uttar Pradesh	2	Sharifpur Khadder	78.0549	29.4753
		1	Ranjeetpur	78.0455	29.391
		10	Gokulpur Chhppar	78.0452	29.3488
		4	Kharkhali	78.0725	28.9713
		1	Tigri	78.153	28.8256
		1	Osita Mustkam	78.1416	28.7833
		2	Alamgirpur	78.1619	28.746
		3	Pooth	78.1987	28.6648
		15	Farida Khadar	78.2091	28.5346
		3	Kirtoli	78.605	28.0375
		3	Sukarra	78.7315	27.9827
		1	Kachhla Ghat	78.8556	27.9336
		25	Manikapur Kham	78.8939	27.9049
		2	Gurguch Pur	79.7126	27.2244
		2	Katri Jalesar	79.7972	27.1779
		33	Kusumkhor	79.8866	27.1533
		1	Miyamau	80.7919	26.0602
		1	Khanpur	80.819	26.0242
		1	Bhitoura	80.8566	26.0428
		3	Gegaso	80.9028	26.0553
		12	Bar	81.0359	26.0479
		1	Gotani Kachar	81.378	25.6999
		2	Shahjadpur Kachhar	81.4172	25.6727
		7	Roopnarayanpur Shailabi Ka	81.4922	25.6235
		8	Kureser	81.7397	25.4914
		1	Jirat Lawaen Gairabad	81.9893	25.3424
		1	Shahbaz Gair Abad	82.0386	25.3494
		15	Lakitaha Kachar	82.076	25.3231
Uttar Pradesh	Uttar Pradesh	1	Churaman Patti	82.4383	25.2362
		1	Majhara	82.4749	25.2051
		8	Vindhyachal	82.5041	25.1716
		1	Chandika	82.7646	25.1348
		1	Sindhora	82.8107	25.1168
		4	Chunar	82.8598	25.1176
		12	Baikunthpur	83.0044	25.2094
		1	Mirpur Tirwah	83.2621	25.5159

End Location	End Longitude	End Latitude	Length (km)	CPS
Haridwar	78.1637	29.9434	285	RZ
Kishanpur Jhara Ahat	78.1628	29.8556	10	CPS III
Bhogpur	78.1764	29.8127	5	RZ
Sharifpur Khadder	78.0549	29.4753	45	CPS III
Ranjeetpur	78.0455	29.391	10	CPS II
Gokulpur Chhppar	78.0452	29.3488	5	CPS III
Kharkhali	78.0725	28.9713	50	CPS II
Tigri	78.153	28.8256	20	CPS III
Osita Mustkam	78.1416	28.7833	5	CPS II
Alamgirpur	78.1619	28.746	5	CPS III
Pooth	78.1987	28.6648	10	CPS II
Farida Khadar	78.2091	28.5346	15	CPS III
Kirtoli	78.605	28.0375	75	CPS II
Sukarra	78.7315	27.9827	15	CPS III
Kachhla Ghat	78.8556	27.9336	15	CPS II
Manikapur Kham	78.8939	27.9049	5	CPS III
Gurguch Pur	79.7126	27.2244	125	CPS II
Katri Jalesar	79.7972	27.1779	10	CPS III
Kusumkhor	79.8866	27.1533	10	CPS II
Miyamau	80.7919	26.0602	165	CPS III
Khanpur	80.819	26.0242	5	CPS II
Bhitoura	80.8566	26.0428	5	CPS III
Gegaso	80.9028	26.0553	5	CPS II
Bar	81.0359	26.0479	15	CPS III
Gotani Kachar	81.378	25.6999	60	CPS II
Shahjadpur Kachhar	81.4172	25.6727	5	CPS III
Roopnarayanpur Shailabi Ka	81.4922	25.6235	10	CPS II
Kureser	81.7397	25.4914	35	CPS III
Jirat Lawaen Gairabad	81.9893	25.3424	40	CPS II
Shahbaz Gair Abad	82.0386	25.3494	5	CPS III
Lakitaha Kachar	82.076	25.3231	5	CPS II
Churaman Patti	82.4383	25.2362	75	CPS III
Majhara	82.4749	25.2051	5	CPS II
Vindhyachal	82.5041	25.1716	5	CPS III
Chandika	82.7646	25.1348	40	CPS II
Sindhora	82.8107	25.1168	5	CPS III
Chunar	82.8598	25.1176	5	RZ
Baikunthpur	83.0044	25.2094	20	CPS III
Mirpur Tirwah	83.2621	25.5159	60	CPS II
Chakari Gangwarar	83.3018	25.4877	5	CPS III

State -1	State- 2	No. of BEUs	Start Location	Start Longitude	Start Latitude
		5	Chakari Gangwarar	83.3018	25.4877
		2	Bayanpur	83.5004	25.4066
		3	Jamania Rural	83.5387	25.4374
Bihar	Uttar Pradesh	16	Wazirabad	83.5627	25.5538
		1	Shivpur Diyar	84.1851	25.718
		4	Alamchak	84.2347	25.7108
		1	Gopalpur Mafi	84.3992	25.7717
		1	Parmadpur	84.4231	25.7351
		1	Jawania	84.4614	25.7071
		19	Salempur Diyara	84.5021	25.68
Bihar	Bihar	2	Raghopur East	85.3616	25.5608
		13	Jangi Pakahi	85.4583	25.5339
		3	Hathdeh	86.0093	25.3604
		25	Sihman Barari	86.1313	25.3348
		2	Ismailpur Paschimi	87.1379	25.3035
		3	Kahalgaon	87.2179	25.2807
		4	South Muradpur	87.2928	25.3987
Bihar	Jharkhand	5	Bhawanipur	87.4826	25.3995
Jharkhand	Bihar	3	Murela	87.6905	25.2876
Jharkhand	West Bengal	1	Kesarpur	87.7914	25.2015
		2	Hiranandapur	87.7871	25.1565
		3	Paschim Narayanpur	87.8207	25.0765
		5	Plasgachhi	87.9272	24.9875
West Bengal	West Bengal	3	Farakka	87.9083	24.7664
		5	Nalahati	88.2129	23.8405
		3	Sitahati	88.1532	23.7026
		9	Raghunathpur	88.2151	23.6143
		2	Kashthasali	88.3663	23.4626
		1	Nabadwip	88.3637	23.3814
		1	Chakpansila	88.3676	23.3423
		1	Mohisunra	88.3551	23.3341
		3	Samudragarh	88.331	23.3381
		1	Kalna	88.3701	23.2267
		3	Santipur -Guptipara	88.4158	23.2094
		5	Char Rasulpur	88.4521	23.1537
		5	Birpara	88.4261	23.0098
		4	Bhadreswar	88.357	22.8246
		6	Uttarpara	88.3541	22.6654
		8	Batanagar	88.2066	22.515
		17	Noorpur	88.0696	22.2293

End Location	End Longitude	End Latitude	Length (km)	CPS
Bayanpur	83.5004	25.4066	25	CPS II
Jamania Rural	83.5387	25.4374	10	CPS III
Wazirabad	83.5627	25.5538	15	CPS II
Shivpur Diyar	84.1851	25.718	80	CPS III
Alamchak	84.2347	25.7108	5	CPS II
Gopalpur Mafi	84.3992	25.7717	20	CPS III
Parmadpur	84.4231	25.7351	5	CPS II
Jawania	84.4614	25.7071	5	CPS III
Salempur Diyara	84.5021	25.68	5	CPS II
Raghopur East	85.3616	25.5608	95	CPS III
Jangi Pakahi	85.4583	25.5339	10	RZ
Hathdeh	86.0093	25.3604	65	CPS III
Sihman Barari	86.1313	25.3348	15	RZ
Ismailpur Paschimi	87.1379	25.3035	125	CPS III
Kahalgaon	87.2179	25.2807	10	CPS II
South Muradpur	87.2928	25.3987	15	CPS III
Bhawanipur	87.4826	25.3995	20	RZ
Murela	87.6905	25.2876	25	CPS II
Kesarpur	87.7914	25.2015	15	CPS III
Hiranandapur	87.7871	25.1565	5	RZ
Paschim Narayanpur	87.8207	25.0765	10	CPS III
Plasgachhi	87.9272	24.9875	15	RZ
Farakka	87.9083	24.7664	25	CPS III
Nalahati	88.2129	23.8405	150	RZ
Sitahati	88.1532	23.7026	25	CPS III
Raghunathpur	88.2151	23.6143	15	CPS II
Kashthasali	88.3663	23.4626	45	CPS III
Nabadwip	88.3637	23.3814	10	RZ
Chakpansila	88.3676	23.3423	5	CPS III
Mohisunra	88.3551	23.3341	5	RZ
Samudragarh	88.331	23.3381	5	CPS III
Kalna	88.3701	23.2267	15	RZ
Santipur -Guptipara	88.4158	23.2094	5	CPS III
Char Rasulpur	88.4521	23.1537	15	RZ
Birpara	88.4261	23.0098	25	CPS III
Bhadreswar	88.357	22.8246	25	RZ
Uttarpara	88.3541	22.6654	20	CPS III
Batanagar	88.2066	22.515	30	RZ
Noorpur	88.0696	22.2293	40	CPS III
Ganga Sagar	87.9323	21.6285	85	RZ

13.4 DISCUSSION

Large river channels represent highly dynamic ecological corridors where habitat suitability varies longitudinally due to changes in hydrology, geomorphology, and anthropogenic pressures (Ward & Stanford, 1995; Thorp et al., 2006; Vörösmarty et al., 2010; Zeiringer et al., 2018). The mainstem of the Ganga River, extending across diverse climatic and socio-ecological regions, supports a remarkably diverse assemblage of freshwater biodiversity but is increasingly subjected to intensifying anthropogenic stressors (Dudgeon et al., 2006; Sinha et al., 2010). Understanding the spatial distribution of suitable habitats along the main channel is therefore essential for identifying conservation priorities. By integrating habitat suitability patterns of multiple indicator species, the present study provides a spatial assessment of conservation priority stretches along the main stem of the Ganga River, highlighting areas that require focused conservation interventions or ecological restoration measures. Previous studies have emphasized that spatial identification of priority conservation areas is fundamental for maintaining biodiversity and ecosystem functioning (Belote & Wilson, 2020).

The analysis identified substantial stretches of the Ganga River that require conservation attention, with the majority of suitable habitats falling within moderate and low conservation priority categories. Notably, the modelling outputs did not identify any CPS I stretches within the analysed river segments, suggesting that highly suitable habitats are either spatially restricted or increasingly fragmented within the contemporary river network. This pattern may reflect the cumulative impacts of river regulation, habitat modification, and increasing anthropogenic pressures along the Ganga River. Instead, conservation priority areas were largely represented by CPS II and CPS III stretches, indicating that although many river sections retain ecological value, they may already be experiencing varying degrees of habitat degradation. These patterns are likely influenced by key environmental variables that structure riverine habitats. Hydrological characteristics such as water depth, flow velocity, and channel width are known to influence habitat suitability for riverine megafauna including the Gangetic dolphin and gharial, while geomorphological features such as sandbar availability are important for riverine birds that depend on exposed sediment bars for nesting and foraging (Thorp et al., 2006; Sinha et al., 2010; Kelkar et al., 2010). Variations in these environmental conditions, including bioclimatic variables, hydro-morphological characteristics such as channel depth, flow velocity, and channel width, as well as anthropogenic pressures, likely influence the spatial distribution of the conservation priority stretches identified in this study.

These findings are consistent with patterns reported from large river basins globally, where habitat fragmentation, altered flow regimes, and intensive human use limit the availability of highly suitable habitats for freshwater species (Dudgeon et al., 2006; Vörösmarty et al., 2010; Bian et al., 2024). In the Ganga basin and other Asian river systems, assessments of freshwater megafauna have also shown that suitable habitats often persist as fragmented or moderately suitable stretches rather than continuous high-quality river segments (Carrizo et al., 2017; He et al., 2019).

The predominance of restoration stretches in this downstream region likely reflects the cumulative impacts of upstream disturbances combined with intense anthropogenic pressures such as urbanization, industrial discharge, and altered sediment dynamics along the lower Ganga-Hooghly river system (Sinha & Kannan, 2014; Chowdhury et al., 2016; Badola et al., 2025). Studies from the Hooghly River have documented that dolphin habitats in this region are influenced by multiple stressors including pollution, fishing pressure, boat traffic, and modified river flow regimes, which can significantly affect habitat suitability and species persistence (Chowdhury et al., 2016; Badola et al., 2025). These cumulative pressures may contribute to habitat degradation and explain the predominance of restoration zones identified in the downstream reaches of the river.

The spatial distribution of conservation priority stretches shows strong regional variation along the Ganga River. Uttar Pradesh contained the largest extent of priority segments, with 570 km classified under CPS II and 425 km under CPS III. Together, these stretches highlight the ecological importance of the middle reaches of the Ganga River. The middle reaches of large rivers are often characterized by relatively stable hydrological conditions, wider channels, and complex floodplain systems that support diverse aquatic habitats (Ward & Stanford, 1995; Thorp et al., 2006). Such geomorphological and hydrological characteristics may partly explain the higher concentration of moderate suitability habitats within this region. These river segments are particularly important for river-dependent fauna such as the Gangetic dolphin and associated riverine bird assemblages that rely on relatively undisturbed channel habitats, exposed sandbars, and stable hydrological regimes (Buckton & Ormerod, 2002; Sinha et al., 2010; Sinha & Kannan, 2014; WII, 2021; Sonkar et al., 2024; WII-GACMC, 2025).

In contrast, Bihar was largely represented by CPS III stretches, with 205 km falling within this category and only 10 km classified under CPS II. This distribution suggests relatively lower habitat suitability across much of the river section within the state. Low to Moderate habitat suitability in downstream segments may be associated with cumulative upstream disturbances such as altered sediment transport, water abstraction, and increased pollution loads that degrade riverine habitat structure and ecological functioning (Allan & Castillo, 2007; Best, 2019). Interstate segments between Bihar and Uttar Pradesh also showed a predominance of CPS III stretches, suggesting that habitat conditions within these transitional reaches are influenced by broader basin-scale pressures rather than localized factors alone. Several stretches were analysed as interstate segments

because the river channel forms administrative boundaries between states, and multiple BEUs extend across these borders. Considering these reaches as shared segments allows a more realistic representation of habitat continuity and ecological processes along the main river channel (WII, n.d.). Additionally, the presence of large-scale inland waterway navigation and extensive sand mining activities in several stretches of the river in Bihar may further alter riverbed structure, flow dynamics, and habitat quality, contributing to the moderate suitability observed in this region (Kondolf, 1997; Mishra, 2022; Ali et al., 2025).

Jharkhand exhibited relatively limited conservation priority stretches, although small segments were identified within interstate sections. For example, the Jharkhand-Bihar stretch included both CPS II and CPS III segments, while the Jharkhand-West Bengal stretch was identified as CPS III. These findings suggest that suitable habitats within these transitional zones may occur in fragmented patches rather than continuous stretches, reflecting localized habitat variability along the river corridor.

In contrast, downstream regions in West Bengal displayed a different pattern, where restoration stretches were particularly extensive. Approximately 335 km of the river within the state was designated as a restoration zone, representing the largest restoration extent among the assessed regions. In addition, 170 km were classified under CPS III and 15 km under CPS II.

Large river deltas and lower reaches often experience significant ecological modification due to these processes (Syvitski et al., 2005; Best, 2019), which may substantially reduce habitat suitability for ecologically sensitive aquatic species. Previous studies from the lower Ganga basin have also highlighted that heavy river traffic, bank modification, and pollution in the Hooghly stretch can influence habitat conditions for river-dependent species such as the Gangetic dolphin and other aquatic fauna (Sinha & Kannan, 2014; WBCB, 2020; Panigrahi & Pattanayak, 2020).

These spatial patterns emphasize the need for reach-specific management strategies that simultaneously protect relatively intact habitats and restore degraded river segments along the river's longitudinal gradient. Similar multi-zonal conservation approaches have been recommended for the Ganga basin, where intact or moderately suitable stretches require protection, while degraded reaches demand targeted ecological restoration and regulated resource use (Hussain et al., 2020).

The spatial distribution of CPS (Table 13.2) highlights a notable lack of congruence between priority conservation stretches and the extant protected area network along the Ganga River. Although certain CPS segments overlap with key protected areas-such as Hastinapur Wildlife Sanctuary, Kachhua Wildlife Sanctuary, and the Vikramshila Gangetic Dolphin Sanctuary-as well as parts of the Upper Ganga River Ramsar Site, underscoring their recognized ecological significance (Khan et al., 2013; Sonkar et al., 2019; Choudhary et al., 2006; Joshi et al., 1995), this coverage remains limited and spatially uneven. A substantial proportion of CPS II and CPS III stretches, particularly across the middle and lower Ganga reaches, occur outside formally protected boundaries, indicating the underrepresentation of ecologically important river segments within the current conservation framework and emphasizing the need for integrated, basin-scale conservation strategies that extend beyond site-based protections (Dudgeon et al., 2006; Carrizo et al., 2017).

Several of these priority stretches also coincide with river sections that are ecologically important for the Gangetic dolphin. These priority stretches may collectively function as components of a broader riverine biodiversity corridor along the Ganga River, facilitating movement, dispersal, and ecological connectivity for river-dependent species across fragmented habitats. Even stretches categorized under moderate and lower habitat suitability (CPS II and



CPS III) may function as important ecological corridors that support dolphin movement, feeding, and breeding along the main river channel (Sinha et al., 2010). In regulated rivers such as the Ganga, dolphin populations often occur in fragmented patches between barrages, making the maintenance of connecting river stretches essential for sustaining population connectivity and metapopulation viability. Protecting such river segments is therefore critical not only for conserving suitable dolphin habitats but also for maintaining longitudinal connectivity between key river sections that are otherwise separated by major hydraulic structures such as the Narora and Farakka barrages (Sinha et al., 2010; Kelkar et al., 2010; Braulik et al., 2021).

However, sustaining these habitats remains challenging under multiple human pressures across the basin. Fishing activities, canal diversions, and water extraction continue to contribute to both direct and indirect mortality risks for river dolphins (Behera et al., 2013; Dewhurst-Richman et al., 2020). Entanglement in fishing gear, accidental capture, and occasional poaching remain major threats to the species (Smith & Smith, 1998; Reeves et al., 2005; Sinha & Kannan, 2014). Nevertheless, conservation interventions centred on community engagement and awareness programmes have shown encouraging outcomes in reducing intentional killings and improving local participation in conservation efforts (Choudhary et al., 2006; 2015; Nugroho, 2015). Strengthening protection and management of these conservation priority stretches could therefore play a crucial role in maintaining habitat connectivity and improving long-term survival prospects for Gangetic dolphin populations in the Ganga River. Importantly, these stretches also support other focal taxa included in the assessment, such as the gharial and river-dependent birds (Indian skimmer, black-bellied tern, river tern, and river lapwing), which exhibit strong dependence on specific hydro-morphological conditions and are similarly vulnerable to habitat alteration and disturbance. Conservation of these river segments is therefore likely to generate synergistic benefits across multiple taxa and contribute to maintaining overall riverine ecosystem integrity. Climate change further exacerbates existing pressures on the Ganga River by altering hydrological regimes and increasing the frequency of extreme events, thereby potentially influencing habitat suitability patterns and the spatial distribution of conservation priority stretches identified in this study (Siddha & Sahu, 2022; Wohl et al., 2015).

Effective implementation will require sustained ecological monitoring, adaptive management strategies, and the integration of conservation objectives with the socio-economic realities of river-dependent communities (Palmer et al., 2014; Roni et al., 2018). Such spatial prioritization can also support basin-scale river management initiatives, including environmental flow regulation, habitat protection, and targeted restoration within heavily modified segments of the Ganga basin (Hussain et al., 2020; Das et al., 2022). Ultimately, adopting such an integrated and spatially informed approach is essential for safeguarding freshwater biodiversity and maintaining the long-term ecological resilience of the Ganga River. Overall, the identification of Conservation Priority Stretches provides a scientific basis for guiding spatially explicit conservation planning along the Ganga River and supports integrated river basin management aimed at sustaining freshwater biodiversity and ecosystem resilience.

Identification of CPS also aligns with the commitment to the Kunming-Montreal Global Biodiversity Framework, which calls for restoring 30% of the degraded ecosystems by 2030 and also with the Freshwater Challenge, which calls for restoration of 30,000 km length of rivers globally. These CPS can further be brought under the Other Effective Area Based Conservation Measures (OECMs), which are beyond the traditional Protected Areas, but at the same time acknowledges and safeguarding the ecological significance of the areas, in this case, the length of the Ganga River.



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CHAPTER 14

CONSERVATION IMPLICATIONS AND CONSERVATION PLANNING FRAMEWORK

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SUMMARY

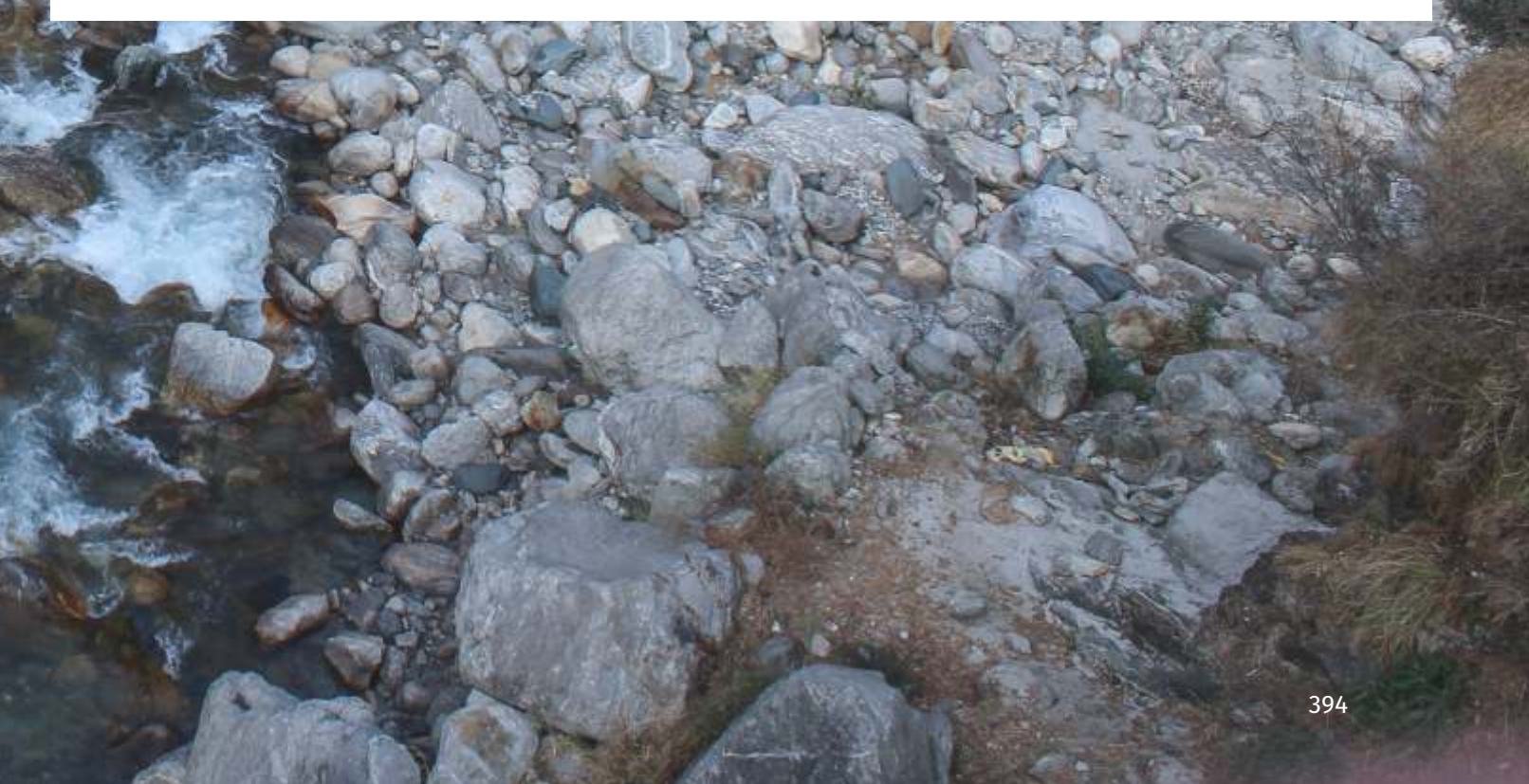
The chapter presents the synthesis of the ecological conditions, conservation concerns, and future management priorities of the Ganga River. A total of 998 taxa were recorded during the study, of which 990 species were confirmed from six major taxonomic groups, including flora, ichthyofauna, avifauna, herpetofauna, macroinvertebrates, and aquatic mammals. Among these, flora represented the highest diversity with 747 species, followed by 114 fish species, 65 bird species, 32 amphibians and reptiles, 30 macroinvertebrates, and two aquatic mammal species. Despite supporting rich biodiversity, the river ecosystem is facing increasing ecological stress due to habitat fragmentation, pollution, invasive species, altered flow regimes, sand mining, urbanisation, and unregulated resource extraction. The study highlights that biodiversity along the river is gradually shifting from native and habitat-specialist communities to disturbance-tolerant and invasive assemblages. Protected stretches of the Ganga River, especially stretches associated with wildlife sanctuaries, continue to support comparatively higher diversity and function as important ecological refuges. River islands, floodplains, riparian vegetation, and natural flow regimes were identified as critical components for maintaining the ecological integrity of the river system. The findings further indicate that while pollution control initiatives and conservation programmes under the National Mission for Clean Ganga have improved certain aspects of water quality, emerging threats such as microplastics, endocrine-disrupting chemicals, and habitat degradation continue to affect aquatic biodiversity. The chapter strongly emphasises that conservation of the Ganga River cannot be achieved through isolated species-based approaches alone. Instead, it requires integrated river basin management, long-term biodiversity monitoring, restoration of ecological flows, habitat protection, regulation of invasive species and sand mining, and improved coordination among different sectors. The chapter also highlights key conservation actions needed for ecological restoration and long-term management of the river basin. Overall, the study concludes that the Ganga River still retains remarkable ecological value and resilience, but its long-term survival depends upon sustained, scientifically informed, and ecosystem-based conservation efforts.

14.1 INTRODUCTION

River restoration globally has evolved from an initial focus on engineering solutions to ecological integration and is now in the resilience era. This transformation saw a policy shift from a focus on disparate use of riverine resources in silos to integrated management. The Integrated River Basin Management (IRBM) is a coordinated process of managing riverine resources, within a river basin through holistic, long-term planning, balancing upstream/downstream needs, ecosystem health, and stakeholder cooperation to tackle pollution, biodiversity loss, and climate change (ICIMOD,). Globally, the Murray-Darling Basin (MDB) in Australia, the Danube and the Rhine River of Europe, the Room for Rivers initiatives, are leading river restoration initiative following the IRBM principles. These initiatives reflect the core principles of IRBM, viz., cross-sectoral coordination, the alignment of hydrological, ecological, and socioeconomic objectives within a single, coherent governance architecture. The stringent enforcement of the laws and policies is central to IRBM. These initiatives have shown that river restoration as a strategic, policy-driven commitment can maintain the ecological integrity and long-term resilience of the rivers.

Among the Indian rivers, the Ganga River was the first to catch the attention of the policy planners, with respect to its water quality. The Ganga Action Plan (GAP) (1985) was thus born out of this attention; it was the first centrally sponsored and structured program for improving the water quality of the Ganga River. The GAP I and GAP II, later led to the evolution of the broader National River Conservation Plan (NRCP) in 1995, which later evolved as the National Ganga River Basin Authority (2009) and the Namami Gange Program (2014). Following the global analogy, the focus was primarily on tackling the water quality challenges of the Ganga River. The GAP I and II focused on engineering solutions, which are static and do not evolve with time. As the scientific communities brought in more evidence in favour of ecological considerations in managing and restoring the rivers, the river conservation paradigm shifted to holistic approaches. Thus, the GAP I and II, were replaced by the *Namami Gange* Program, and it is wholesome and holistic in its approach, as it addresses the water quality (*Nirmal dhara*) as well as the flow of the river (*Aviral dhara*). The National Mission for Clean Ganga (NMCG), established under the Namami Gange program, has been a catalyst for advancing India's approach from conventional river pollution control toward a holistic, basin-wide approach to river rejuvenation.

Aquatic species conservation and river restoration are inseparable endeavours, as the structural and ecological integrity of river systems determine the health of freshwater biodiversity. Heavily modified rivers, through channelization, damming, pollution, and associated land use changes in the floodplain, lose the complex mosaic of habitats, which are essential for life history strategies of aquatic species. The loss of physical habitat and changes in water quality exert compounding pressures on sensitive aquatic species, driving population declines through range contraction, reduced reproductive success, and the progressive fragmentation of viable habitat across the basin. River restoration is thus not a singular and linear effort. It involves replanting native vegetation along riverbanks, restoring natural flow regimes, and reconnecting fragmented river reaches, which aid in rebuilding the lost habitats, allowing native species to recolonize and populations to recover over time. Without ecologically restoring the river, a true river restoration would be incomplete. A river with thriving aquatic communities reinforces river health by improving water clarity, oxygenating sediments, and transporting nutrients into river catchments, which translates into a healthy and functional riverine ecosystem



14.2 STATUS OF BIODIVERSITY: A SYNTHESIS

The present study documented a total of 998 taxa of six major taxonomic groups of flora and fauna along the Ganga River, of which 990 species were confirmed (Figure 14.1). Flora constitutes the majority of the recorded biodiversity (75.45%; 747 species), followed by ichthyofauna (11.52%; 114 species) and avifauna 6.57% (65 species). While herpetofauna (amphibians, turtles, and crocodilians) accounted for 3.23% (32 species), macroinvertebrates account for 3% (30 species), and aquatic/semi-aquatic mammals for only 0.20% (2 species). Overall, 35 species (3.53%) across different taxonomic groups are classified as Threatened or Near Threatened according to the IUCN Red List. However, a substantial proportion of species (44%; 436 species) have not been evaluated/ assessed by IUCN, while an additional 1.51% (15 species) are classified as Data Deficient (DD). This lack of comprehensive conservation status assessments poses a significant challenge for biodiversity conservation, as the absence of clearly defined threat categories can lead to uncertainties and potential misinformed decision-making at the local and global levels. Although the Indian Wild Life (Protection) Act, 1972 provides stringent legal protection to major faunal taxa under Schedules I and II, the representation of floral species remains largely limited, as only 19 species are currently enlisted under Schedule III as "specified plants".

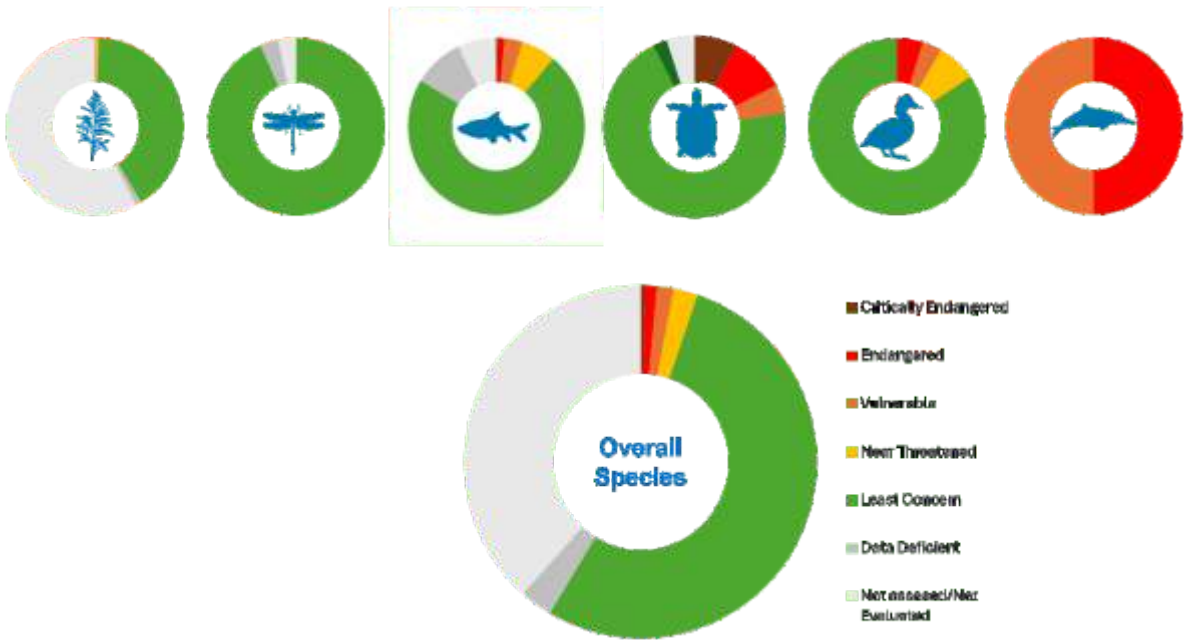


Figure 14.1 IUCN status of different taxonomic groups recorded along the Ganga River

Apart from these limitations, exotic/invasive species continue to infest the Ganga River. A total of 131 exotic/ invasive species (120 plant sp., 11 fish sp.) were recorded from the Ganga River. Both taxonomic groups are facing rapid invasion in attributed to the introduction of exotic/invasive species accidentally or intentionally to meet the demand of people, for instance, *Nile tilapia* and carps for consumption.

14.3 DRIVERS OF CHANGE AND THEIR POLICY INTERFACE

Akin to the rivers globally, the Ganga River is being impacted by an interplay of anthropogenic and natural drivers, which determines the river's current hydrological connectivity, geomorphological conditions, biodiversity values, and ecological resilience. The drivers operate in a most complex way, producing impacts either independently or in combination with each other, resulting in cascading impacts which vary across spatio-temporal scales. The negative and positive drivers have distinct implications for river health and conservation outcomes. Among negative drivers, agricultural intensification, urbanisation, industrial expansion, and energy demands drive land use changes, resulting in habitat fragmentation and alteration of natural flow regimes. Riverine resources form the backbone of the livelihood and economy of the local population residing along the Ganga River. Unsustainable rate of resource extraction in the form of fishing, sand mining, water withdrawal, and species trade disturbs the biota and its substrate, which hampers the functioning of the riverine ecosystem. In addition, the use of the rivers for transportation, tourism, untreated waste disposal, and

invasive species also impacts the riverine ecosystem. Climate change further exacerbates these pressures. Together, these drivers threaten ecological resilience and reduce the adaptive capacity of freshwater ecosystems. Simultaneously, positive drivers such as species and habitat protection through a range of activities, which include creating a protected area network, sustainable agriculture practices, and increased public awareness, contribute towards river conservation. Government-led policy interventions have been instrumental in the protection and conservation of the aquatic ecosystem. A total of 60 policy instruments of the Government of India, which are being implemented by about 19 ministries and the policies of the five Ganga River states were analysed

The Government of India's Ministry of Environment, Forest and Climate Change (MoEFCC), is a key ministry whose mandate is protection and conservation of natural resources of the country and thus has the power to notify areas as Protected Areas for in-situ conservation of the species and protection of the habitat. In doing so, the MoEFCC thus also has regulatory control over the ecological stressors, operating within the PA boundaries and other conservation area categories. The core legislations such as the Wild Life (Protection) Act, 1972 and the Environment (Protection) Act, 1986 have the prohibitory stances across the multiple negative drivers, and promote species and habitat protection. The policy-driver interface matrix makes it clear that 'species protection' is in only 27% of the 59 central government policies studied, while about 23% mentions habitat protection as one of the actions for conservation. Almost half of the central government's legislation is silent on agriculture as a driver. Pollution or nutrient load is most actively addressed driver, followed by water withdrawal, and industries. Invasive species, sand mining, and species trade are amongst the most neglected negative drivers in the policy instruments. The policy interventions post 2000 have been holistic in their approach, with a shift from pollution centric to ecosystem based governance, as is evident through Table 14.1. Policies of the Ministry of Jal Shakti (MoJS), including the *Namami Gange* Programme, the National Water Policy, and the recent National Water Mission (as part of the National Action Plan for Climate Change - NAPCC), emphasise restoration and conservation outcomes (positive drivers), with land use change drivers being regulated in two of the three instruments studied. They remain silent or neutral regarding riverine resource extraction. This approach indicates a programmatic rather than regulatory, focused on mitigation and rejuvenation without sufficiently holistically constraining drivers of degradation. Policy instruments of other ministries viz., agriculture (MoAFW) and Fisheries (MoFAH&D) reveal a predominantly promotion-oriented policy framework. Schemes like the Soil Health Card and Paramparagat Krishi Vikas Yojana, Agricultural Policy Vision, National Mission for Sustainable Agriculture (as part of the National Action Plan for Climate Change - NAPCC) actively promote sustainable practices, yet remain silent on restricting harmful activities such as excessive water withdrawal or nutrient loading. The Indian Fisheries Act, 1897 permits fishing and species trade while prohibiting destructive practices only partially, reflecting an economic-utilitarian bias. This illustrates a broader pattern: production-oriented sectors prioritize livelihood and economic outputs, with limited regulatory integration of ecological constraints.

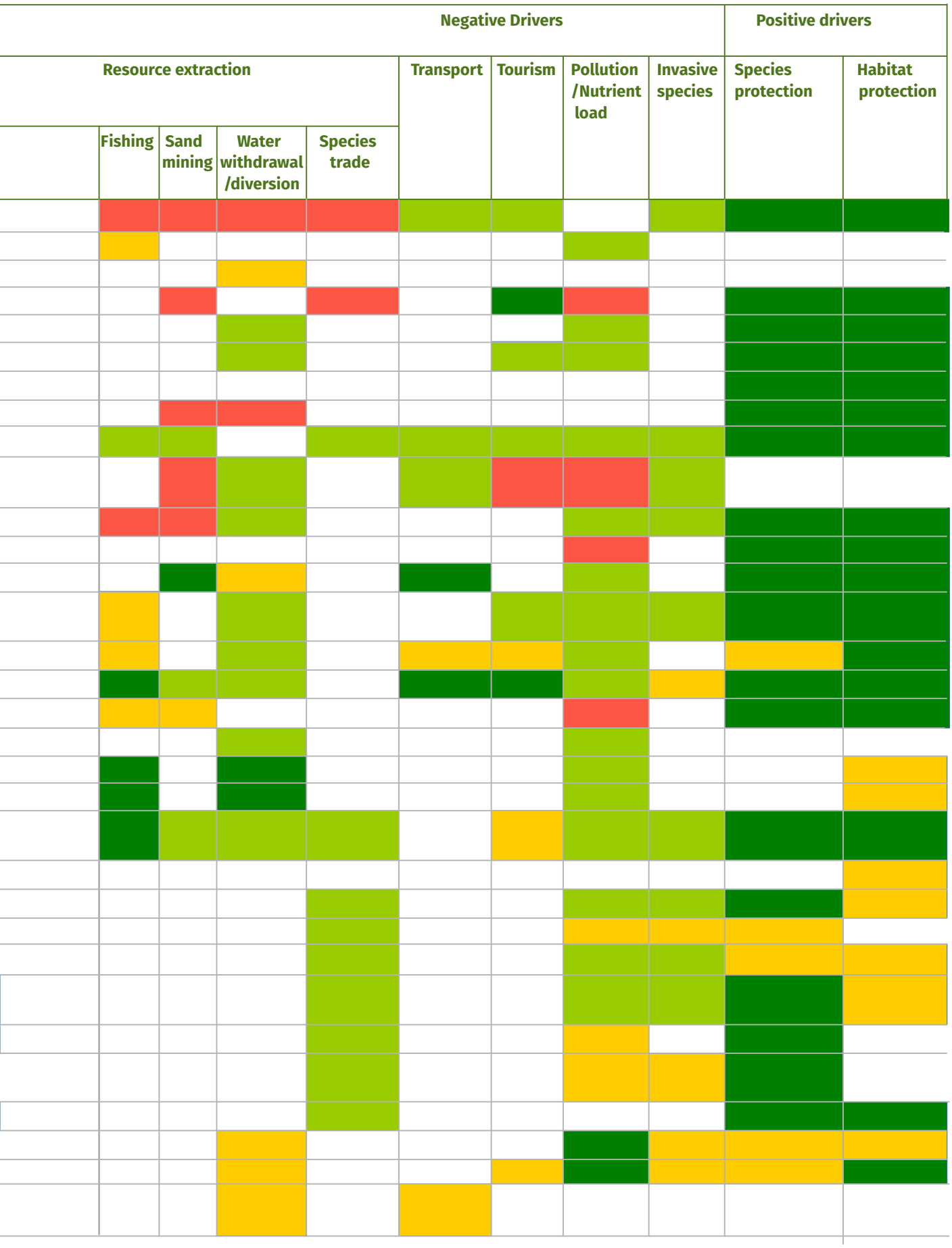
Infrastructure and development-focused ministries largely promote activities linked to transport, energy, and construction. While some policies incorporate sustainability narratives (e.g., green highways, net-zero targets), these are primarily promotive rather than regulative or restrictive. This reflects a systemic pattern where economic infrastructure development is institutionally decoupled from ecological regulation, relying instead on external environmental clearances. More than half of the policy instruments are silent on "sand mining", a critical driver of river degradation, indicating significant governance gaps in addressing geomorphological impacts on the river system. At the state level there is inconsistency: while some policies strictly prohibit certain activities, others remain silent on the same drivers, indicating uneven governance across the basin (Table 14.1).

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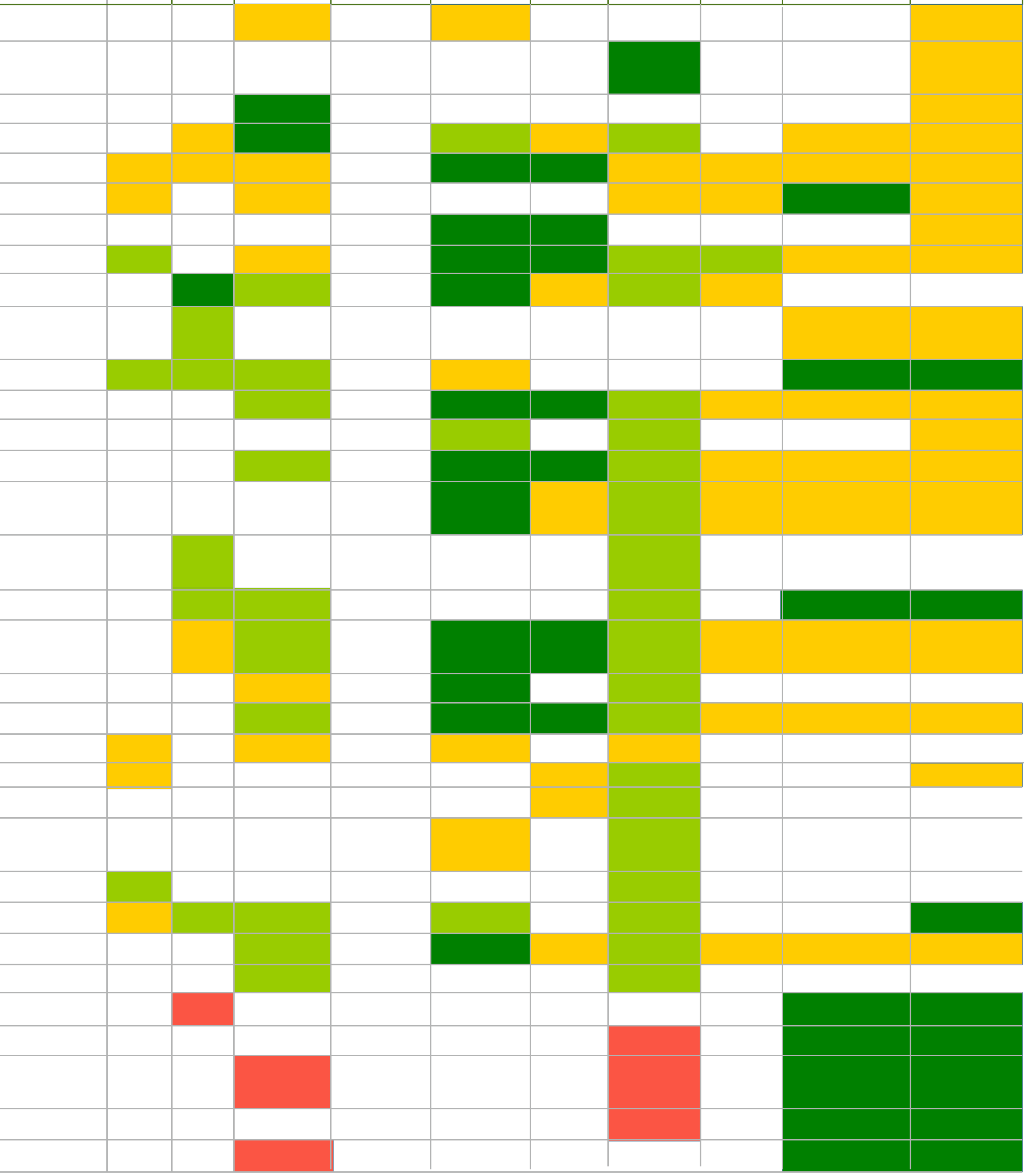
Table 14.1 Interface of drivers and policies

Ministry	Policy or legislative tool impacting the drivers of Ganga River's ecological integrity	Negative Drivers				
		Land use change				
		Agriculture	Urban Areas	Industries	Energy	
MoEF&CC	Wild Life (Protection) Act, 1972					
	Water (Prevention and Control of Pollution) Act, 1974					
	Water (Prevention and Control of Pollution) Cess Act, 1977					
	Environment (Protection) Act, 1986					
	Environment (Protection) Rule, 1986					
	National Environment Policy (NEP), 2006					
	Biological Diversity Act, 2002					
	National Action Plan on Climate Change, 2008					
	National Biodiversity Action Plan (NBAP), 2008					
	Guidelines for Declaration of Eco-sensitive zones around PAs, 2011					
	Wetland (Conservation and Management) Rules, 2017					
	Solid Waste Management Rules 2016					
	Sustainable Sand Mining Management Guidelines, 2016					
	National Plan for Conservation of Aquatic Ecosystems, 2019 (and guidelines, 2024)					
MoJS	National Water Policy, 2012					
	Namami Gange Programme, 2014					
	National Ganga Council, 2016					
	National Water Mission, 2021					
MoAFW	Agricultural Policy Vision, 2020					
	National Mission for Sustainable Agriculture, 2010					
	Draft National lnland Fisheries and Aquaculture Policy, 2019					
	Wasteland Development Policy					
	The Destructive Insects and Pests Act, 1914					
	The Seeds Act, 1966					
	The Insecticides Act, 1968					
	The Prevention and Control of Infectious and Contagious Diseases in Animals Act, 2009					
	The Prevention of Cruelty to Animals Act, 1960					
	The Protection of Plant Varieties and Farmers' Rights Act, 2001					
MoFAH&D	Indian Fisheries Act, 1897					
	Soil Health Card Scheme					
	Paramparagat Krishi Vikas Yojana (PKVY)					
Ministry of Home Affairs	Disaster Management (Amendment) Act, 2025					

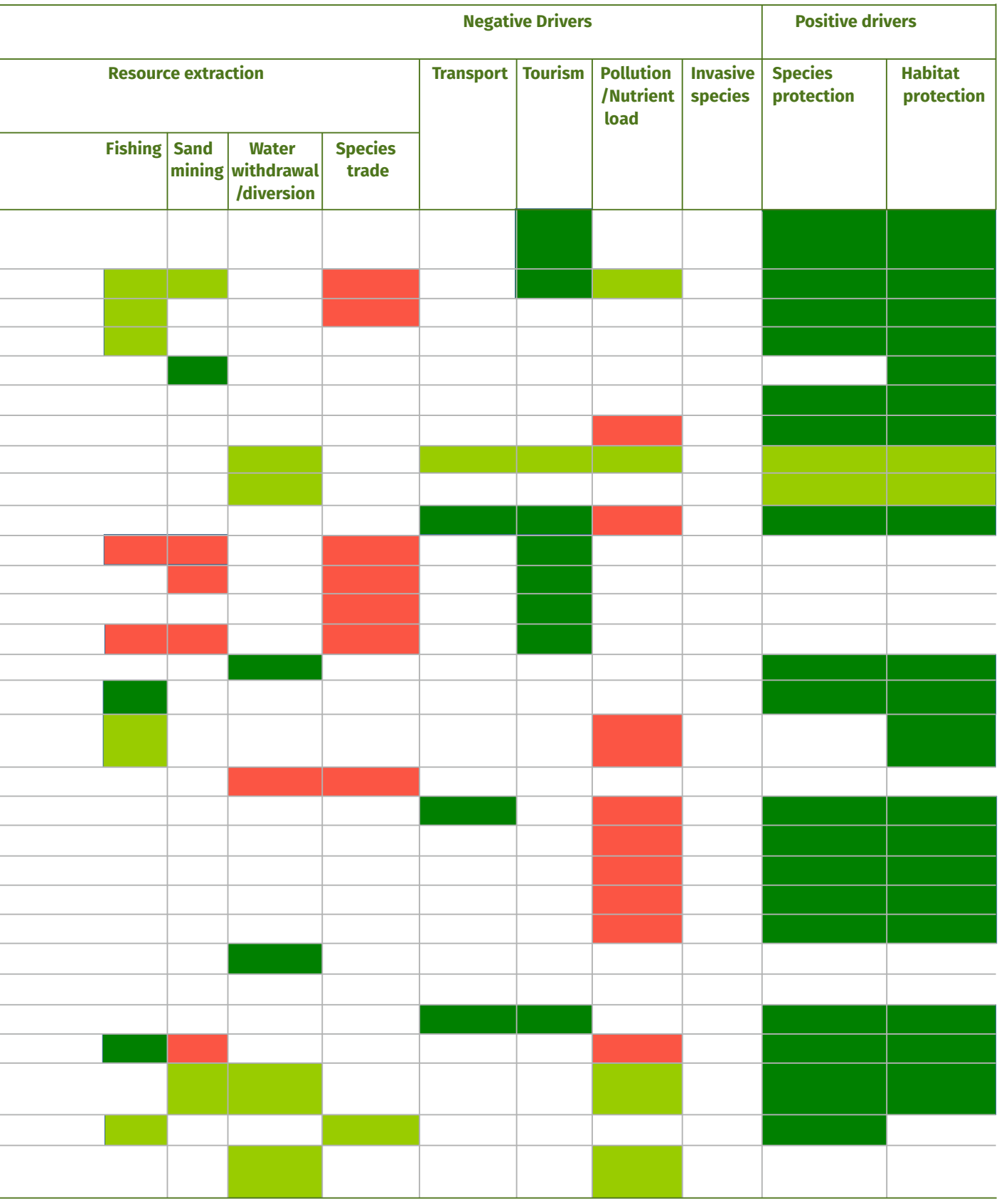

Negative Drivers
Positive drivers
Resource extraction
Transport
Tourism
Pollution /Nutrient load
Invasive species
Species protection
Habitat protection
Fishing
Sand mining
Water withdrawal /diversion
Species trade

Ministry	Policy or legislative tool impacting the drivers of Ganga River's ecological integrity	Negative Drivers				
		Land use change				
		Agriculture	Urban Areas	Industries	Energy	
	Management of Glacial Lake Outburst Floods (GLOFs)					
	National Disaster Management Guidelines - Flood Management, 2008 Management, 2008					
MoP	Policy on Hydropower Development (Updated 2024-25)					
	Pumped Storage Projects (PSP) Guidelines, 2023-2025					
MoST	National Geospatial Policy (NGP), 2022					
	Scientific Social Responsibility (SSR) Guidelines, 2022					
MoPSW	National Waterways Act, 2016					
	Inland Vessels Act, 2021					
	Dredging Guidelines and "Waste to Wealth" (2023-2025)					
MoM	Mines and Minerals (Development and Regulation) Amendment Act, 2025					
	Sand Mining Framework, 2018					
MoR	The Railways (Amendment) Act, 2024-25					
	Net Zero Carbon Emitter Policy (Target 2030)					
	Amrit Bharat Station Scheme (Ganga Stretch)					
MoRTH	Green Highways (Plantation, Transplantation, Beautification, and Maintenance) Policy					
	Sustainable Construction and "Waste to Wealth" Initiatives					
MoC	Mining Plan and Mine Closure Plan Guidelines (2025)					
MoCI	National Industrial Corridor Development Programme (NICDP)					
	The Industries Development and Regulation Act, 1951					
	The Special Economic Zones Act, 2005					
MoPR	Gram Panchayat Development Plan (GPDP) Guidelines					
	Ganga Gram					
MoHUA	Swachh Bharat Mission- URBAN					
	AMRUT 2.0 (Atal Mission for Rejuvenation and Urban Transformation)					
MoCA&PD	Bureau of Indian Standards (BIS) Water Quality Norms					
	CPCB Comprehensive Charter 2.0 (2022/2024)					
	Ethanol Supply Year (ESY) 2025-26 Policy					
MoMSME	MSME Sustainable (ZED) Certification Scheme					
Uttarakhand	Uttarakhand Flood Plain Zoning Act, 2012					
	Policy on Safe Reuse of Treated Water (2024-2025)					
	Uttarakhand Water Management and Regulatory (Amendment) Act, 2016					
	Zero-Tolerance Pollution Policy					
	Integrated Watershed Management Program (IWMP)					

Negative Drivers									Positive drivers	
Resource extraction					Transport	Tourism	Pollution /Nutrient load	Invasive species	Species protection	Habitat protection
	Fishing	Sand mining	Water withdrawal /diversion	Species trade						



Ministry	Policy or legislative tool impacting the drivers of Ganga River's ecological integrity	Negative Drivers			
		Land use change			
		Agriculture	Urban Areas	Industries	Energy
	State Action Plan on Climate Change (SAPCC) - River and Soil Conservation				
	Uttarakhand Forest Policy, 2001				
	Uttarakhand Fisheries Act, 2003				
	Uttarakhand Fisheries Policy, 2003				
	Uttarkhand River Training Policy, 2016				
	Uttarakhand Water Policy				
Uttar Pradesh	Uttar Pradesh State Water Policy				
	State Water Policy, 1999				
	Participatory Irrigation Management Act, 2009				
	Ganga Flood Plain Zoning & Boundary Demarcation				
	One District One Wetland (ODOW)				
	New River Revival Scheme (2025)				
Bihar	Jal-Jeevan-Hariyali Mission				
	Action Plan for Conservation of River Ganga in Bihar				
	Kosi-Mechi Intra-State Link Project				
	Bihar State Fisheries Act, 2006				
	Bihar Fish Jalkar Management Act, 2006 & Amendment, 2007				
	River Rejuvenation Committee (RRC) Directives				
Jharkhand	Jharkhand Industrial Roadmap (2026 Transformation)				
	JSPCB Assessment (2025)				
	Jharkhand State Water Policy (2011)				
	15-Point Directive on Idol Immersion				
	Construction-Free Zone Regulation				
West Bengal	Nodi Bandhan Project & Basin Master Plans				
	Adi Ganga Rejuvenation Plan				
	West Bengal Inland Water Transport (WBIWT) Project				
	ICAR-CIFRI River Ranching Strategy				
	East Kolkata Wetlands (Conservation and Management) Act, 2006				
	West Bengal Inland Fisheries Act, 1984				
	West Bengal Ground Water Resources (Management, Control and Regulation) Act, 2005				


Negative Drivers
Positive drivers
Resource extraction
Transport
Tourism
Pollution /Nutrient load
Invasive species
Species protection
Habitat protection
Fishing
Sand mining
Water withdrawal /diversion
Species trade

14.4 CONSERVATION IMPLICATIONS

The River is undergoing ecological simplification across the monitored taxa

The study presents the evidence for a shift from native-rich, structurally diverse communities to homogenized, disturbance-tolerant assemblages. Among the recorded flora, about 16% (120 species) were non-native, which are causing biotic homogenization across the middle and lower stretches. The complex structure associated with the riverine ecosystem has been lost over the last five decades. Swamp forests of the Doon Valley, comprising the characteristic cane breaks, tall grasslands with *Phragmites karka* and *Saccharum* spp. in the upper Gangetic plains, and Sal (*Shorea robusta*) forests at the foothills of the Himalaya, have been drastically reduced or fragmented. Odonate diversity also declined between 2017-18 and 2024-25. Literature suggests that pollution-sensitive taxa, Ephemeroptera, Plecoptera, and Trichoptera (EPT), declined progressively downstream and were replaced by tolerant families like Chironomidae and Physidae. In Uttarakhand, taxonomic richness declined significantly between 1994 and 2023, most dramatically at Devprayag (from 13 to just 2 taxa). Though literature suggests 11 invasive fish species, we recorded seven invasive species, with Cyprinus carpio the most widespread, followed by Oreochromis niloticus. Among avifauna, the species richness remained stable, but abundance declined. Trend analysis for black-bellied tern, river tern, and river lapwing showed non-significant declining trajectories - a warning signal for habitat specialists.

Protected areas are biodiversity lifelines

The stretch of the Ganga River that passes through the Hastinapur Wildlife Sanctuary stretch (Bijnor-Narora) was consistently the most diverse zone for fish, odonates, waterbirds, gharial and Gangetic dolphin. The phase I report of the NMCG-WII project also highlighted the significance of the Protected Areas (PA) in providing relatively undisturbed habitat for the aquatic species (WII-GACMC, 2018). The most significant drivers of ecosystem loss and biodiversity decline is habitat loss. The land use changes are minimal around the PAs.

Invasive species require urgent attention

The Ganga River is experiencing a cascading invasion across flora (*Alternanthera philoxeroides Prosopis juliflora*, *Lantana camara*, *Pontederia crassipes*, *Parthenium hysterophorus*), and fauna (*Cyprinus carpio*, *Oreochromis niloticus*, *Pterygoplichthys disjunctivus*). Targeted removal programs, especially in transition zones where natives still persist, are essential before aiming at range expansion. Cross-sectoral policy analysis revealed that of 59 central government legislations, only 10 instruments prohibit the introduction of invasive species. It remains one of the most neglected negative drivers.

Native vegetation restoration is essential

The Ganga River's floodplain is witnessing changes in the native vegetation composition. The native hygrophilous vegetation - the swamps of the Doon valley, the grasslands of the Gangetic khadar - have been replaced by either monoculture plantations or other land uses. The replacement of native riparian vegetation disturbs the microhabitats of invertebrates, fish (as nursery habitats), and avifauna, which have cascading effects on the ecosystem functioning, impacting the water purification, water retention, and soil erosion control functions of the ecosystem. The native hygrophilous tall grasslands along the Ganga River also provide habitat to some of the rare and endangered terrestrial species, such as the vulnerable swamp deer (*Rucervus duvaucelii*).

River islands provide critical habitats

The Ganga River is characterised by the presence of mid-channel islands, particularly in the middle zone. This study and the literature emphasise the ecological importance of the Ganga River's mid-river islands for endangered breeding birds (Indian skimmer, black-bellied tern, little tern, small pratincole). Declining trend in encounter rate of these specialist species, and the soft shell turtles, suggests the lesser availability of the optimal nesting sites for these species. These islands are subjected to sand mining, and cucurbit cultivation in the summer season. Some of the river islands have been converted into full-fledged human habitations with permanent farms. A report on river islands in the Ganga River provides a detailed list of identified islands and their current status, with respect to their habitat suitability (WII-GACMC, 2024). Mapping of the river islands on the spatial platform, past land uses change detection of these islands and seasonal usage by waterbirds or other aquatic species as nesting sites is must. Seasonal and periodic monitoring of the river islands through a dedicated island protection and monitoring framework coordinated between irrigation departments and forest authorities, especially during the April-July breeding season, is urgently required. Sand mining is also one of the most neglected drivers in the policy instruments.

Flow regime restoration is non-negotiable

This study and the literature provide evidence that dams and barrages are among the primary drivers of biodiversity loss in the upper and middle reaches. Flow-deficient stretches below barrages show drastically reduced richness of the macroinvertebrates. E-flow releases without a flood pulse component have failed to prevent macroinvertebrate collapse (Devprayag), range restriction of golden mahseer (*Tor putitora*), and loss of sandbar affecting nesting waterbirds. Flow regulation also resulted in fragmentation of the dolphin population, with persistent zero-sighting stretches (Farrukhabad-Kannauj) attributable to canal diversions creating shallow flow conditions below habitat thresholds.

Managing connectivity and gene flow

The high within-population genetic variation in *Wallago attu* (84.7% variation within populations) and maternal gene flow detected across river systems in Pangshura turtles confirm that tributary networks function as a single interconnected genetic landscape. Any infrastructure or land-use decision that severs these corridors - a dam, a barrage, unregulated sand extraction - has consequences that extend far beyond the immediate site. The lineages documented in this study, from the ancient Lissemys complex to the phylogenetically basal Platanista, represent biological heritage that cannot be reconstructed once lost. Conserving it requires moving beyond single-species thinking toward integrated, basin-scale governance that addresses habitat connectivity, genetic integrity, and anthropogenic stressors as inseparable components of a single, coherent challenge.

Emerging contaminants need to be regulated

The study demonstrates regulated pollutants show statistically significant declines between 2018 and 2025. The mainstem meets prescribed standards at 69% of monitored stretches, with conductivity and pH accounting for most of the residual non-compliance. Dissolved oxygen achieves full annual compliance but falls below threshold at seven sites during lean flow, including Varanasi, indicating a seasonal rather than structural deficit. While concentrations of heavy metals are declining, absolute loads continue to warrant sustained monitoring. The Ganga River is getting statistically cleaner by the parameters India monitors and ecologically more dangerous by the parameters it does not. The trend reflects the combined effect of industrial effluent standards, banned-substance enforcement, and sewage treatment capacity commissioned under *Namami Gange*. The tissue samples of select fish species confirm direct exposure of threatened species, including the gharial, smooth-coated otter, and Gangetic dolphin, to regulated and unregulated contaminants through prey-based bioaccumulation.



Rescue and rehabilitation centres are critical to species conservation and recovery

The pilot rescue and rehabilitation centres established across the Ganga River have emerged as a critical conservation strategy to address threats related to poaching, net entanglement, injury and mortality. The integration of scientific monitoring tools, such as digital morphometric techniques, has strengthened evidence-based management. Rescue operations, followed by scientific rehabilitation protocols in controlled facilities, allow for treatment of trauma and injury, implementation of quarantine to prevent pathogen spread, and eventual reintroduction of healthy individuals into suitable habitats. From a One Health point of view, these efforts reduce the risk of zoonotic disease transmission and improve ecosystem functioning by restoring species. Rescue and rehabilitation of aquatic species, by integrating veterinary science, environmental monitoring, capacity building and community awareness, ensures that conservation is not done in isolation but as part of a broader, systemic approach to sustaining riverine health and public health outcomes.

River remains undefined by any legal instrument

The term 'River' in India is defined on functionally and statutorily based on the specific purpose of the law, ranging from pollution control, water disputes, or urban planning. Most of the legislation that governs the consumptive use of riverine resources and focuses only on a particular resource or use rather than the river as an integrated ecosystem. As per this approach, the riverine system is a collection of independent, separable, individually governable components - water (regulated under pollution and irrigation law), fish (under fisheries acts), sand (under minor minerals rules), land (under revenue and land acquisition law), and riparian forests (under forest law). Most of these laws focus on the utilisation of the resources, rather than conservation and protection. The legislation of the Ministry of Environment, Forests, and Climate Change is the only one that focuses on conservation and protection of the aquatic species (Wild Life (Protection) Act, 1972) and their habitat (Environment Protection Act, 1986). As is evident, each component is governed by a different authority, under a different statute, with a different mandate. Nowhere does the law recognize that these components together as an integrated, interdependent, and self-sustaining ecological system. There is a need for a comprehensive legal definition, which is beyond the individual components and sees the river as a single entity within which heterogeneity has to be maintained. The definition must acknowledge the river's spatial and temporal dimensions. This is particularly true for the Ganga River, which sustains about half of India's population and the well-being of this population is deeply connected to the ecological resilience of the River.

14.5 CONSERVATION ACTIONS

Conservation efforts must focus not just on the water but on protecting the connectivity of the river along its longitudinal, lateral and vertical corridors. This report's collective findings argue against managing individual species in isolation. The Ganga basin functions as a single landscape, and threats operate at basin scale. Effective conservation therefore demands coordinated river-basin governance that treats tributary connectivity, and multi-taxa monitoring as a unified programme rather than separate species recovery plans. Recovery plans tend to be species-specific due to specific ecological and biological requirements. Whereas monitoring can be unified.

Establish a unified legal definition of a River

India's river conservation and restoration initiatives are multi-sectoral and multi-agency, which highlights the inter-sectoral coherence required to achieve this mammoth task. Water is a state subject in India, and the central government supplements the state's efforts through technical and financial support. States have the power to legislate on water supply, irrigation, canals, and drainage, while the Centre has jurisdiction only over inter-state rivers. This complexity calls for moving beyond resource-specific definitions and enact a single, comprehensive legal definition of a river that recognizes it as an integrated ecological system - encompassing its water channel, riverbed, banks, riparian vegetation, sediment flow, floodplains, and associated biodiversity. The definition must be adopted uniformly across all central and state legislation, replacing the current patchwork of fragmented, purpose-driven interpretations. To enable the definition on ground, spatial and temporal boundaries of the river need to be drawn on GIS platform, to include the high and low flow, floodplains, riparian zones, seasonal wetlands and connected groundwater.

In case of the Ganga River, a strong precedent already is in place. The National Ganga Council (NGC), established through the Environment (Protection) Act, 1986, vide notification no. S.O. 3187(E) dt. 7th October 2016, defines the Ganga River. The definition of the "Ganga River", is one of the most holistic and comprehensive, as it includes all the tributaries of the Ganga River from headwaters to the Ganga Sagar. The NGC's holistic mandate addresses floodplain and basin governance, ecological flow, pollution abatement, and biodiversity conservation through inter-state and inter-sectoral coordination. However, the legal bindingness of this framework is partial and uneven. Since the Environment (Protection) Act, 1986, has no overriding power and it always remains subordinate to other laws, the definition of the Ganga River under this notification is administratively operative, it does not carry supreme legal force.

Institutionalise long-term standardized biomonitoring

This study provides temporal references and evidence for multi-taxa assemblages along the Ganga River. The individual chapters on various taxa in this report highlight the importance of continued monitoring following consistent and standardized methodologies. Periodic microsatellite and mitochondrial DNA sampling at fixed stations across the river system, integrated into broader biodiversity monitoring frameworks, would allow managers to detect early signs of genetic erosion, evaluate the effectiveness of connectivity restoration measures, and adjust stocking programmes in near real-time. Such a programme would also serve as an early warning system for cryptic population declines that would otherwise go undetected until they reach a critical threshold. A permanent Biodiversity Monitoring Unit, following the BEU approach on a periodic basis, needs to be institutionalized under NMCG, with data fed into adaptive management decisions

Restore habitat heterogeneity

The existing e-flow notification of the NMCG needs to be extended, monitored, and strictly implemented. Environmental flow standards ensuring minimum ecological flows and incorporating the natural flood pulse, throughout the year, need to be operationalized. The e-flow notification must move away from minimum baseflow and should incorporate the 'flood pulse' concept, simulating the natural hydrograph to maintain riverine ecosystem complexity and heterogeneity. The e-flow should be calibrated to biological response thresholds, determined by the EPT index recovery in the Upper zone, sandbar availability for aquatic species (nesting waterbirds, turtles, gharial) in the Middle zone, and CPUE throughout the three zones of the Ganga River. The e-flow notification may be reviewed and revised periodically (every five years), if needed, based on the recovery response of various taxa.

Protect sand bars and river islands

Sand bars and river islands provide key nesting and resting habitats for the aquatic species and thus are critical to life history strategies of those species. The sand bars and river islands are subjected to the anthropogenic - mining, agriculture, invasive species, and natural drivers - flooding. These drivers make the sand bars and river islands the most vulnerable habitats. The vegetation chapter provides evidence that the local plant communities (*Saccharum spontaneum*, *Phragmites karka*, *Cynodon dactylon*) provide structural nesting substrate. These are also early successional communities and are most vulnerable to invasion by *Prosopis juliflora*. No single regulatory instrument currently mandates the detection, monitoring, or removal of any of these species in the Ganga mainstem. Sand mining is listed as 'silent' in most national policies (Table 14.1), a critical driver of river degradation, indicating significant governance gaps in addressing geomorphological impacts on the river system. No seasonal moratorium exists for protecting the active nesting colonies. A seasonal moratorium on all sand mining operations within 1 km of confirmed island nesting colonies needs to be enforced during the nesting season.

Since river islands are dynamic, a real-time GPS-based river island registry needs to be maintained and updated annually following pre-monsoon surveys. This island registry should be circulated to the state departments and line agencies, so that they can consult the registry for issuing sand mining and agriculture permits. Though the central government's legislation and guidelines mandate regulation of sand mining activities, but there is a need for stricter compliance by the state governments, as the sand mining leases and activities are controlled by the state governments.

Protect the Conservation Priority Stretches

The Ganga River remains ecologically diverse and extraordinary, supporting 990 species as evident from the recent surveys (Figure 14.1). The identified CPS are interspersed along the PAs and also between the PAs. The biodiversity decline is steepest in the unprotected stretches of the River. The native vegetation remains restricted to isolated remnants near PA boundaries. CPS framework must be replace the current ad hoc conservation designation process. Given India's commitment to protect and restore 30% of its terrestrial and freshwater ecosystem, these CPS may be designated as OECMs. For enhancing the ecological resilience of the Ganga River, it is critical to protect the identified CPS. Further, actions such as imposition of binding limits on nitrogen application near BEU stretches classified as CPS II or CPS III need to be implemented. Expanding protection to ecologically critical but currently unprotected stretches - particularly riverine grasslands, island nesting habitats, and remnant floodplain swamps - is a high-priority conservation action. Restoration of longitudinal connectivity, through the installation of fish passes, ecologically sensitive flow regulation, and a moratorium on river-fragmentation and other anthropogenic stressors in ecologically critical reaches, should therefore be treated as a system-level priority rather than a species-specific one.

Urban planning and floodplain protection

Natural flow of the river, floodplain wetlands, and groundwater form important aspects of the freshwater conservation. Restoring native vegetation along the floodplain is essential to maintain the River's role in controlling runoff and improving water quality. Floodplain zoning regulation must demarcate a '1000 m ecological setback zone' within which no new construction without EIA, no expansion of agriculture into remnant native vegetation patches and mandatory native vegetation retention of ≥15% ground cover should be part of the Urban River Management Plan. Native species restoration through a planned and systematic approach, considering the floodplain dynamics and natural vegetation succession in floodplains, would restore habitat structure for both terrestrial and aquatic species and enhance soil stability simultaneously.

Pollution control

Pollution abatement has been a primary objective of the NMCG. Despite the installation of STPs, the study found performance and coverage gaps. Closing each category requires a different instrument: capacity gaps require continued execution, performance gaps require contractual and fiscal reform, and coverage gaps require new policy instruments. There is a need for stricter enforcement to fill the performance gaps, and new installations to fill the coverage gaps. For emerging contaminants, there is a need to notify ambient water quality criteria under the Environment (Protection) Act, 1986. EDCs and other hormonal contents in water are still out of the purview of the legal framework. Permissible thresholds should also be included in existing policies and laws.

Inter-sectoral coherence and coordination is must

Conservation-oriented legislation clearly prohibits most negative drivers. However, development-oriented legislation governing hydropower, inland navigation, sand mining, and industrial corridors predominantly permits or promotes negative drivers. The cross-sectoral policy analysis revealed that there is 'policy silence' on major negative drivers. For example, agriculture, responsible for nutrient load in the Ganga is addressed only indirectly through soil health and organic farming promotion schemes. These instruments contain no provisions restricting riparian buffer conversion, no binding limits on nitrogen application near river banks and sand bars. The lateral habitat loss is entirely unaddressed in current water governance policy. Similarly, microplastic pollution, documented in the tissues of Gangetic dolphin prey species (Sah et al., 2024a, b) and in water samples across the middle Ganga, has no dedicated regulatory instrument. The Solid Waste Management Rules 2016 and plastic ban notifications are not enforced as river-specific obligations. This rule also does not acknowledge the implications of plastic waste on biodiversity and ecosystem functions. Sand mining is identified to be most concentrated in HBZ-4 and HBZ-6, which are also the zones with the highest turtle abundance. It is also evident that sandbar availability directly controls the breeding success of Endangered island-nesting waterbirds and turtles. Sand mining as a driver is prohibited in only two of the 19 legislative frameworks of the MoEFCC. It is also interesting to note that while MoEFCC, has issued guidelines for regulating sand mining, the MoM provides the sand mining framework, whilst the state government has control over the activity. The NGC's mandate is to promote inter-sectoral coherence and coordination for the conservation of the Ganga River, but due to

14.6 PRIORITY FRAMEWORK AND CONCLUSION

It is evident that the Ganga River would need continuous interventions for the sustenance of the ecological integrity. Some interventions need immediate attention to allow ecological recovery of the River, whilst other intervention would take time to establish and show positive effects. Table 14.2 outlines these priority actions.

Table 14.2 Timelines, priority actions and measurable targets for ecological recovery of the Ganga River

Tier	Timeline	Priority Actions	Measurable Target
TIER 1 Immediate (0-2 years)	2026-2028	1. Achieve ≥90% functional capacity at all STPs along the mainstem Ganga and its priority tributaries, with real-time effluent quality monitoring.	STP compliance
		2. Independent third-party audits of all non-functional STPs.	≥90% of design capacity operational
		3. Enact and enforce vessel speed limits and navigation exclusion zones in the Conservation Priority stretches.	Dolphin vessel-strike incidents
		4. Identify the active gharial nesting sites and breeding waterbird colonies and impose a time-bound moratorium on sand extraction within 1 km of active nesting sites.	Sandbar moratorium: notified and gazetted
		5. Reinstate comprehensive biodiversity monitoring (2026 survey season) along with the monitoring of the hydrological parameters and anthropogenic stressors.	ER data from ≥50% of 2018 survey reaches
		6. Revise e-flow requirements to incorporate climate-adaptive provisions.	gazetted E-flow review
		7. Include atmospheric deposition parameters (heavy metals, PAHs, nitrogen compounds) in the CPCB Ganga water quality monitoring network. Commission source apportionment study for airborne pollutant contributions to river water and sediment quality.	Notified inclusion of the atmospheric deposition parameters in water quality monitoring
		8. Strengthen the existing rescue and rehabilitation facilities and establish new at critical locations.	Number of rescue centres functional and number of individuals rescued
TIER 2 Medium-term (2-5 years)	2028-2032	1. Develop BEU-level conservation action plans for all identified CPS, integrating riverine species, habitat quality, and stressor data.	BEU conservation plans:
		2. Establish legally protected sandbar reserves covering ≥80% of active nesting sites of turtles and waterbirds.	Number of notified Sandbar reserves: legal notification covering ≥80% of colonies
		3. Reinforce the natural farming across the Ganga grams, with nature based solutions in the 5 km riparian buffer.	Percentage of villages adopting natural farming
		4. Restore continuous riparian forest corridors of ≥500 m width along ≥30% of the main-stem Ganga, closing the gap between the 1,341 km² afforestation target and the 33 km² planted by 2025.	Riparian forest: ≥400 km² new cover
		5. Institutionalise the BEU monitoring framework as a statutory obligation under the Environment Protection Act, with legally mandated five-year reporting cycles.	Monitoring framework

The Ganga River remains ecologically extraordinary - supporting 747 plant taxa, 30 odonate species, 114 fish species, 32 herpetofauna (amphibians and reptiles), 65 avifaunal species and two semi-aquatic and aquatic mammalian species (Figure 14.1). However, all taxa are under simultaneous stress, and the convergence of flow regulation, habitat fragmentation, pollution, and biological invasions creates a compound threat that is greater than any single stressor alone. This study also demonstrates the vitality of continuous long-term biodiversity monitoring, as for most of the taxa, comparative patterns and trends could be presented, highlighting their conservation needs. Such trends help in the planning and management of aquatic species, and further demand for micro-level or riverscape-level planning of particular species. Our findings highlight that while some species continue to thrive in the Ganga River with or without hindrance, there are species or taxa that require special attention and more efforts to ensure their long-term persistence in the Ganga River. Several threatened species are excellent ecological indicators of environmental changes. Such proxies seek attention on the specific aspects or problems for management. Hence, each taxon plays an imperative role in shaping aquatic ecosystems and in balancing their integrity. An undisturbed healthy riverine ecosystem is resilient to any changes. But in the case of the Ganga River, which is subjected to severe anthropogenic use, no interventions will lead to its ecological demise. This study suggests that the efforts of NMCG in the past decade have made the Ganga River resilient, but this resilience is conditional on sustained and coordinated intervention.



Annexure I

Table 1: List of plant species recorded along the River Ganga

S.no	Plant Name (Botanical name)	Family	Order	Nativity
1	*Euryale ferox Salisb.*	Nymphaeaceae Salisb.	Nymphaeales	Native
2	*Nymphaea nouchali Burm.f.*	Nymphaeaceae Salisb.	Nymphaeales	Native
3	*Nymphaea pubescens* Willd.	Nymphaeaceae Salisb.	Nymphaeales	Native
4	*Nymphaea rubra* Roxb. ex Andrews	Nymphaeaceae Salisb.	Nymphaeales	Native
5	*Peperomia pellucida* Kunth	Piperaceae Giseke	Piperales	Exotic
6	*Houttuynia cordata* Thunb.	Saururaceae Martynov	Piperales	Native
7	*Machilus gamblei King* ex Hook.f.	Lauraceae Juss.	Laurales	Native
8	*Acorus calamus* L.	Acoraceae Martinov	Acorales	Native
9	*Hydrilla verticillata* (L.f.) Royle	Hydrocharitaceae Juss.	Alismatales	Native
10	*Hydrocharis dubia* (Blume) Backer	Hydrocharitaceae Juss.	Alismatales	Native
11	*Ottelia alismoides* (L.) Pers.	Hydrocharitaceae Juss.	Alismatales	Native
12	*Vallisneria natans* (Lour.) H. Hara	Hydrocharitaceae Juss.	Alismatales	Native
13	*Najas minor* All.	Hydrocharitaceae Juss.	Alismatales	Native
14	*Najas marina* L.	Hydrocharitaceae Juss.	Alismatales	Native
15	*Najas graminea* Delile	Hydrocharitaceae Juss.	Alismatales	Native
16	*Nechamandra alternifolia* (Roxb. ex Wight)	Hydrocharitaceae Juss.	Alismatales	Native
17	*Sagittaria guayanensis* subsp. *lappula* (D.Don) Bogin	Alismataceae Vent	Alismatales	Native
18	*Sagittaria montevidensis* Cham. & Schltdl.	Alismataceae Vent	Alismatales	Exotic
19	*Sagittaria trifolia* L.	Alismataceae Vent	Alismatales	Native
20	*Butomus umbellatus* L.	Butomaceae Mirb.	Alismatales	Native
21	*Potamogeton crispus* L.	Potamogetonaceae Rchb.	Alismatales	Native
22	*Colocasia esculenta* (L.)Schott.	Araceae Juss.	Alismatales	Native
23	*Alocasia fornicata* (Kunth) Schott	Araceae Juss.	Alismatales	Native
24	*Cryptocoryne ciliata* (Roxb.) Schott	Araceae Juss.	Alismatales	Native
25	*Pistia stratiotes* L.	Araceae Juss.	Alismatales	Native
26	*Lemna minor* L.	Araceae Juss.	Alismatales	Native
27	*Lemna perpusilla* Torr.	Araceae Juss.	Alismatales	Native
28	*Spirodela polyrhiza* (L.) Schleid.	Araceae Juss.	Alismatales	Native
29	*Zeuxine strateumatica* (L.) Schlechter	Orchidaceae Juss.	Asparagales	Native
30	*Crinum defixum* Ker Gawl.	Amaryllidaceae J.St.-Hil.	Asparagales	Native
31	*Dioscorea bulbifera* L.	Dioscoreaceae R.Br.	Dioscoreales	Native
32	*Pandanus odorifer* (Forssk.) Kuntze	Pandanaceae R.Br.,	Pandanales	Native
33	*Calamus tenuis* Roxb.	Arecaceae Bercht. & J.Presl	Arecales	Native
34	*Nypa fruticans* Wurmb	Arecaceae Bercht. & J.Presl	Arecales	Native
35	*Borassus flabellifer* L.	Arecaceae Bercht. & J.Presl	Arecales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Pricky water lily	Herb	-	A	RF	LC
Blue water lily	Herb	-	A	RF	LC
Hairy water lily	Herb	-	A	RF	LC
Red water Lily	Herb	-	A	RF	LC
Slate pencil plant	Herb	-	Moist loving	-	-
Fish mint	Herb	-	Moist loving	-	-
Som	Tree	-	SA	Riparian	LC
Sweet Flag	Herb	-	SA	Marshy	-
Wterhymes	Herb	-	A	SUB	LC
Asian frogbit	Herb	-	A	RF	LC
Duck lettuce	Herb	-	A	SUB	LC
Jallil	Herb	-	A	SUB	LC
Jhangi	Herb	-	A	SUB	LC
Spiny water nymph	Herb	-	A	SUB	-
Rice-field water-nymph	Herb	-	A	SUB	LC
Indian Oxygen-Weed	Herb	-	A	SUB	-
Burr Arrowhead	Herb	-	A	RF	LC
Aztec Arrowhead	Herb	-	A	EM	-
Threeleaf arrowhead	Herb	-	A	EM	LC
Flowering rush	Herb	-	SA	Marshy	LC
Crisp leaved pondweed	Herb	-	A	SUB	LC
Indian taro	Herb	-	SA	Marshy	LC
Baibing	Herb	-	SA	Marshy	LC
Water trumpet	Herb	-	A	EM	LC
Water lettuce	Herb	-	A	FF	LC
Common Duckweed	Herb	-	A	FF	LC
Duckweed	Herb	-	A	FF	LC
Gaint Duckweed	Herb	-	A	FF	LC
Lawn orchid	Herb	-	Moist loving	-	LC
River Crinum Lily	Herb	-	A	EM	-
Air yam	Herb	-	T	-	
Kewda	Shrub	-	SA	Riparian	LC
Slender rattan cane	Climbing Shrub	-	SA	Riparian	LC
-	Tree	-	A	EM	LC
Asian palmyra palm	Tree	-	T		LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
36	*Phoenix sylvestris* (L.) Roxb.	Arecaceae Bercht. & J.Presl	Arecales	Native
37	*Actinoscirpus grossus* (L.f.) Goetgh. & D.A.Simpson	Cyperaceae Juss.	Poales	Native
38	*Bolboschoenus maritimus* (L.) Palla	Cyperaceae Juss.	Poales	Native
39	*Bolboschoenus glaucus* (Lam.) S.G.Sm.	Cyperaceae Juss.	Poales	Native
40	*Carex fedia* Nees	Cyperaceae Juss.	Poales	Native
41	*Bulbostylis barbata* (Rottb.) C.B.Clarke	Cyperaceae Juss.	Poales	Native
42	*Cyperus alulatus* J.Kern	Cyperaceae Juss.	Poales	Native
43	*Cyperus alternifolius* L.	Cyperaceae Juss.	Poales	Exotic
44	*Cyperus compressus* L.	Cyperaceae Juss.	Poales	Native
45	*Cyperus cyperoides* (L.) Kuntze	Cyperaceae Juss.	Poales	Native
46	*Cyperus rotundus* L.	Cyperaceae Juss.	Poales	Native
47	*Cyperus distans* L.f.	Cyperaceae Juss.	Poales	Native
48	*Cyperus difformis* L.	Cyperaceae Juss.	Poales	Native
49	*Cyperus exaltatus* Retz.	Cyperaceae Juss.	Poales	Native
50	*Cyperus imbricatus* Retz.	Cyperaceae Juss.	Poales	Native
51	*Cyperus iria* L.	Cyperaceae Juss.	Poales	Native
52	*Cyperus michelianus* subsp. *pygmaeus* (Rottb.) Asch. & Graebn.	Cyperaceae Juss.	Poales	Native
53	*Cyperus polystachyos* Rottb.	Cyperaceae Juss.	Poales	Native
54	*Cyperus pangorei* Rottb.	Cyperaceae Juss.	Poales	Native
55	*Cyperus niveus* Retz	Cyperaceae Juss.	Poales	Native
56	*Cyperus mindorensis* (Steud.) Huygh	Cyperaceae Juss.	Poales	Native
57	*Cyperus brevifolius* (Rottb.) Hassk.	Cyperaceae Juss.	Poales	Native
58	*Cyperus tenuifolius* (Steud.) Dandy	Cyperaceae Juss.	Poales	Native
59	*Cyperus squarrosus* L.	Cyperaceae Juss.	Poales	Native
60	*Cyperus pilosus* Vahl	Cyperaceae Juss.	Poales	Native
61	*Cyperus pumilus* L.	Cyperaceae Juss.	Poales	Native
62	*Cyperus flavidus* Retz.	Cyperaceae Juss.	Poales	Native
63	*Cyperus tenuispica* Steud.	Cyperaceae Juss.	Poales	Native
64	*Cyperus sanguinolentus* Vahl	Cyperaceae Juss.	Poales	Native
65	*Fimbristylis dichotoma* (L.) Vahl	Cyperaceae Juss.	Poales	Native
66	*Fimbristylis ovata* (Burm.f.) J.Kern	Cyperaceae Juss.	Poales	Native
67	*Fimbristylis schoenoides* (Retz.) Vahl	Cyperaceae Juss.	Poales	Native
68	*Fimbristylis dipsacea* (Rottb.) C.B.Clarke	Cyperaceae Juss.	Poales	Native
69	*Fimbristylis miliacea* (L.) Vahl	Cyperaceae Juss.	Poales	Native
70	*Eleocharis geniculata* (L.) Roem. & Schult.	Cyperaceae Juss.	Poales	Native
71	*Eriophorum comosum* (Wall.) Nees	Cyperaceae Juss.	Poales	Native
72	*Eleocharis palustris* (L.) Roem. & Schult.	Cyperaceae Juss.	Poales	Native
73	*Eleocharis dulcis* (Burm.f.) Trin. ex Hensch.	Cyperaceae Juss.	Poales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Indian date palm	Tree	-	SA	Riparian	-
Greater club rush	Graminoid	Sedge	A	EM	LC
Bayonet grass	Graminoid	Sedge	SA	Marshy	LC
Glaucous tuber-bulrush	Graminoid	Sedge	SA	Marshy	LC
Valerian Sedge	Graminoid	Sedge	SA	Marshy	-
Bearded Watergrass	Graminoid	Sedge	SA	Marshy	-
Winged Sedge	Graminoid	Sedge	SA	Marshy	LC
Umbrella palm	Graminoid	Sedge	SA	Marshy	LC
Poorland Flat Sedge	Graminoid	Sedge	SA	Marshy	LC
Common Flat Sedge	Graminoid	Sedge	SA	Marshy	LC
Nut grass	Graminoid	Sedge	SA	Marshy	LC
Slender cyperus	Graminoid	Sedge	SA	Marshy	LC
Variable flatsedge	Graminoid	Sedge	SA	Marshy	LC
Tall Flat Sedge	Graminoid	Sedge	SA	Marshy	LC
Shingle flatsedge	Graminoid	Sedge	SA	Marshy	LC
Rice flat sedge	Graminoid	Sedge	SA	Marshy	LC
Pygmy Sedge	Graminoid	Sedge	SA	Marshy	LC
Bunchy sedge	Graminoid	Sedge	SA	Marshy	LC
Mat Sedge	Graminoid	Sedge	SA	Marshy	LC
Snow White Sedge	Graminoid	Sedge	SA	Marshy	-
White Water Sedge	Graminoid	Sedge	SA	Marshy	LC
Green Water Sedge	Graminoid	Sedge	SA	Marshy	LC
Thinleaf Flatsedge	Graminoid	Sedge	SA	Marshy	-
Bearded Flatsedge	Graminoid	Sedge	SA	Marshy	LC
	Graminoid	Sedge	SA	Marshy	LC
Dwarf Sedge	Graminoid	Sedge	SA	Marshy	LC
Yellow Flatsedge	Graminoid	Sedge	SA	Marshy	LC
	Graminoid	Sedge	SA	Marshy	LC
Purple-glume flat sedge	Graminoid	Sedge	SA	Marshy	LC
Eight day grass	Graminoid	Sedge	SA	Marshy	LC
One-Spike Fimbry	Graminoid	Sedge	SA	Marshy	LC
Ditch fimbry	Graminoid	Sedge	SA	Marshy	LC
Harper's Fimbristylis	Graminoid	Sedge	SA	Marshy	LC
Lesser fimbristylis	Graminoid	Sedge	SA	Marshy	-
Knoblike Spikesedge	Graminoid	Sedge	SA	Marshy	LC
Hairy Cottongrass	Graminoid	Sedge	Moist loving	Lithophytic	-
Common spike rush	Graminoid	Sedge	SA	Marshy	LC
Water chestnut	Graminoid	Sedge	A	EM	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
74	*Scleria lithosperma* (L.) Sw.	Cyperaceae Juss.	Poales	Native
75	*Schoenoplectiella articulata* (L.) Lye	Cyperaceae Juss.	Poales	Native
76	*Schoenoplectiella mucronata* (L.) J.Jung & H.K.Choi	Cyperaceae Juss.	Poales	Native
77	*Schoenoplectiella juncoides* (Roxb.) Lye	Cyperaceae Juss.	Poales	Native
78	*Schoenoplectiella supina* (L.) Lye	Cyperaceae Juss.	Poales	Native
79	*Juncus bufonius* L.	Juncaceae Juss.	Poales	Native
80	*Juncus prismatocarpus* R.Br.	Juncaceae Juss.	Poales	Native
81	*Alopecurus aequalis* Sobol.	Poaceae Barnhart	Poales	Native
82	*Alloteropsis cimicina* (L.) Stapf	Poaceae Barnhart	Poales	Native
83	*Apluda mutica* L.	Poaceae Barnhart	Poales	Native
84	*Arundo donax* L.	Poaceae Barnhart	Poales	Native
85	*Arundinella pumila* (Hochst. ex A.Rich.) Steud.	Poaceae Barnhart	Poales	Native
86	*Arundinella bengalensis* (Spreng.) Druce	Poaceae Barnhart	Poales	Native
87	*Axonopus compressus* (Sw.) P.Beauv.	Poaceae Barnhart	Poales	Exotic
88	*Bambusa bambos* (L.) Voss	Poaceae Barnhart	Poales	Native
89	*Cenchrus pedicellatus* (Trin.) Morrone	Poaceae Barnhart	Poales	Native
90	*Cenchrus setigerus* Vahl	Poaceae Barnhart	Poales	Native
91	*Cenchrus ciliaris* L.	Poaceae Barnhart	Poales	Native
92	*Cenchrus echinatus* L.	Poaceae Barnhart	Poales	Native
93	*Chloris barbata* Sw.	Poaceae Barnhart	Poales	Native
94	*Chloris virgata* Sw.	Poaceae Barnhart	Poales	Native
95	*Coix lacryma-jobi* L.	Poaceae Barnhart	Poales	Native
96	*Chrysopogon aciculatus* (Retz.) Trin.	Poaceae Barnhart	Poales	Native
97	*Chrysopogon fulvus* (Spreng.) Chiov.	Poaceae Barnhart	Poales	Native
98	*Chrysopogon zizanioides* (L.) Roberty	Poaceae Barnhart	Poales	Native
99	*Cynodon dactylon* (L.) Pers.	Poaceae Barnhart	Poales	Native
100	*Cyrtococcum patens* (L.) A. Camus	Poaceae Barnhart	Poales	Native
101	*Dendrocalamus strictus* (Roxb.) Nees	Poaceae Barnhart	Poales	Native
102	*Dactyloctenium aegyptium* (L.) Willd.	Poaceae Barnhart	Poales	Native
103	*Dactyloctenium aristatum* Link	Poaceae Barnhart	Poales	Native
104	*Desmostachya bipinnata* (L.) Stapf	Poaceae Barnhart	Poales	Native
105	*Dichanthium annulatum* (Forssk.) Stapf	Poaceae Barnhart	Poales	Native
106	*Dichanthium foveolatum* (Delile) Roberty	Poaceae Barnhart	Poales	Native
107	*Digitaria stricta* Roth	Poaceae Barnhart	Poales	Native
108	*Digitaria ciliaris* (Retz.) Koeler	Poaceae Barnhart	Poales	Native
109	*Echinochloa colona* (L.) Link	Poaceae Barnhart	Poales	Native
110	*Echinochloa crus-galli* (L.) P.Beauv.	Poaceae Barnhart	Poales	Native
111	*Echinochloa frumentacea* Link	Poaceae Barnhart	Poales	Native
112	*Eragrostis atrovirens* (Desf.) Trin. ex Steud.	Poaceae Barnhart	Poales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Slender Nut-Rush	Graminoid	Sedge	SA	Marshy	LC
Jointed Sedge	Graminoid	Sedge	A	EM	LC
Bog Bulrush	Graminoid	Sedge	A	EM	LC
South-Asian Club-Rush	Graminoid	Sedge	SA	Marshy	-
Prostrate Club-Rush	Graminoid	Sedge	SA	Marshy	LC
Toad rush	Graminoid	Rush	SA	Marshy	LC
Branching rush	Graminoid	Rush	SA	Marshy	LC
Orange foxtail	Graminoid	Grass	SA	Marshy	LC
Summer Grass	Graminoid	Grass	Moist loving		-
Mauritian grass	Graminoid	Grass	SA	Marshy	-
Narkat	Graminoid	Grass	SA	Marshy	LC
Dwarf Reedgrass	Graminoid	Grass	SA	Marshy	-
	Graminoid	Grass	Moist loving	-	-
Broadleaf carpetgrass	Graminoid	Grass	Moist loving	-	LC
Giant thorny bamboo	Graminoid	Grass	Moist loving	-	-
Deenanath Grass	Graminoid	Grass	Moist loving	-	LC
Birdwood Grass	Graminoid	Grass	Moist loving	-	-
Buffel grass	Graminoid	Grass	Moist loving	-	LC
Indian sand bur	Graminoid	Grass	Moist loving	-	-
Swollen fingergrass	Graminoid	Grass	Moist loving	-	-
Feather Finger Grass	Graminoid	Grass	Moist loving	-	-
Job's Tears	Graminoid	Grass	SA	Marshy	-
Golden Beardgrass	Graminoid	Grass	Moist loving	-	-
Reddish-yellow beardgrass	Graminoid	Grass	Moist loving	-	-
Vetiver grass	Graminoid	Grass	SA	Marshy	-
Scutch grass	Graminoid	Grass	Moist loving	-	-
Bowgrass	Graminoid	Grass	Moist loving	-	-
Calcutta bamboo	Graminoid	Grass	Moist loving	-	-
Aegyptium crowfoot	Graminoid	Grass	Moist loving	-	-
Najm	Graminoid	Grass	Moist loving	-	-
Dharbha, Kush	Graminoid	Grass	Moist loving	-	LC
Sheda Grass	Graminoid	Grass	Moist loving	-	-
Bluegrass	Graminoid	Grass	Moist loving	-	-
Crab grass	Graminoid	Grass	Moist loving	-	-
-	Graminoid	Grass	Moist loving	-	-
Jungle rice	Graminoid	Grass	SA	Marshy	-
Barnyard Grass	Graminoid	Grass	SA	Marshy	-
Indian barnyard millet	Graminoid	Grass	SA	Marshy	-
Thalia Lovegrass	Graminoid	Grass	Moist loving	-	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
113	*Eragrostis tenella* (L.) P.Beauv. ex Roem. & Schult.	Poaceae Barnhart	Poales	Native
114	*Eragrostis unioloides* (Retz.) Nees ex Steud.	Poaceae Barnhart	Poales	Native
115	*Eragrostis ciliaris* (L.) R.Br.	Poaceae Barnhart	Poales	Native
116	*Eragrostis nutans* (Retz.) Nees ex Steud.	Poaceae Barnhart	Poales	Native
117	*Eragrostis pilosa* (L.) P.Beauv.	Poaceae Barnhart	Poales	Native
118	*Eragrostis tremula* Hochst. ex Steud.	Poaceae Barnhart	Poales	Native
119	*Eragrostis minor* Host	Poaceae Barnhart	Poales	Native
120	*Eragrostis coarctata* Stapf	Poaceae Barnhart	Poales	Native
121	*Eleusine indica* (L.) Gaertn.	Poaceae Barnhart	Poales	Native
122	*Eriochloa procera* (Retz.) C.E.Hubb.	Poaceae Barnhart	Poales	Native
123	*Enteropogon dolichostachyus* (Lag.) Keng	Poaceae Barnhart	Poales	Native
124	*Ischaemum rugosum* L.	Poaceae Barnhart	Poales	Native
125	Ischaemum ciliare Retz.	Poaceae Barnhart	Poales	Native
126	*Isachne globosa* (Thunb.) Kuntze	Poaceae Barnhart	Poales	Native
127	*Iseilema laxum* Hack.	Poaceae Barnhart	Poales	Native
128	*Hemarthria compressa* (L.f.) R.Br.	Poaceae Barnhart	Poales	Native
129	*Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult.	Poaceae Barnhart	Poales	Native
130	*Hygroryza aristata* (Retz.) Nees ex Wight & Arn.	Poaceae Barnhart	Poales	Native
131	*Imperata cylindrica* (L.) Raeusch.	Poaceae Barnhart	Poales	Native
132	*Leptochloa panicea* (Retz.) Ohwi	Poaceae Barnhart	Poales	Native
133	*Leptochloa chinensis* (L.) Nees	Poaceae Barnhart	Poales	Native
134	*Leersia hexandra* Sw.	Poaceae Barnhart	Poales	Native
135	*Neyraudia arundinacea* (L.) Henrard	Poaceae Barnhart	Poales	Native
136	*Oplismenus compositus* (L.) P.Beauv.	Poaceae Barnhart	Poales	Native
137	*Oplismenus burmanni* (Retz.) P.Beauv.	Poaceae Barnhart	Poales	Native
138	*Oryza rufipogon* Griff.	Poaceae Barnhart	Poales	Native
139	*Panicum paludosum* Roxb.	Poaceae Barnhart	Poales	Native
140	*Panicum repens* L.	Poaceae Barnhart	Poales	Native
141	*Dichanthelium acuminatum* (Sw.) Gould & C.A. Clark	Poaceae Barnhart	Poales	Exotic
142	*Paspalum scrobiculatum* L.	Poaceae Barnhart	Poales	Native
143	*Paspalum dilatatum* Poir.	Poaceae Barnhart	Poales	Exotic
144	*Paspalum distichum* L.	Poaceae Barnhart	Poales	Exotic
145	*Paspalidium flavidum* (Retz.) A.Camus	Poaceae Barnhart	Poales	Native
146	*Pennisetum orientale* Rich.	Poaceae Barnhart	Poales	Native
147	*Perotis indica* (L.) Kuntze	Poaceae Barnhart	Poales	Native
148	*Phalaris minor* Retz.	Poaceae Barnhart	Poales	Native
149	*Poa annua* L.	Poaceae Barnhart	Poales	Native
150	*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae Barnhart	Poales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Japanese lovegrass	Graminoid	Grass	Moist loving	-	-
Chinese Lovegrass	Graminoid	Grass	Moist loving	-	LC
Gophertail Lovegrass	Graminoid	Grass	Moist loving	-	-
-	Graminoid	Grass	Moist loving	-	-
Soft lovegrass	Graminoid	Grass	Moist loving	-	-
Weeping lovegrass	Graminoid	Grass	Moist loving	-	-
-	Graminoid	Grass	Moist loving	-	-
-	Graminoid	Grass	Moist loving	-	LC
Indian goosegrass	Graminoid	Grass	Moist loving	-	LC
Tropical Cupgrass	Graminoid	Grass	SA	Marshy	LC
Long-Spike Finger Grass	Graminoid	Grass	Moist loving	-	-
Saramolla grass	Graminoid	Grass	SA	Marshy	-
Indian Muraina Grass	Graminoid	Grass	Moist loving		-
Bloodgrass	Graminoid	Grass	SA	Marshy	LC
Musal Grass	Graminoid	Grass	Moist loving		-
Whip Grass	Graminoid	Grass	SA	Marshy	LC
Black speargrass	Graminoid	Grass	Moist loving	-	-
Bengal wild rice	Graminoid	Grass	A	FF	-
Cogon grass	Graminoid	Grass	SA	Marshy	LC
Thread Sprangletop	Graminoid	Grass	Moist loving	-	LC
Red sprangletop	Graminoid	Grass	Moist loving	-	-
Swamp rice grass	Graminoid	Grass	SA	Marshy	LC
Bichla Grass	Graminoid	Grass	Moist loving	-	LC
Running mountain grass	Graminoid	Grass	Moist loving	-	LC
Wavy-Leaf Basketgrass	Graminoid	Grass	Moist loving	-	-
Wild rice	Graminoid	Grass	SA	Marshy	LC
-	Graminoid	Grass	SA	Marshy	-
Creeping panic	Graminoid	Grass	SA	Marshy	LC
Tapered rosette grass, Woolly Panic Grass	Graminoid	Grass	Moist loving		-
Kodo millet	Graminoid	Grass	SA	Marshy	-
Dallas grass	Graminoid	Grass	SA	Marshy	-
Water finger-grass	Graminoid	Grass	SA	Marshy	-
Yellow Watercrown Grass	Graminoid	Grass	SA	Marshy	LC
Oriental Fountain Grass	Graminoid	Grass	Moist loving	-	LC
Indian comet grass	Graminoid	Grass	Moist loving	-	-
Small-seeded canary grass	Graminoid	Grass	Moist loving	-	-
Annual Bluegrass	Graminoid	Grass	Moist loving	-	LC
Tall Reed	Graminoid	Grass	SA	Marshy	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
151	*Polypogon monspeliensis* (L.) Desf.	Poaceae Barnhart	Poales	Native
152	*Rottboellia cochinchinensis* (Lour.) Clayton	Poaceae Barnhart	Poales	Native
153	*Saccharum narenga* (Nees ex Steud.) Hack.	Poaceae Barnhart	Poales	Native
154	*Saccharum spontaneum* L.	Poaceae Barnhart	Poales	Native
155	*Saccharum bengalense* Retz.	Poaceae Barnhart	Poales	Native
156	*Saccharum ravennae* (L.) L.	Poaceae Barnhart	Poales	Native
157	*Setaria glauca* (L.) P.Beauv.	Poaceae Barnhart	Poales	Native
158	*Setaria pumila* (Poir.) Roem. & Schult.	Poaceae Barnhart	Poales	Native
159	*Setaria palmifolia* (J.Koenig) Stapf	Poaceae Barnhart	Poales	Native
160	*Setaria intermedia* Roem. & Schult.	Poaceae Barnhart	Poales	Native
161	*Setaria verticillata* (L.) P.Beauv.	Poaceae Barnhart	Poales	Native
162	*Sacciolepis indica* (L.) Chase	Poaceae Barnhart	Poales	Native
163	*Sporobolus virginicus* (L.) Kunth	Poaceae Barnhart	Poales	Native
164	*Sporobolus diandrus* (Retz.) P.Beauv.	Poaceae Barnhart	Poales	Native
165	*Urochloa ramosa* (L.) T.Q.Nguyen	Poaceae Barnhart	Poales	Native
166	*Urochloa distachyos* (L.) T.Q.Nguyen	Poaceae Barnhart	Poales	Native
167	*Urochloa mutica* (Forssk.) T.Q.Nguyen	Poaceae Barnhart	Poales	Exotic
168	*Urochloa reptans* (L.) Stapf	Poaceae Barnhart	Poales	Native
169	*Themeda arundinacea* (Roxb.) A.Camus	Poaceae Barnhart	Poales	Native
170	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda	Poaceae Barnhart	Poales	Native
171	*Eriocaulon cinereum* R.Br.	Eriocaulaceae Martinov	Poales	Native
172	*Eriocaulon quinquangulare* L.	Eriocaulaceae Martinov	Poales	Native
173	*Typha angustifolia* L.	Typhaceae Juss.	Poales	Native
174	*Typha elephantina* Roxb.	Typhaceae Juss.	Poales	Native
175	*Pontederia crassipes* Mart.	Pontederiaceae Kunth	Commelinales	Exotic
176	*Pontederia hastata* L.	Pontederiaceae Kunth	Commelinales	Native
177	*Pontederia vaginalis* Burm.f.	Pontederiaceae Kunth	Commelinales	Native
178	*Commelina benghalensis* L.	Commelinaceae Mirb.	Commelinales	Native
179	*Commelina diffusa* Burm.f.	Commelinaceae Mirb.	Commelinales	Native
180	*Commelina erecta* L.	Commelinaceae Mirb.	Commelinales	Native
181	*Cyanotis cristata* (L.) D.Don	Commelinaceae Mirb.	Commelinales	Native
182	*Cyanotis axillaris* (L.) D.Don ex Sweet	Commelinaceae Mirb.	Commelinales	Native
183	*Murdannia nudiflora* (L.) Brenan	Commelinaceae Mirb.	Commelinales	Native
184	*Murdannia spirata* (L.) G.Brückn. Subsp. Spirata.	Commelinaceae Mirb.	Commelinales	Native
185	*Floscopa scandens* Lour.	Commelinaceae Mirb.	Commelinales	Native
186	*Ceratophyllum demersum* L.	Ceratophyllaceae Gray	Ceratophyllales	Native
187	*Grevillea robusta* A.Cunn. ex R.Br.	Proteaceae Juss.	Proteales	Exotic
188	*Berberis asiatica* Roxb. ex DC.	Berberidaceae Juss.	Ranunculales	Native
189	*Berberis lycium* Royle	Berberidaceae Juss.	Ranunculales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Annual beard-grass	Graminoid	Grass	SA	Marshy	LC
Corngrass	Graminoid	Grass	Moist loving	-	-
-	Graminoid	Grass	SA	Marshy	-
Wild sugarcane	Graminoid	Grass	SA	Marshy	LC
Munj Sweetcane, Sarkanda	Graminoid	Grass	SA	Marshy	-
Ekra	Graminoid	Grass	SA	Marshy	LC
-	Graminoid	Grass	Moist loving	-	-
Yellow foxtail	Graminoid	Grass	Moist loving	-	-
Palm Grass	Graminoid	Grass	Moist loving	-	-
Chiktu	Graminoid	Grass	Moist loving	-	-
Bristly Foxtail	Graminoid	Grass	Moist loving	-	-
Glenwoodgrass	Graminoid	Grass	Moist loving	-	LC
Seashore dropseed	Graminoid	Grass	Moist loving	-	-
-	Graminoid	Grass	Moist loving	-	-
Browntop Millet	Graminoid	Grass	Moist loving	-	LC
Creeping signal grass	Graminoid	Grass	Moist loving	-	LC
Buffalo grass	Graminoid	Grass	SA	Marshy	LC
Creeping Signal Grass	Graminoid	Grass	Moist loving		LC
Hathi ghas	Graminoid	Grass	SA	Marshy	-
Asian broom grass	Graminoid	Grass	Moist loving		-
Pipewort	Graminoid	Pipewort	SA	Marshy	LC
Five-Angled Pipewort	Graminoid	Pipewort	SA	Marshy	-
Narrow leaf cattail	Graminoid	Cattail	SA	Marshy	LC
Elephant grass	Graminoid	Cattail	SA	Marshy	LC
Common water hyacinth	Herb	-	A	FF	LC
Heart shaped false pickerelweed	Herb	-	A	EM	LC
Oval leaf pondweed	Herb	-	A	EM	LC
Bengal dayflower	Herb	-	Moist loving	-	-
Climbing dayflower	Herb	-	Moist loving	-	LC
White-Mouth Dayflower	Herb	-	Moist loving	-	LC
Crested Dew-Grass	Herb	-	Moist loving	-	LC
Kana	Herb	-	Moist loving	-	LC
Dove weed	Herb	-	Moist loving	-	-
Asiatic Dewflower	Herb	-	Moist loving	-	-
Climbing Flower Cup	Herb	-	SA	Marshy	
Coontail	Herb	-	A	SUB	LC
Southern silky oak	Tree	-	T	-	LC
Asian Barberry	Shrub	-	T	-	-
Indian Lycium	Shrub	-	T	-	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
190	*Clematis gouriana* Roxb. ex DC.	Ranunculaceae Juss.	Ranunculales	Native
191	*Ranunculus aquatilis* L.	Ranunculaceae Juss.	Ranunculales	Native
192	*Ranunculus sceleratus* L.	Ranunculaceae Juss.	Ranunculales	Native
193	Ranunculus muricatus L.	Ranunculaceae Juss.	Ranunculales	Native
194	*Argemone mexicana* L.	Papaveraceae Juss.	Ranunculales	Exotic
195	*Cissampelos pareria* L.	Menispermaceae Juss.	Ranunculales	Native
196	*Stephania japonica* (Thunb.) Miers	Menispermaceae Juss.	Ranunculales	Native
197	*Tiliacora acuminata* (Lam.) Hook.f. & Thomson	Menispermaceae Juss.	Ranunculales	Native
198	*Tinospora cordifolia* (Thunb.) Miers	Menispermaceae Juss.	Ranunculales	Native
199	*Cocculus hirsutus* (L.) W.Theob.	Menispermaceae Juss.	Ranunculales	Native
200	*Nelumbo nucifera* Gaertn.	Nelumbonaceae A.Rich	Proteales	Native
201	*Cayratia trifolia* (L.) Domin	Vitaceae Juss.	Vitales	Native
202	*Tribulus terrestris* L.	Zygophyllaceae R.Br.	Zygophyllales	Native
203	Celastrus paniculatus Willd.	Celastraceae R.Br.	Celastrales	Native
204	*Oxalis corniculata* L.	Oxalidaceae R.Br.	Oxalidales	Native
205	*Oxalis debilis* Kunth	Oxalidaceae R.Br.	Oxalidales	Exotic
206	*Acalypha indica* L.	Euphorbiaceae Juss.	Malpighiales	Native
207	*Croton bonplandianus* Baill.	Euphorbiaceae Juss.	Malpighiales	Exotic
208	*Chrozophora plicata* (Vahl) A.Juss. ex Spreng.	Euphorbiaceae Juss.	Malpighiales	Native
209	*Chrozophora rottleri* (Geiseler) Spreng.	Euphorbiaceae Juss.	Malpighiales	Native
210	*Euphorbia hirta* L.	Euphorbiaceae Juss.	Malpighiales	Exotic
211	*Euphorbia heterophylla* L.	Euphorbiaceae Juss.	Malpighiales	Exotic
212	*Euphorbia helioscopia* L.	Euphorbiaceae Juss.	Malpighiales	Native
213	Euphorbia dracunculoides Lam.	Euphorbiaceae Juss.	Malpighiales	Native
214	*Euphorbia hypericifolia* L.	Euphorbiaceae Juss.	Malpighiales	Exotic
215	*Euphorbia serpens* Kunth	Euphorbiaceae Juss.	Malpighiales	Exotic
216	*Euphorbia prostrata* Aiton	Euphorbiaceae Juss.	Malpighiales	Exotic
217	*Euphorbia thymifolia* L.	Euphorbiaceae Juss.	Malpighiales	Exotic
218	*Euphorbia indica* Lam.	Euphorbiaceae Juss.	Malpighiales	Native
219	*Mallotus nudiflorus* (L.) Kulju & Welzen	Euphorbiaceae Juss.	Malpighiales	Native
220	*Ricinus communis* L.	Euphorbiaceae Juss.	Malpighiales	Exotic
221	*Sapium insigne* (Royle) Trimen	Euphorbiaceae Juss.	Malpighiales	Native
222	*Sapium sebiferum* (L.) Dum.Cours.	Euphorbiaceae Juss.	Malpighiales	Exotic
223	*Tragia hispida* Willd.	Euphorbiaceae Juss.	Malpighiales	Native
224	*Jatropha gossypiifolia* L.	Euphorbiaceae Juss.	Malpighiales	Exotic
225	*Jatropha curcas* L.	Euphorbiaceae Juss.	Malpighiales	Exotic
226	*Phyllanthus emblica* L.	Phyllanthaceae Martynov	Malpighiales	Native
227	*Phyllanthus niruri* L.	Phyllanthaceae Martynov	Malpighiales	Native
228	*Phyllanthus reticulata* Poir.	Phyllanthaceae Martynov	Malpighiales	Native
229	*Phyllanthus urinaria* L.	Phyllanthaceae Martynov	Malpighiales	Native
230	*Phyllanthus virgatus* G.Forst.	Phyllanthaceae Martynov	Malpighiales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Indian travellers joy	Herb	-	T	-	-
White water crowfoot	Herb	-	A	SUB	LC
Celery-leaved buttercup	Herb	-	SA	Marshy	LC
Rough-fruit buttercup	Herb	-	SA	Marshy	-
Mexican prickly poppy	Herb	-	Moist loving	-	-
Velvet leaf pareira	Climber	-	Moist loving	-	-
Snake vine	Climber	-	Moist loving	-	-
Tapering leaf tiliacora	Climbing Shrub	-	Moist loving	-	-
Amrita	Climber	-	T	-	-
Broom Creeper	Climber	-	T	-	-
Lotus Sweetjuice	Herb	-	A	RF	DD
Bush grape	Climber	-	Moist loving	-	-
Gokharu	Herb	-	Moist loving	-	LC
Black oil plant, Jyotishmati	Shrub	-	T	-	-
Creeping woosorrel	Herb	-	Moist loving	-	-
Large-flowered pink-sorrel	Herb	-	Moist loving	-	-
India copperleaf	Herb	-	Moist loving	-	-
Ban tulsi	Herb	-	Moist loving	-	-
Betha	Herb	-	Moist loving	-	-
Rottler's Chrozophora	Herb	-	Moist loving	-	-
Asthma plant	Herb	-	Moist loving	-	-
Mexican fireplant	Herb	-	Moist loving	-	LC
Sun spurge	Herb	-	Moist loving	-	-
Dragon Spurge	Herb	-	Moist loving	-	-
Golden spurge	Herb	-	Moist loving	-	-
Matted sandmat	Herb	-	Moist loving	-	-
Prostrate spurge	Herb	-	Moist loving	-	-
Red Caustic-creeper	Herb	-	Moist loving	-	-
Gulabi Dudhi	Herb	-	Moist loving	-	-
False white teak	Tree	-	SA	Riparian	LC
Caster bean plant	Shrub	-	Moist loving	-	-
Tiger's Milk Spruce	Tree	-	SA	Riparian	-
Chinese tallow	Tree	-	T	-	-
Bristly Climbing Nettle	Climber	-	Moist loving	-	-
Bellyache bush	Shrub	-	Moist loving	-	-
Physic Nut, Jatropha	Shrub	-	Moist loving	-	LC
Amla	Tree	-	T	-	LC
Gale of wind	Herb	-	Moist loving	-	-
Black honey shrub	Shrub	-	Moist loving	-	-
Stome breaker phyllanthus	Herb	-	Moist loving	-	-
Seed under leaf phyllanthus	Herb	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
231	*Phyllanthus maderaspatensis* L.	Phyllanthaceae Martynov	Malpighiales	Native
232	*Breynia vitis-idaea* (Burm.f.) C.E.C.Fisch.	Phyllanthaceae Martynov	Malpighiales	Native
233	*Putranjiva roxburghii* Wall.	Putranjivaceae Meisn.	Malpighiales	Native
234	*Passiflora foetida* L.	Passifloraceae Juss. ex Roussel	Malpighiales	Exotic
235	*Casearia tomentosa* Roxb.	Salicaceae Mirb.	Malpighiales	Native
236	*Populus deltoides* W.Bartram ex Marshall	Salicaceae Mirb.	Malpighiales	Exotic
237	*Salix tetrasperma* Roxb.	Salicaceae Mirb.	Malpighiales	Native
238	*Hybanthus enneaspermus* (L.) F.Muell.	Violaceae Batsch	Malpighiales	Native
239	*Bergia ammannioides* Roxb.	Elatinaceae Dumort	Malpighiales	Native
240	*Aeschynomene indica* L.	Fabaceae Lindl.	Fabales	Native
241	*Acacia auriculiformis* A.Cunn. ex Benth.	Fabaceae Lindl.	Fabales	Exotic
242	*Acacia catechu* (L.) Willd.,Oliv.	Fabaceae Lindl.	Fabales	Native
243	*Acacia farnesiana* (L.) Wight et Arn.	Fabaceae Lindl.	Fabales	Exotic
244	*Acacia nilotica* (L.) P.J.H.Hurter & Mabb.	Fabaceae Lindl.	Fabales	Native
245	*Acacia pennata* (L.) Willd.	Fabaceae Lindl.	Fabales	Native
246	*Acacia leucophloea* (Roxb.) Willd.	Fabaceae Lindl.	Fabales	Native
247	*Alysicarpus monilifer* (L.) DC.	Fabaceae Lindl.	Fabales	Native
248	*Alysicarpus vaginalis* (L.)DC.	Fabaceae Lindl.	Fabales	Native
249	*Alysicarpus ovalifolius* (Schumach.) J.Léonard	Fabaceae Lindl.	Fabales	Native
250	*Albizia lebbeck* (L.) Benth.	Fabaceae Lindl.	Fabales	Native
251	*Albizia chinensis* (Osbeck) Merr.	Fabaceae Lindl.	Fabales	Native
252	*Albizia julibrissin* Durazz.	Fabaceae Lindl.	Fabales	Native
253	*Albizia procera* (Roxb.) Benth.	Fabaceae Lindl.	Fabales	Native
254	*Alhagi maurorum* Medik.	Fabaceae Lindl.	Fabales	Native
255	Bauhinia variegata L.	Fabaceae Lindl.	Fabales	Native
256	*Cassia fistula* L.	Fabaceae Lindl.	Fabales	Native
257	*Cajanus scarabeoides* (L.) Thouars	Fabaceae Lindl.	Fabales	Native
258	*Caesalpinia bonduc* (L.) Roxb.	Fabaceae Lindl.	Fabales	Native
259	*Crateva adansonii* DC.	Fabaceae Lindl.	Fabales	Native
260	*Crotalaria medicaginea* Lam.	Fabaceae Lindl.	Fabales	Native
261	*Crotalaria mysoriensis* Roth	Fabaceae Lindl.	Fabales	Native
262	*Crotalaria pallida* Aiton	Fabaceae Lindl.	Fabales	Native
263	*Crotalaria retusa* L.	Fabaceae Lindl.	Fabales	Native
264	*Crotalaria juncea* L.	Fabaceae Lindl.	Fabales	Native
265	*Crotalaria prostrata* Rottler ex Willd.	Fabaceae Lindl.	Fabales	Native
266	*Dalbergia sissoo* Roxb.	Fabaceae Lindl.	Fabales	Native
267	*Delonix regia* (Bojer ex Hook.) Raf.	Fabaceae Lindl.	Fabales	Exotic
268	*Desmodium gangeticum* (L.)DC.	Fabaceae Lindl.	Fabales	Native
269	*Desmodium triflorum* (L.)DC.	Fabaceae Lindl.	Fabales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Madras Leaf-Flower	Herb	-	Moist loving	-	LC
Mountain Coffee Bush	Shrub	-	Moist loving	-	L
Putranjiva	Tree	-	Moist loving	-	LC
Stinking passionflower	Climber	-	Moist loving	-	-
Toothed leaf Chilla	Tree	-	T	-	-
Eastern cottonwood	Tree	-	T	-	LC
Indian Willow	Tree	-	SA	Riparian	LC
Spade flower	Herb	-	Moist loving		-
Ammannia waterwort	Herb	-	SA	Marshy	LC
Indian Joint Vetch	Herb	-	SA	Marshy	LC
Earleaf Acacia	Tree	-	T	-	LC
Kher	Tree	-	Moist loving	-	LC
Sweet Acscia	Tree	-	T	-	LC
Gum arabic tree	Tree	-	Moist loving	-	LC
Large-Gland Acacia	Climber	-	Moist loving	-	-
White Bark Acacia	Tree	-	T	-	LC
Nacklace Alyce Clover	Herb	-	Moist loving	-	-
Alyce Clover	Herb	-	Moist loving	-	-
False moneywort	Herb	-	Moist loving	-	-
Siris	Tree	-	T	-	-
Chinese Albizia	Tree	-	T	-	LC
Persian acacia	Tree	-	T	-	VU
white siris	Tree	-	T		LC
Camelthorn-bush	Herb	-	Moist loving	-	-
Mountain Ebony	Tree	-	T	-	LC
Amaltash	Tree	-	T	-	LC
Showy pigeonpea	Climber	-	Moist loving	-	-
Knicker nut	Shrub	-	Moist loving	-	LC
Garlic pear tree	Tree	-	Moist loving	-	LC
Medick Rattlepod	Herb	-	Moist loving	-	-
Mysore Rattlepod	Herb	-	Moist loving	-	-
Smooth crotolaria	Herb	-	Moist loving	-	-
Rattleweed	Herb	-	Moist loving	-	-
Indian Hemp	Herb	-	Moist loving	-	-
Prostrate Rattlepod	Herb	-	Moist loving	-	-
Indin rosewood	Tree	-	Moist loving	-	LC
Flame Tree	Tree	-	T	-	LC
Salparni	Herb	-	Moist loving	-	-
Three-flower beggarweed	Herb	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
270	*Indigofera linifolia* (L.f.) Retz.	Fabaceae Lindl.	Fabales	Native
271	*Indigofera linnaei* Ali	Fabaceae Lindl.	Fabales	Native
272	*Indigofera tinctoria* L.	Fabaceae Lindl.	Fabales	Native
273	*Indigofera trita* L.f.	Fabaceae Lindl.	Fabales	Native
274	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae Lindl.	Fabales	Exotic
275	*Medicago polymorpha* L.	Fabaceae Lindl.	Fabales	Exotic
276	*Medicago lupulina* L.	Fabaceae Lindl.	Fabales	Native
277	*Melilotus albus* Medik.	Fabaceae Lindl.	Fabales	Exotic
278	*Melilotus indicus* (L.) All.	Fabaceae Lindl.	Fabales	Native
279	*Mimosa himalayana* Gamble	Fabaceae Lindl.	Fabales	Native
280	*Mimosa hamata* Willd.	Fabaceae Lindl.	Fabales	Native
281	*Mimosa pudica* L.	Fabaceae Lindl.	Fabales	Exotic
282	*Neptunia oleracea* Lour.	Fabaceae Lindl.	Fabales	Native
283	*Pithecellobium dulce* (Roxb.) Benth.	Fabaceae Lindl.	Fabales	Exotic
284	*Pongamia pinnata* (L.) Pierre	Fabaceae Lindl.	Fabales	Native
285	*Prosopis juliflora* (Sw.) DC.	Fabaceae Lindl.	Fabales	Exotic
286	*Senna absus* (L.) Roxb.	Fabaceae Lindl.	Fabales	Native
287	*Senna alata* (L.) Roxb.	Fabaceae Lindl.	Fabales	Exotic
288	*Senna occidentalis* (L.) Link	Fabaceae Lindl.	Fabales	Exotic
289	*Senna siamea* (Lam.) Irwin et Barneby	Fabaceae Lindl.	Fabales	Exotic
290	*Senna tora* (L.) Roxb.	Fabaceae Lindl.	Fabales	Exotic
291	*Senna sophera* (L.) Roxb	Fabaceae Lindl.	Fabales	Exotic
292	*Senna uniflora* (Mill.) H.S.Irwin & Barneby	Fabaceae Lindl.	Fabales	Exotic
293	*Sesbania sesban* (L.) Merr.	Fabaceae Lindl.	Fabales	Native
294	*Tamarindus indica* L.	Fabaceae Lindl.	Fabales	Exotic
295	*Tephrosia purpurea* (L.) Pers.	Fabaceae Lindl.	Fabales	Native
296	*Tephrosia pumila* (Lam.) Pers.	Fabaceae Lindl.	Fabales	Native
297	*Teramnus labialis* (L.f.) Spreng.	Fabaceae Lindl.	Fabales	Native
298	*Trifolium resupinatum* L.	Fabaceae Lindl.	Fabales	Exotic
299	*Trifolium alexandrinum* L.	Fabaceae Lindl.	Fabales	Exotic
300	*Vicia sativa* L.	Fabaceae Lindl.	Fabales	Native
301	*Vicia hirsuta* (L.) Gray	Fabaceae Lindl.	Fabales	Native
302	Zornia gibbosa Span.	Fabaceae Lindl.	Fabales	Native
303	*Polygala arvensis* Willd.	Polygalaceae Hoffmanns. & Link	Fabales	Native
304	*Cannabis sativa* L.	Cannabaceae Mrtinov	Rosales	Exotic
305	*Trema orientalis* (L.) Blume	Cannabaceae Mrtinov	Rosales	Native
306	*Artocarpus heterophyllus* Lam.	Moraceae Gaudich.	Rosales	Native
307	*Artocarpus lacucha* Buch.-Ham.	Moraceae Gaudich.	Rosales	Native
308	*Streblus asper* Lour.	Moraceae Gaudich.	Rosales	Native
309	*Ficus assamica* Miq.	Moraceae Gaudich.	Rosales	Native
310	*Ficus benghalensis* L.	Moraceae Gaudich.	Rosales	Native
311	*Ficus racemosa* L.	Moraceae Gaudich.	Rosales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Birdsville indigo	Herb	-	Moist loving	-	LC
Nine-leaved indigo	Herb	-	Moist loving	-	-
True indigo	Herb	-	Moist loving	-	-
Asian Indigo	Shrub	-	Moist loving	-	LC
Hotse tamarind	Tree	-	Moist loving	-	-
Toothed bur clover	Herb	-	Moist loving	-	LC
Black medick	Herb	-	Moist loving	-	LC
White Sweet Clover	Herb	-	Moist loving	-	LC
Indian Sweet Clover	Herb	-	Moist loving	-	-
Himalayan mimosa	Shrub	-	Moist loving	-	-
Hooked Mimosa	Shrub	-	T	-	-
Touch me not plant	Herb	-	Moist loving	-	LC
Water Mimosa	Herb	-	A	FF	LC
Monkeypod tree	Tree	-	Moist loving	-	LC
Karanj	Tree	-	SA	Riparian	LC
Vilayati babul	Tree	-	Moist loving	-	LC
Tropical Sensitive Pea	Herb	-	Moist loving	-	-
Candle Bush	Shrub	-	Moist loving	-	-
Coffee senna	Shrub	-	Moist loving	-	LC
Siamese cassia	Tree	-	T	-	LC
Chinese senna	Herb	-	Moist loving	-	-
Sophera Senna	Shrub	-	Moist loving	-	-
Oneleaf senna	Shrub	-	Moist loving	-	-
Egyptian rattlepod	Herb	-	Moist loving	-	-
Tamarind tree	Tree	-	T	-	LC
Common tephrosia	Shrub	-	T	-	-
Indigo Sauvage	Herb	-	T	-	LC
Mashaparni	Climber	-	Moist loving	-	-
Persian clover	Herb	-	Moist loving	-	LC
Berseem clover	Herb	-	Moist loving	-	NA
Common Vetch	Herb	-	Moist loving	-	LC
Tiny Vetch,	Herb	-	Moist loving	-	-
Grass like Zornia	Herb	-	Moist loving	-	-
Field Milkwort	Herb	-	Moist loving	-	-
Hemp	Herb	-	Moist loving	-	-
Indian Charcoal tree	Tree	-	Moist loving	-	LC
Jackfruit	Tree	-	T	-	-
Monkey jack.	Tree	-	T	-	-
Siamese rough bush	Tree	-	SA	Riparian	LC
-	Shrub	-	SA	Riparian	-
Banayan tree	Tree	-	Moist loving	-	-
Gular	Tree	-	SA	Riparian	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
312	*Ficus heterophylla* L.f.	Moraceae Gaudich.	Rosales	Native
313	*Ficus hispida* L.f.	Moraceae Gaudich.	Rosales	Native
314	*Ficus microcarpa* L. f.	Moraceae Gaudich.	Rosales	Native
315	*Ficus palmata* subsp. *virgata* (Roxb.) Browicz	Moraceae Gaudich.	Rosales	Native
316	*Ficus religiosa* L.	Moraceae Gaudich.	Rosales	Native
317	*Ficus semicordata* Buch.Ham. ex Sm.	Moraceae Gaudich.	Rosales	Native
318	*Ficus tinctoria* subsp. *gibbosa* (Blume) Corner	Moraceae Gaudich.	Rosales	Native
319	*Ficus virens* Aiton	Moraceae Gaudich.	Rosales	Native
320	*Ficus rumphii* Bl.	Moraceae Gaudich.	Rosales	Native
321	*Broussonetia papyrifera* (L.) Vent.	Moraceae Gaudich.	Rosales	Exotic
322	*Morus alba* L.	Moraceae Gaudich.	Rosales	Exotic
323	*Holoptelea integrifolia* (Roxb.) Planch.	Ulmaceae Mirb.	Rosales	Native
324	*Potentilla indica* (Andrews) Th.Wolf	Rosaceae Juss.	Rosales	Native
325	*Potentilla supina* L.	Rosaceae Juss.	Rosales	Native
326	*Rosa macrophylla* Lindl.	Rosaceae Juss.	Rosales	Native
327	*Rosa sempervirens* L.	Rosaceae Juss.	Rosales	Native
328	*Rubus niveus* Thunb.	Rosaceae Juss.	Rosales	Native
329	*Rubus ellipticus* Sm.	Rosaceae Juss.	Rosales	Native
330	*Sorbaria sorbifolia* (L.) A.Braun	Rosaceae Juss.	Rosales	Native
331	*Ventilago denticulata* Willd.	Rhamnaceae Juss.	Rosales	Native
332	Ziziphus nummularia (Burm.f.) Wight & Arn.	Rhamnaceae Juss.	Rosales	Native
333	*Ziziphus mauritiana* Lam.	Rhamnaceae Juss.	Rosales	Native
334	*Ziziphus oenopolia*(L.) Mill.	Rhamnaceae Juss.	Rosales	Native
335	*Pilea microphylla* (L.) Liebm.	Urticaceae Juss.	Rosales	Exotic
336	*Pouzolzia pentandra* (Roxb.) Benn.	Urticaceae Juss.	Rosales	Native
337	*Pouzolzia zeylanica* (L.) Benn.	Urticaceae Juss.	Rosales	Native
338	*Pouzolzia hirta* (Blume) Hassk.	Urticaceae Juss.	Rosales	Native
339	*Boehmeria virgata var. macrostachya* (Wight) Friis & Wilmot-Dear	Urticaceae Juss.	Rosales	Native
340	*Urtica dioica* L.	Urticaceae Juss.	Rosales	Native
341	*Actinostemma tenerum* Griff.	Cucurbitaceae Juss.	Cucurbitales	Native
342	*Citrullus colocynthis* (L.) Schrad.	Cucurbitaceae Juss.	Cucurbitales	Native
343	*Coccinia grandis* (L.) Voigt	Cucurbitaceae Juss.	Cucurbitales	Native
344	Cucumis maderaspatanus L.	Cucurbitaceae Juss.	Cucurbitales	Native
345	*Ctenolepis garcinii* (Burm.f.) C.B.Clarke	Cucurbitaceae Juss.	Cucurbitales	Native
346	*Diplocyclos palmatus* (L.) C.Jeffrey	Cucurbitaceae Juss.	Cucurbitales	Native
347	*Trichosanthes cucumerina* subsp. *Cucumerina*	Cucurbitaceae Juss.	Cucurbitales	Native
348	*Trichosanthes tricuspidata* Lour.	Cucurbitaceae Juss.	Cucurbitales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Creeping fig	Shrub	-	SA	Riparian	-
Opposite leaf fig	Tree	-	Moist loving	-	LC
Laurel Fig	Tree	-	Moist loving	-	LC
Punjab Fig	Shrub	-	Moist loving	-	-
Pipal	Tree	-	Moist loving	-	LC
Drooping fig	Tree	-	SA	Riparian	LC
Dye Fig, Humped Fig	Tree	-	SA	Riparian	-
White fig	Tree	-	Moist loving	-	LC
Golden Rumph's Fig	Tree	-	SA	Riparian	-
Paper mulberry	Tree	-	Moist loving	-	LC
White mulberry	Tree	-	Moist loving	-	-
Indian elm	Tree	-	Moist loving	-	-
Indian-strawberry	Herb	-	Moist loving	-	-
Spreading Cinquefoil	Herb	-	Moist loving	-	LC
-	Shrub	-	T	-	-
Wild rose	Shrub	-	T	-	-
Mysore Raspberry	Shrub	-	Moist loving	-	-
Yellow Himalayan Raspberry	Shrub	-	T	-	LC
Himalayan Sorbaria	Shrub	-	Moist loving	-	-
Toothed-Leaf Red Creeper	Climbing Shrub	-	T	-	-
Jhar Beri	Shrub	-	Moist loving	-	LC
Indian jujube	Herb	-	Moist loving	-	LC
Jackel jujube	Herb	-	T	-	-
Angeloweed	Herb	-	Moist loving	-	-
Narrow-lef pouzolzs bush	Herb	-	SA	Marshy	-
Graceful pouzolzs bush	Herb	-	SA	Marshy	-
Hairy Pouzolz's Bush	Herb	-	SA	Marshy	
False Nettle	Shrub	-	Moist loving	-	-
Common nettle	Herb	-	Moist loving	-	LC
Tender Ray -flower gourd	Climber	-	Moist loving	-	-
Vine of Sodom	Climber	-	Moist loving	-	-
Ivy gourd	Climber	-	Moist loving	-	-
Madras pea pumpkin	Climber	-	Moist loving	-	-
Garcins bur cucumber	Climber	-	Moist loving	-	-
Shivlingi	Climber	-	Moist loving	-	-
Snake gourd	Climber	-	Moist loving	-	-
Indrayan	Climber	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
349	*Luffa echinata* Roxb.	Cucurbitaceae Juss.	Cucurbitales	Native
350	*Terminalia arjuna* (Roxb.) Wight & Arn.	Combretaceae R.Br.	Cucurbitales	Native
351	Terminalia elliptica Willd.	Combretaceae R.Br.	Cucurbitales	Native
352	*Terminalia pendula* (Edgew.) Gere & Boatwr.	Combretaceae R.Br.	Cucurbitales	Native
353	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr.	Combretaceae R.Br.	Cucurbitales	Native
354	*Combretum ovalifolium* Roxb. ex G.Don	Combretaceae R.Br.	Cucurbitales	Native
355	*Combretum decandrum* Roxb.	Combretaceae R.Br.	Cucurbitales	Native
356	*Betula utilis* D.Don	Betulaceae Gray	Fagales	Native
357	*Quercus leucotrichophora* A.Camus	Fagaceae Dumort.	Fagales	Native
358	*Syzygium cumini* (L.) Skeels	Myrtaceae Juss.	Myrtales	Native
359	*Eucalyptus tereticornis* Sm.	Myrtaceae Juss.	Myrtales	Exotic
360	*Ammannia baccifera* L.	Lythraceae J.St.-Hil	Myrtales	Native
361	*Ammannia multiflora* Roxb.	Lythraceae J.St.-Hil	Myrtales	Native
362	*Ammannia auriculata* Willd.	Lythraceae J.St.-Hil	Myrtales	Native
363	Lagerstroemia speciosa (L.) Martyn	Lythraceae J.St.-Hil	Myrtales	Native
364	*Rotala rotundifolia* (Buch.-Ham. ex Roxb.) Koehne	Lythraceae J.St.-Hil	Myrtales	Native
365	*Trapa natans* L.	Lythraceae J.St.-Hil	Myrtales	Native
366	*Woodfordia fruticosa* (L.) Kurz	Lythraceae J.St.-Hil	Myrtales	Native
367	*Ludwigia adscendens* (L.) H.Hara	Onagraceae Juss.	Myrtales	Native
368	*Ludwigia octovalvis* (Jacq.) P.H.Raven	Onagraceae Juss.	Myrtales	Native
369	Ludwigia perennis L.	Onagraceae Juss.	Myrtales	Native
370	*Oenothera rosea* Aiton.	Onagraceae Juss.	Myrtales	Exotic
371	Oenothera laciniata Hill	Onagraceae Juss.	Myrtales	Exotic
372	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae (R.Br.) Lindl.	Sapindales	Native
373	Mangifera indica L.	Anacardiaceae (R.Br.) Lindl.	Sapindales	Native
374	*Spondias pinnata* (L.f.) Kurz	Anacardiaceae (R.Br.) Lindl.	Sapindales	Native
375	*Garuga pinnata* Roxb.	Burseraceae Kunth	Sapindales	Native
376	*Aesculus indica* (Wall. ex Cambess.) Hook.	Sapindaceae Juss.	Sapindales	Native
377	*Cardiospermum halicacabum* L.	Sapindaceae Juss.	Sapindales	Native
378	*Dodonaea viscosa* Jacq.	Sapindaceae Juss.	Sapindales	Native
379	*Schleichera oleosa* (Lour.) Oken	Sapindaceae Juss.	Sapindales	Native
380	*Azadirachta indica* A.Juss.	Meliaceae Juss.	Sapindales	Exotic
381	*Melia azedarach* L.	Meliaceae Juss.	Sapindales	Native
382	*Toona ciliata* M. Roem.	Meliaceae Juss.	Sapindales	Native
383	*Aegle marmelos* (L.) Correa	Rutaceae Juss.	Sapindales	Native
384	*Glycosmis pentaphylla* (Retz.) DC.	Rutaceae Juss.	Sapindales	Native
385	*Murraya koenigii* (L.) Spreng.	Rutaceae Juss.	Sapindales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Bitter spong gourd	Climber	-	Moist loving	-	LC
Arjun	Tree	-	SA	Riparian	-
Indian laurel	Tree	-	T	-	-
Buttontree	Tree	-	T	-	-
Axle Wood Tree	Tree	-	T	-	-
Piluki	Climbing Shrub	-	T	-	-
-	Climbing Shrub	-	T	-	-
Bhoj Patra Tree	Tree	-	T	-	LC
Banjh Oak	Tree	-	T	-	-
Jamun	Tree	-	SA	Riparian	-
Forest Red Gum	Tree	-	T	-	LC
Blistering ammannia	Herb	-	SA	Marshy	-
Many Flowered Ammannia	Herb	-	SA	Marshy	-
Eared Redstem	Herb	-	SA	Marshy	LC
Pride of India	Tree	-	T	-	LC
Roundleaf toothcup	Herb	-	A	EM	LC
Singhara	Herb	-	A	FF	LC
Fire Flame bush	Shrub	-	Moist loving	-	LC
Water primerose	Herb	-	A	FF	LC
Willow Primrose	Herb	-	SA	Marshy	LC
Perennial water primerose	Herb	-	SA	Marshy	-
Pink Evening Primrose	Herb	-	Moist loving	-	-
Cutleaf Evening Primrose	Herb	-	Moist loving	-	-
Indian ash tree,	Tree	-	T	-	LC
Mango	Tree	-	T	-	DD
Amra	Tree	-	T	-	LC
Garuga	Tree	-	T	-	-
Indian Horse Chestnut	Tree	-	T	-	LC
Ballon vine	Climber	-	Moist loving	-	LC
Hop Bush	Shrub	-	Moist loving	-	-
Ceylon oak	Tree	-	T	-	LC
Neem tree	Tree	-	T	-	LC
Chinaberry tree	Tree	-	T	-	LC
Indian mahogany	Tree	-	T	-	LC
Bel	Tree	-	T	-	NT
Gin berry	Shrub	-	T	-	LC
Kadipatta,curry leaf tree	Shrub	-	T	-	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
386	*Murraya paniculata* (L.) Jack	Rutaceae Juss.	Sapindales	Native
387	*Ailanthus excelsa* Roxb.	Simaroubaceae DC.	Sapindales	Native
388	*Bixa orellana* L.	Bixaceae Kunth	Malvales	Exotic
389	*Shorea robusta* C.F.Gaertn.	Dipterocarpaceae Blume	Malvales	Native
390	*Abutilon indicum* (L.) Sweet	Malvaceae Juss.	Malvales	Native
391	*Abutilon pannosum* (G.Forst.) Schltdl.	Malvaceae Juss.	Malvales	Native
392	Bombax ceiba L.	Malvaceae Juss.	Malvales	Native
393	*Corchorus aestuans* L.	Malvaceae Juss.	Malvales	Native
394	*Corchorus capsularis* L.	Malvaceae Juss.	Malvales	Native
395	Corchorus trilocularis L.	Malvaceae Juss.	Malvales	Native
396	*Helicteres isora* L.	Malvaceae Juss.	Malvales	Native
397	*Hibiscus manihot* L.	Malvaceae Juss.	Malvales	Native
398	Hibiscus micranthus L.f.	Malvaceae Juss.	Malvales	Native
399	*Malva verticillata* L.	Malvaceae Juss.	Malvales	Native
400	*Malvastrum coromandelianum* (L.) Garcke	Malvaceae Juss.	Malvales	Native
401	*Melochia corchorifolia* L.	Malvaceae Juss.	Malvales	Native
402	*Sida acuta* Burm.f.	Malvaceae Juss.	Malvales	Native
403	*Sida cordifolia* L.	Malvaceae Juss.	Malvales	Native
404	*Sida cordata* (Burm.f.)	Malvaceae Juss.	Malvales	Native
405	*Sida rhombifolia* L.	Malvaceae Juss.	Malvales	Native
406	Sida rhomboidea Roxb. ex Fleming	Malvaceae Juss.	Malvales	Native
407	*Sterculia villosa* Roxb. ex Sm.	Malvaceae Juss.	Malvales	Native
408	Triumfetta rotundifolia Lam.	Malvaceae Juss.	Malvales	Native
409	*Triumfetta rhomboidea* Jacq.	Malvaceae Juss.	Malvales	Native
410	Pentapetes phoenicea L.	Malvaceae Juss.	Malvales	Native
411	*Urena lobata* L.	Malvaceae Juss.	Malvales	Native
412	*Waltheria indica* L.	Malvaceae Juss.	Malvales	Exotic
413	Moringa oleifera Lam.	Moringaceae Martinov	Brassicales	Native
414	*Cleome viscosa* L.	Cleomaceae Bercht. & J.Presl	Brassicales	Native
415	*Cleome rutidosperma* DC.	Cleomaceae Bercht. & J.Presl	Brassicales	Native
416	*Cleome gynandra* L.	Cleomaceae Bercht. & J.Presl	Brassicales	Native
417	*Capparis zeylanic*a L.	Capparaceae Juss.	Brassicales	Native
418	*Capparis decidua* (Forssk.) Edgew.	Capparaceae Juss.	Brassicales	Native
419	Capparis sepiaria L.	Capparaceae Juss.	Brassicales	Native
420	*Salvadora persica* L.	Salvadoraceae Lindl.	Brassicales	Native
421	*Salvadora oleoides* Decne.	Salvadoraceae Lindl.	Brassicales	Native
422	*Capsella bursa-pastoris* (L.) Medik.	Brassicaceae Burnett	Brassicales	Native
423	*Cardamine hirsuta* L.	Brassicaceae Burnett	Brassicales	Native
424	*Erysimum capitatum* (Dougl. ex Hook.) Greene	Brassicaceae Burnett	Brassicales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Orange jasmine	Shrub	-	T	-	-
Maharuk	Tree	-	T	-	-
Farvah	Tree	-	T	-	LC
Sal	Tree	-	T	-	LC
Bala	Shrub	-	T	-	-
Ragged Mallow	Shrub	-	T	-	-
Shalmali	Tree	-	SA	Riparian	-
East indian mallow	Herb	-	Moist loving	-	-
White Jute	Herb	-	Moist loving	-	-
Wild Jute	Herb	-	T	-	-
Indian screw tree	Tree	-	Moist loving	-	-
Manihot mallow	Herb	-	Moist loving	-	-
-	Herb	-	T		
Chinese mallow	Herb	-	Moist loving	-	-
Three lobed false mallow	Herb	-	Moist loving	-	-
Chocolate weed	Herb	-	Moist loving	-	LC
Common wireweed	Herb	-	Moist loving	-	-
Flannel weed	Herb	-	Moist loving	-	-
Long stock sida	Herb	-	Moist loving	-	-
Arrowleaf sida	Herb	-	Moist loving	-	-
-	Herb	-	Moist loving	-	-
Hairy Sterculia	Tree	-	T	-	LC
Roundleaf Burr-Bush	Herb	-	Moist loving	-	-
Burr Bush	Herb	-	Moist loving	-	-
Midday Flower	Herb	-	Moist loving	-	-
Caesarweed	Shrub	-	Moist loving	-	LC
Sleepy Morning	Herb	-	T	-	
Drumstick tree	Tree	-	T	-	LC
Asian spider flower	Herb	-	Moist loving	-	-
Fringed Spider Flower	Herb	-	Moist loving	-	-
Wild Spider Flower	Herb	-	Moist loving	-	-
Ceylon caper	Shrub	-	Moist loving	-	-
Karira	Tree	-	T	-	LC
Hedge caper	Shrub	-	T	-	-
Toothbrush Tree	Tree	-	SA	Riparian	LC
Bada Peelu	Tree	-	Moist loving	-	DD
Shepherd's purse	Herb	-	Moist loving	-	-
Hairy Bitter Cress	Herb	-	Moist loving	-	-
Western wallflower	Herb	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
425	*Lepidium didymum* L.	Brassicaceae Burnett	Brassicales	Exotic
426	*Lepidium sativum* L.	Brassicaceae Burnett	Brassicales	Exotic
427	*Rorippa cochlearioides* (Roth) Al-Shehbaz & Jonsell	Brassicaceae Burnett	Brassicales	Native
428	*Rorippa indica* (L.) Hiern	Brassicaceae Burnett	Brassicales	Native
429	*Rorippa dubia* (Pers.) H.Hara	Brassicaceae Burnett	Brassicales	Native
430	*Rorippa palustris* (L.) Besser	Brassicaceae Burnett	Brassicales	Native
431	*Nasturtium officinale* W.T.Aiton	Brassicaceae Burnett	Brassicales	Exotic
432	Glinus lotoides L.	Molluginaceae Bartl.	Caryophyllales	Native
433	*Glinus oppositifolius* (L.) Aug.DC.	Molluginaceae Bartl.	Caryophyllales	Native
434	*Fagopyrum esculentum* Moench	Polygonaceae Juss.	Caryophyllales	Native
435	*Persicaria barbata* (L.) H.Hara	Polygonaceae Juss.	Caryophyllales	Native
436	*Persicaria capitata* (Buch.-Ham. ex D.Don) H.Gross	Polygonaceae Juss.	Caryophyllales	Native
437	*Persicaria chinensis* (L.) H.Gross	Polygonaceae Juss.	Caryophyllales	Native
438	*Persicaria limbata* (Meisn.) H.Hara	Polygonaceae Juss.	Caryophyllales	Native
439	*Polygonum glabrum* (Willd.)M.Gomez	Polygonaceae Juss.	Caryophyllales	Native
440	*Persicaria hydropiper* (L.)	Polygonaceae Juss.	Caryophyllales	Native
441	*Persicaria lapathifolia* (L.) Delarbre	Polygonaceae Juss.	Caryophyllales	Native
442	*Polygonum lanatum* Roxb.	Polygonaceae Juss.	Caryophyllales	Native
443	Persicaria pulchra Soják	Polygonaceae Juss.	Caryophyllales	Native
444	*Persicaria decipiens* (R.Br.) K.L.Wilson	Polygonaceae Juss.	Caryophyllales	Exotic
445	*Polygonum plebeium* R.Br.	Polygonaceae Juss.	Caryophyllales	Native
446	*Persicaria orientalis* (L.) Spach	Polygonaceae Juss.	Caryophyllales	Native
447	*Rumex dentatus* L.	Polygonaceae Juss.	Caryophyllales	Native
448	*Rumex hastatus* D.Don	Polygonaceae Juss.	Caryophyllales	Native
449	*Rumex nepalensis* Spreng.	Polygonaceae Juss.	Caryophyllales	Native
450	*Portulaca oleracea* L.	Portulacaceae Juss	Caryophyllales	Exotic
451	*Portulaca pilosa* L.	Portulacaceae Juss	Caryophyllales	Exotic
452	*Achyranthes aspera* L.	Amaranthaceae Juss.	Caryophyllales	Native
453	*Aerva lanata* (L.) Juss. ex Schult.	Amaranthaceae Juss.	Caryophyllales	Native
454	*Alternanthera paronychioides* A.t. Hil.	Amaranthaceae Juss.	Caryophyllales	Exotic
455	Alternanthera pungens Kunth	Amaranthaceae Juss.	Caryophyllales	Exotic
456	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae Juss.	Caryophyllales	Native
457	*Alternanthera ficoidea* (L.) Sm.	Amaranthaceae Juss.	Caryophyllales	Exotic
458	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae Juss.	Caryophyllales	Exotic
459	*Amaranthus graecizans* L.	Amaranthaceae Juss.	Caryophyllales	Native
460	*Amaranthus spinosus* L.	Amaranthaceae Juss.	Caryophyllales	Exotic
461	*Amaranthus viridis* L.	Amaranthaceae Juss.	Caryophyllales	Exotic
462	*Chenopodium album* L.	Amaranthaceae Juss.	Caryophyllales	Native
463	*Chenopodiastrum murale* (L.) S.Fuentes, Uotila & Borsch	Amaranthaceae Juss.	Caryophyllales	Native
464	*Digera muricata* (L.) Mart.	Amaranthaceae Juss.	Caryophyllales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Bitter Cress	Herb	-	Moist loving	-	-
Garden Cress	Herb	-	Moist loving	-	-
Scurvy grass yellow cress	Herb	-	SA	Marshy	-
Indian Field-Cress	Herb	-	SA	Marshy	-
Diverse-Leaf Yellow Cress	Herb	-	Moist loving	-	-
Bog yellow-cress	Herb	-	SA	Marshy	LC
Yellowcress	Herb	-	SA	Marshy	LC
Lotus Sweetjuice	Herb	-	Moist loving	-	LC
Jima	Herb	-	Moist loving	-	LC
Common buckwheat	Herb	-	SA	Marshy	-
Bearded knotweed	Herb	-	SA	Marshy	LC
Pinkhead smartweed	Herb	-	SA	Marshy	-
Chinese knotweed	Herb	-	SA	Marshy	-
Knotweed	Herb	-	SA	Marshy	LC
Common marsh buckwheat	Herb	-	SA	Marshy	LC
Water pepper	Herb	-	SA	Marshy	LC
Pale Knotweed	Herb	-	SA	Marshy	LC
	Herb	-	SA	Marshy	-
	Herb	-	SA	Marshy	LC
Small Water-Pepper	Herb	-	SA	Marshy	-
Common knotweed	Herb	-	SA	Marshy	LC
Princess-feather	Herb	-	SA	Marshy	-
Toothed dock	Herb	-	SA	Marshy	LC
Arrowleaf Dock	Herb	-	Moist loving	-	-
Nepal Dock	Herb	-	Moist loving	-	
Common purslane	Herb	-	Moist loving	-	LC
Hairy pigweed	Herb	-	Moist loving	-	-
Devils horsewhip	Herb	-	Moist loving	-	-
Mountain Knotgarss	Herb	-	Moist loving	-	-
Smooth chaff flower	Herb	-	Moist loving	-	-
Khaki weed	Herb	-	Moist loving	-	-
Stalkless joyweed	Herb	-	SA	Marshy	-
Josephs goat	Herb	-	Moist loving	-	-
Alligator weed	Herb	-	SA	Marshy	-
Mediterranean amaranth	Herb	-	Moist loving	-	-
Spiny amaranth	Herb	-	Moist loving	-	-
Green amaranth	Herb	-	Moist loving	-	-
Wild spinach	Herb	-	Moist loving	-	-
Nettle-Leaved Goosefoot	Herb	-	Moist loving	-	-
False Amaranth	Herb	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
465	*Gomphrena serrata* L.	Amaranthaceae Juss.	Caryophyllales	Exotic
466	*Gomphrena globosa* L.	Amaranthaceae Juss.	Caryophyllales	Exotic
467	*Pupalia lappacea* (L.) Juss.	Amaranthaceae Juss.	Caryophyllales	Native
468	*Arenaria serpyllifolia* L. Var. Serpyllifolia	Caryophyllaceae Juss.	Caryophyllales	Native
469	*Cerastium glomeratum* Thuill	Caryophyllaceae Juss.	Caryophyllales	Native
470	*Drymaria cordata* (L.) Willd. ex Schult.	Caryophyllaceae Juss.	Caryophyllales	Native
471	*Polycarpaea corymbosa* (L.) Lam	Caryophyllaceae Juss.	Caryophyllales	Native
472	*Spergula arvensis* L.	Caryophyllaceae Juss.	Caryophyllales	Native
473	*Polycarpon prostratum* (Forssk.) Asch. & Schweinf. Syn. *Spergula prostrata (Forssk.) D.Dietr.*	Caryophyllaceae Juss.	Caryophyllales	Native
474	*Stellaria media* (L.) Vill	Caryophyllaceae Juss.	Caryophyllales	Native
475	*Stellaria aquatica* (L.) Scop.	Caryophyllaceae Juss.	Caryophyllales	Native
476	*Boerhavia diffusa* L.	Nyctaginaceae Juss.	Caryophyllales	Native
477	*Tamarix indica* Willd.	Tamaricaceae Lnk	Caryophyllales	Native
478	*Tamarix dioica* Roxb. ex Roth	Tamaricaceae Lnk	Caryophyllales	Native
479	*Tamarix ericoides* Rottler & Willd.	Tamaricaceae Lnk	Caryophyllales	Native
480	*Tamarix aphylla* (L.) H.Karst.	Tamaricaceae Lnk	Caryophyllales	Native
481	*Basella alba* L.	Basellaceae Raf.	Caryophyllales	Native
482	*Opuntia cochenillifera* (L.) Mill.	Cactaceae Juss.	Caryophyllales	Exotic
483	*Trianthema portulacastrum* L.	Aizoaceae Martinov	Caryophyllales	Native
484	*Dendrophthoe falcata* (L.f.) Ettingsh.	Loranthaceae Juss.	Santalales	Native
485	*Ardisia solanacea* Roxb.	Primulaceae Batsch ex Borkh.	Ericales	Native
486	*Anagallis arvensis* L.	Primulaceae Batsch ex Borkh.	Ericales	Exotic
487	*Androsace umbellata* (Lour.) Merr.	Primulaceae Batsch ex Borkh.	Ericales	Native
488	*Mimusops elengi* L.	Sapotaceae Juss	Ericales	Native
489	*Madhuca longifolia* (L.) J.F.Macbr.	Sapotaceae Juss	Ericales	Native
490	*Barringtonia acutangula* (L.) Gaertn.	Lecythidaceae A.Rich.	Ericales	Native
491	*Diospyros malabarica* (Desr.) Kostel.	Ebenaceae Gürke	Ericales	Native
492	*Diospyros montana* Roxb.	Ebenaceae Gürke	Ericales	Native
493	*Alangium salviifolium* (L.f.) Wangerin	Cornaceae Bercht. & J.Presl	Cornales	Native
494	*Cornus capitata* Wall.	Cornaceae Bercht. & J.Presl	Cornales	Native
495	*Lyonia ovalifolia* (Wall.) Drude	Ericaceae Durande	Ericales	Native
496	*Acanthus ilicifolius* L.	Acanthaceae Juss.	Lamiales	Native
497	*Andrographis echioides* (L.) Nees	Acanthaceae Juss.	Lamiales	Native
498	*Blepharis maderaspatensis* (L.) B.Heyne ex Roth	Acanthaceae Juss.	Lamiales	Native
499	*Blepharis integrifolia* (L. fil.) E. Mey. & Drege	Acanthaceae Juss.	Lamiales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Prostrate Gomphrena	Herb	-	Moist loving	-	-
Globe amaranth	Herb	-	Moist loving	-	-
Forest Burr	Herb	-	Moist loving	-	LC
Thyme-leaf sandwort	Herb	-	Moist loving	-	-
Sticky Chickweed	Herb	-	Moist loving	-	-
Heartleaf drymary	Herb	-	SA	Riparian	-
Oldmans cap	Herb	-	Moist loving	-	-
Cornspurry	Herb	-	Moist loving	-	-
Prostrate Manyseed	Herb	-	Moist loving	-	LC
Chickweed	Herb	-	Moist loving	-	-
Water Chickweed	Herb	-	Moist loving	-	
Punarnava	Herb	-	Moist loving	-	-
Indian Tamarisk	Shrub	-	SA	Marshy	-
Red Tamarisk	Shrub	-	SA	Marshy	-
Erica Tamarisk	Shrub	-	SA	Marshy	-
Athel Pine	Shrub	-	SA	Marshy	LC
Malabar spinach	Herb	-	T	-	-
Velvet Opuntia	Shrub	-	T	-	DD
Desert horsepurslane	Herb	-	Moist loving	-	-
Honey Suckle Mistletoe	Shrub	-	Ephiphytic parasites	-	
Shoebutton ardisia	Shrub	-	T	-	-
The Scarlet Pimpernel	Herb	-	Moist loving	-	-
Umbelled Rock Jasmine	Herb	-	Moist loving	-	-
Bakul	Tree	-	T	-	-
Mahu	Tree	-	T	-	-
Freshwater Mangrove	Tree	-	SA	Riparian	LC
Malabar ebony	Tree	-	SA	Riparian	-
Bombay ebony	Tree	-	SA	Riparian	-
Akol	Tree	-	Moist loving	-	LC
Himalayan Strawberry Tree	Tree	-	T	-	LC
	Tree	-	T	-	LC
Holly mangrove	Shrub	-	SA	Riparian	LC
Bugloss Chiretta	Herb	-	Moist loving	-	-
Creeping Blepharis	Herb	-	Moist loving	-	-
Narrow-Leaf Blepharis	Herb	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
500	*Dicliptera chinensis* (L.) Juss.	Acanthaceae Juss.	Lamiales	Native
501	*Dicliptera paniculata* (Forssk.)	Acanthaceae Juss.	Lamiales	Native
502	*Eranthemum roseum* (Vahl) R.Br.	Acanthaceae Juss.	Lamiales	Native
503	*Hygrophila auriculata* (Schumach.) Heine	Acanthaceae Juss.	Lamiales	Native
504	*Hygrophila polysperma* (Roxb.) T.Anderson	Acanthaceae Juss.	Lamiales	Native
505	*Hygrophila ringens* (L.) R.Br. ex Spreng.	Acanthaceae Juss.	Lamiales	Native
506	*Hygrophila serpyllum* (Nees) T.Anderson	Acanthaceae Juss.	Lamiales	Native
507	*Nelsonia canescens* (Lam.) Spreng.	Acanthaceae Juss.	Lamiales	Native
508	*Justicia adhatoda* L.	Acanthaceae Juss.	Lamiales	Native
509	*Justicia gendarussa* Burm.f.	Acanthaceae Juss.	Lamiales	Exotic
510	*Rungia elegans* Dalzell & A.Gibson	Acanthaceae Juss.	Lamiales	Native
511	*Rungia pectinata* (L.) Nees	Acanthaceae Juss.	Lamiales	Native
512	*Rostellularia diffusa* (Willd.) Nees	Acanthaceae Juss.	Lamiales	Native
513	*Rostellularia quinqueangularis* (J.Koenig ex Roxb.) Nees	Acanthaceae Juss.	Lamiales	Native
514	*Lepidagathis incurva* Buch.-Ham. ex D.Don	Acanthaceae Juss.	Lamiales	Native
515	*Lepidagathis cuspidata* Nees	Acanthaceae Juss.	Lamiales	Native
516	*Petalidium barlerioides* (B.Heyne ex Roth) Nees	Acanthaceae Juss.	Lamiales	Native
517	*Ruellia prostrata* Poir.	Acanthaceae Juss.	Lamiales	Native
518	Strobilanthes hirta (Vahl) Blume	Acanthaceae Juss.	Lamiales	Native
519	*Staurogyne glutinosa* (Wall. ex C.B.Clarke) Kuntze	Acanthaceae Juss.	Lamiales	Native
520	Haplophragma adenophyllum (Wall. ex G.Don) Dop	Bignoniaceae Juss.	Lamiales	Native
521	*Jacaranda mimosifolia* D.Don	Bignoniaceae Juss.	Lamiales	Exotic
522	*Anisomeles indica* (L.) Kuntze	Lamiaceae Martinov	Lamiales	Native
523	*Ajuga integrifolia* Buch.-Ham. ex D.Don	Lamiaceae Martinov	Lamiales	Native
524	*Clinopodium umbrosum* (M.Bieb.) K.Koch	Lamiaceae Martinov	Lamiales	Native
525	*Callicarpa macrophylla* Vahl	Lamiaceae Martinov	Lamiales	Native
526	*Clerodendrum viscosum* Vent.	Lamiaceae Martinov	Lamiales	Native
527	Clerodendrum phlomidis L.f.	Lamiaceae Martinov	Lamiales	Native
528	*Colebrookia oppositifolia* Sm.	Lamiaceae Martinov	Lamiales	Native
529	*Hyptis suaveolens* (L.) Poit.	Lamiaceae Martinov	Lamiales	Exotic
530	*Leonotis nepetifolia* (L.) R. Br.	Lamiaceae Martinov	Lamiales	Native
531	*Leucas aspera* (Willd.) Link	Lamiaceae Martinov	Lamiales	Native
532	*Leucas biflora* (Vahl) Sm.	Lamiaceae Martinov	Lamiales	Native
533	*Leucas cephalotes* (Roth)Spreng.	Lamiaceae Martinov	Lamiales	Native
534	*Leucas martinicensis* (Jacq.) R.Br.	Lamiaceae Martinov	Lamiales	Native
535	*Leonurus sibiricus* L.	Lamiaceae Martinov	Lamiales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Chinese Foldwing	Herb	-	Moist loving	-	-
Panicled foldwing	Herb	-	Moist loving	-	-
Rosy eranthemum	Herb	-	T	-	LC
Marsh Barbel	Herb	-	SA	Marshy	LC
Dwarf hygrophila	Herb	-	A	EM	LC
Erect Hygrophila	Shrub	-	SA	Marshy	-
Marsh Carpet	Shrub	-	SA	Marshy	-
Blue Pussyleaf	Shrub	-	Moist loving	-	LC
Adulsa	Shrub	-	Moist loving	-	LC
Willow-leaved justicia	Shrub	-	T	-	-
Elegant Rungia	Herb	-	Moist loving	-	-
Comb Rungia	Herb	-	Moist loving	-	-
Simple Justicia	Herb	-	Moist loving	-	-
Five-Angled Justicia	Herb	-	SA	Marshy	LC
Curved Lepidagathis	Herb	-	Moist loving	-	-
Pointed-Leaf Lepidagathis	Herb	-	Moist loving	-	-
Barleria Petal-Bush	Shrub	-	T	-	-
Bell Weed	Herb	-	Moist loving	-	-
Hairy Coneflower	Herb	-	Moist loving	-	-
-	Herb	-	Moist loving	-	-
Karen wood	Tree	-	T	-	LC
Blue Jacaranda	Tree	-	T	-	VU
Indian catmint	Shrub	-	Moist loving	-	-
Neelkanthi	Herb	-	Moist loving	-	-
Shady Calamint	Herb	-	Moist loving	-	-
Large leaf beauty berry	Shrub	-	Moist loving	-	LC
Hill glory bower	Shrub	-	Moist loving	-	-
Agnimantha	Shrub	-	Moist loving	-	LC
Indian Squirrel til	Shrub	-	Moist loving	-	-
American mint	Shrub	-	Moist loving	-	-
Lions Ear leonotis	Shrub	-	Moist loving	-	-
Common Leucas	Herb	-	Moist loving	-	-
Two-Flowered Leucas	Herb	-	Moist loving	-	-
Head leucas	Herb	-	Moist loving	-	-
Whitewort	Herb	-	Moist loving	-	-
Honeyweed	Herb	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
536	*Micromeria biflora* (Buch.-Ham. Ex D.Don) Benth.	Lamiaceae Martinov	Lamiales	Native
537	*Nepeta hindostana* (B.Heyne ex Roth) Haines	Lamiaceae Martinov	Lamiales	Native
538	*Ocimum americanum* L.	Lamiaceae Martinov	Lamiales	Native
539	*Ocimum tenuiflorum* L.	Lamiaceae Martinov	Lamiales	Native
540	*Pseudocaryopteris bicolor* (Roxb. ex Hardw.) P.D.Cantino	Lamiaceae Martinov	Lamiales	Native
541	*Pogostemon crassicaulis* (Benth.) Press	Lamiaceae Martinov	Lamiales	Native
542	*Pogostemon benghalensis* (Burm.f.) Kuntze	Lamiaceae Martinov	Lamiales	Native
543	*Perilla frutescens* (L.) Britton	Lamiaceae Martinov	Lamiales	Native
544	*Salvia plebeia* R.Br.	Lamiaceae Martinov	Lamiales	Native
545	*Tectona grandis* L.f.	Lamiaceae Martinov	Lamiales	Native
546	*Teucrium viscidum* Blume	Lamiaceae Martinov	Lamiales	Native
547	*Vitex negundo* L.	Lamiaceae Martinov	Lamiales	Native
548	*Pedalium murex* L.	Pedaliaceae R.Br.	Lamiales	Native
549	Bonnaya antipoda (L.) Druce	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
550	*Bonnaya ciliata* (Colsm.) Spreng.	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
551	*Torenia crustacea* (L.) Cham. & Schltdl.	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
552	*Torenia anagallis* (Burm.f.) Wannan, W.R.Barker & Y.S.Liang	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
553	*Lindernia dubia* (L.) Pennell	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
554	*Lindernia tamilnadensis M.G.Prasad & Sunojk.*	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
555	Lindernia rotundifolia (L.) Alston M.G.Prasad & Sunojk.	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
556	*Lindernia procumbens* (Krock.) Philcox	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
557	*Lindernia hyssopioides* (L.) Haines	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
558	*Yamazakia viscosa* (Hornem.) W.R.Barker, Y.S.Liang & Wannan	Linderniaceae Borsch, K.Müll. &Eb.Fisch.	Lamiales	Native
559	*Mazus pumilus* (Burm.f.) Steenis	Mazaceae Reveal	Lamiales	Native
560	*Mazus surculosus* D.Don	Mazaceae Reveal	Lamiales	Native
561	*Oroxylum indicum* (L.) Benth. Ex Kurz	Bignoniaceae Juss.	Lamiales	Native
562	*Limnophila indica* (L.) Druce	Plantaginaceae Juss.	Lamiales	Native
563	*Limnophila aquatica* (Roxb.) Alston	Plantaginaceae Juss.	Lamiales	Native
564	*Limnophila rugosa* (Roth) Merr.	Plantaginaceae Juss.	Lamiales	Native
565	*Limnophila connata* (Buch.-Ham. ex D.Don) Hand.-Mazz.	Plantaginaceae Juss.	Lamiales	Native
566	*Plantago major* L.	Plantaginaceae Juss.	Lamiales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Lemon savory	Herb	-	Moist loving	-	-
North Indian catmint	Herb	-	Moist loving	-	-
American basil	Herb	-	Moist loving	-	-
Holi basil	Herb	-	Moist loving	-	-
Ban basuti	Shrub	-	T	-	-
	Herb	-	A	EM	DD
Bengal shrub-mint	Shrub	-	Moist loving	-	-
Perilla	Herb	-	Moist loving	-	LC
Sage Weed	Herb	-	Moist loving	-	-
Sag	Tree	-	T	-	LC
Sticky Germander.	Herb	-	Moist loving	-	-
Five-leaved chaste tree	Shrub	-	Moist loving	-	LC
Gokhru	Herb	-	Moist loving	-	-
Sparrow Lindernia	Herb	-	SA	Marshy	-
Fringed False Pimpernel	Herb	-	Moist loving	-	LC
Malaysian false pimpernel.	Herb	-	Moist loving	-	LC
Pimpernel Lindernia	Herb	-	SA	Marshy	-
Yellowseed Lindernia	Herb	-	Moist loving	-	-
Tamilnadu Lindernia	Herb	-	Moist loving	-	-
Roundleaf Lindernia	Herb	-	Moist loving	-	LC
-	Herb	-	Moist loving	-	LC
Hyssop Lindernia	Herb	-	SA	Marshy	-
Sticky Lindernia	Herb	-	Moist loving	-	-
Japanese mazus	Herb	-	Moist loving	-	-
Suckering Mazus	Herb	-	Moist loving	-	-
Indian trumpet tree	Tree	-	T	-	-
Indian Marshweed	Herb	-	A	EM	-
Water Marshweed	Herb	-	A	EM	-
Wrinkled Marshweed	Herb	-	SA	Marshy	LC
-	Herb	-	SA	Marshy	LC
Broadleaf plantain	Herb	-	Moist loving	-	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
567	*Scoparia dulcis* L.	Plantaginaceae Juss.	Lamiales	Exotic
568	*Veronica anagallis-aquatica* L.	Plantaginaceae Juss.	Lamiales	Native
569	*Veronica polita* Fr.	Plantaginaceae Juss.	Lamiales	Native
570	*Veronica persica* Poir.	Plantaginaceae Juss.	Lamiales	Native
571	*Veronica salina* Schur	Plantaginaceae Juss.	Lamiales	Native
572	*Bacopa monnieri* (L.) Wettst.	Plantaginaceae Juss.	Lamiales	Native
573	*Mecardonia procumbens* (Mill.) Small	Plantaginaceae Juss.	Lamiales	Exotic
574	*Misopates orontium* (Wall.) D.A.Sutton	Plantaginaceae Juss.	Lamiales	Native
575	*Nanorrhinum ramosissimum* (Wall.) Betsche	Plantaginaceae Juss.	Lamiales	Native
576	*Lindenbergia indica* (L.) Vatke	Orobanchaceae Vent.	Lamiales	Native
577	*Lindenbergia macrostachya* (Benth.) Benth.	Orobanchaceae Vent.	Lamiales	Native
578	*Lindenbergia muraria* (Roxb. ex D.Don)	Orobanchaceae Vent.	Lamiales	Native
579	*Orobanche cernua* Loefl.	Orobanchaceae Vent.	Lamiales	Native
580	*Jamesbrittenia dissecta* (Delile) Kuntze	Scrophulariaceae Juss.	Lamiales	Native
581	*Verbascum chinense* (L.) Santapau	Scrophulariaceae Juss.	Lamiales	Native
582	*Verbascum thapsus* Linnaeus	Scrophulariaceae Juss.	Lamiales	Native
583	*Buddleja asiatica* Lour.	Scrophulariaceae Juss.	Lamiales	Native
584	*Lantana camara* L.	Verbenaceae J.St.-Hil.	Lamiales	Exotic
585	*Lippia alba* (Mill.) N.E. Br. Britton & P.Wilson	Verbenaceae J.St.-Hil.	Lamiales	Exotic
586	*Phyla nodiflora* (L.)	Verbenaceae J.St.-Hil.	Lamiales	Native
587	*Verbena officinalis* L.	Verbenaceae J.St.-Hil.	Lamiales	Native
588	*Martynia annua* L.	Martyniaceae Horaninow	Lamiales	Exotic
589	*Utricularia australis* R.Br.	Lentibulariaceae Rich.	Lamiales	Native
590	*Utricularia aurea* Lour.	Lentibulariaceae Rich.	Lamiales	Native
591	*Utricularia gibba* L.	Lentibulariaceae Rich.	Lamiales	Native
592	*Camonea vitifolia* (Burm.f.) A.R.Simões & Staples	Convolvulaceae Juss.	Solanales	Native
593	*Convolvulus arvensis* L.	Convolvulaceae Juss.	Solanales	Native
594	*Cuscuta campestris* Yunck.	Convolvulaceae Juss.	Solanales	Exotic
595	*Cuscuta reflexa* Roxb.	Convolvulaceae Juss.	Solanales	Native
596	*Evolvulus nummularius* (L.) L.	Convolvulaceae Juss.	Solanales	Exotic
597	*Evolvulus alsinoides* (L.) L.	Convolvulaceae Juss.	Solanales	Native
598	*Merremia hederacea* (Burm.f.) Hallier f.	Convolvulaceae Juss.	Solanales	Native
599	*Merremia emarginata* (Burm.f.) Hallier f. Syn. *Merremia gangetica.*	Convolvulaceae Juss.	Solanales	Native
600	*Operculina turpethum* (L.) Silva Manso	Convolvulaceae Juss.	Solanales	Native
601	*Ipomoea aquatica* Forssk.	Convolvulaceae Juss.	Solanales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Sweet broom weed	Herb	-	Moist loving	-	-
Water speedwell	Herb	-	SA	Marshy	LC
Grey field-speedwell	Herb	-	SA	Marshy	-
Common field-speedwell	Herb	-	SA	Marshy	-
-	Herb	-	SA	Marshy	-
Brahmi	Herb	-	SA	Marshy	LC
Yellow flowered waterhyssop	Herb	-	Moist loving	-	-
Corn Snapdragon,	Herb	-	Moist loving	-	-
Indian Toadflax	Herb	-	Moist loving	-	-
Indian Lindenbergia	Herb	-	Moist loving	-	LC
West-Himalayan Lindenbergia	Herb	-	Moist loving	-	-
Wall Lindenbergia	Herb	-	Moist loving	-	-
Australian broomrape	Herb	-	Moist loving	-	-
Dissected-Leaf Sutera	Herb	-	Moist loving	-	NT
Chinese Mullein	Herb	-	Moist loving	-	-
Great mullein	Herb	-	Moist loving	-	LC
Asian Butterfly Bush	Shrub	-	Moist loving	-	LC
Common lantana	Shrub	-	Moist loving	-	-
Bushy lippia	Shrub	-	Moist loving	-	-
Turkey tangle frogfruit	Herb	-	Moist loving	-	LC
Herb of Grace	Herb	-	Moist loving	-	LC
Devils claws	Shrub	-	Moist loving	-	-
Golden Bladderwort	Herb	-	A	SUB	LC
Golden Bladderwort	Herb	-	A	SUB	LC
-	Herb	-	A	SUB	LC
Grape-leaf Wood Rose	Climber	-	Moist loving	-	-
Field bindweed	Climber	-	Moist loving	-	-
Golden Dodder	Climber	-	Epiphytic parasites	-	-
Giant dodder	Climber	-	Epiphytic parasites	-	LC
Roundleaf bindweed	Herb	-	Moist loving	-	-
Dwarf Morning Glory	Herb	-	Moist loving	-	-
Ivy rosewood	Climber	-	Moist loving	-	-
Kidney Leaf Morning Glory	Herb	-	Moist loving	-	-
Transparent wood Rose	Climber	-	Moist loving	-	-
Water morning glory	Herb	-	A	FF	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
602	*Ipomoea eriocarpa* R.Br.	Convolvulaceae Juss.	Solanales	Native
603	*Ipomoea carnea* Jacq.	Convolvulaceae Juss.	Solanales	Exotic
604	*Ipomoea nil* (L.) Roth	Convolvulaceae Juss.	Solanales	Exotic
605	*Ipomoea obscura* (L.) Ker Gawl.	Convolvulaceae Juss.	Solanales	Native
606	*Ipomoea triloba* L.	Convolvulaceae Juss.	Solanales	Exotic
607	*Ipomoea sagittifolia* Burm.f.	Convolvulaceae Juss.	Solanales	Native
608	Xenostegia tridentata (L.) D.F.Austin & Staples	Convolvulaceae Juss.	Solanales	Native
609	*Distimake aegyptius* (L.) A.R.Simões & Staples	Convolvulaceae Juss.	Solanales	Exotic
610	Datura metel L.	Solanaceae Juss.	Solanales	Exotic
611	*Datura innoxia* Mill.	Solanaceae Juss.	Solanales	Exotic
612	Nicotiana plumbaginifolia Viv.	Solanaceae Juss.	Solanales	Exotic
613	*Physalis minima* L.	Solanaceae Juss.	Solanales	Exotic
614	Physalis pruinosa L.	Solanaceae Juss.	Solanales	Exotic
615	*Solanum nigrum* L.	Solanaceae Juss.	Solanales	Native
616	Solanum sisymbriifolium Lam.	Solanaceae Juss.	Solanales	Exotic
617	*Solanum torvum* Sw.	Solanaceae Juss.	Solanales	Exotic
618	*Solanum violaceum* Ortega	Solanaceae Juss.	Solanales	Native
619	*Solanum virginianum* L.	Solanaceae Juss.	Solanales	Native
620	*Solanum erianthum* D. Don	Solanaceae Juss.	Solanales	Exotic
621	*Solanum chrysotrichum* Schltdl.	Solanaceae Juss.	Solanales	Exotic
622	*Solanum viarum* Dunal	Solanaceae Juss.	Solanales	Exotic
623	*Withania somnifera* (L.) Dunal	Solanaceae Juss.	Solanales	Native
624	Sphenoclea zeylanica Gaertn.	Sphenocleaceae T.Baskerv.	Solanales	Native
625	*Hydrolea zeylanica* (L.) Vahl	Hydroleaceae R.Br. ex Edwards	Solanales	Native
626	Hoppea dichotoma B.Heyne ex Willd.	Gentianaceae Juss.	Gentianales	Native
627	*Canscora diffusa* (Vahl) R.Br. ex Roem. & Schult.	Gentianaceae Juss.	Gentianales	Native
628	*Exacum tetragonum* Roxb.	Gentianaceae Juss.	Gentianales	Native
629	Asclepias curassavica L.	Apocynaceae Juss.	Gentianales	Exotic
630	*Alstonia scholaris* (L.) R.Br.	Apocynaceae Juss.	Gentianales	Native
631	Calotropis procera (Aiton) W.T. Aiton	Apocynaceae Juss.	Gentianales	Native
632	*Calotropis gigantea* (L.) Dryand.	Apocynaceae Juss.	Gentianales	Native
633	*Cryptolepis buchanani* Roem. & Schult.	Apocynaceae Juss.	Gentianales	Native
634	*Dregea volubilis* (L.f.) Benth. Ex Hook.f.	Apocynaceae Juss.	Gentianales	Native
635	*Pergularia daemia* (Forssk.) Chiov.	Apocynaceae Juss.	Gentianales	Native
636	*Pentatropis capensis* (L.f.) Bullock	Apocynaceae Juss.	Gentianales	Native
637	*Hemidesmus indicus* (L.) R. Br.	Apocynaceae Juss.	Gentianales	Native
638	*Ichnocarpus frutescens* (L.) W.T. Aiton	Apocynaceae Juss.	Gentianales	Native
639	*Oxystelma esculentum* (L.f.) Sm.	Apocynaceae Juss.	Gentianales	Native
640	*Vallaris solanacea* (Roth) Kuntze	Apocynaceae Juss.	Gentianales	Native
641	*Centaurium pulchellum* L.	Gentianaceae Juss	Gentianales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Tiny morning glory	Climber	-	Moist loving		-
Bush morning glory	Shrub	-	SA	Marshy	-
Japanese morning glory	Climber	-	Moist loving	-	-
Obscure morning glory	Climber	-	Moist loving	-	-
Little bell morning glory	Climber	-	Moist loving	-	LC
	Climber	-	Moist loving	-	LC
Arrow-leaf Morning Glory	Climber	-	Moist loving	-	-
-	Climber	-	T	-	-
Purple Thorn-Apple	Herb	-	Moist loving	-	-
Datura	Herb	-	Moist loving	-	-
Tex-Mex tobacco	Herb	-	Moist loving	-	-
Wild cape gooseberry	Herb	-	Moist loving	-	-
Strawberry Tomato	Herb	-	Moist loving	-	LC
European black nightshade	Herb	-	Moist loving	-	-
Sticky nightshade	Herb	-	Moist loving	-	-
Turkey Berry	Shrub	-	Moist loving	-	-
Asian nightshade	Herb	-	Moist loving	-	-
Indian nightshade	Herb	-	Moist loving	-	-
Big Eggplant	Tree	-	Moist loving	-	LC
Giant Devil's Fig	Shrub	-	Moist loving	-	LC
Tropical soda apple	Shrub	-	Moist loving	-	LC
Ashwagandha	Shrub	-	Moist loving	-	DD
Chickenspike	Herb	-	SA	Marshy	LC
Ceylon Hydrolea	Herb	-	SA	Marshy	LC
Indian Hoppea	Herb	-	SA	Marshy	-
Spreading Canscora	Herb	-	SA	Marshy	-
Bicolor Persian violet	Herb	-	SA	Marshy	LC
Scarlet Milkweed	Herb	-	SA	Marshy	-
Blackboard tree	Tree	-	T	-	LC
Giant milkweed	Shrub	-	Moist loving	-	-
Crown flower	Shrub	-	Moist loving	-	-
Indian Sarsaparilla	Climber	-	Moist loving	-	-
Green milkweed climber	Climber	-	Moist loving	-	-
Trellis-vine	Climber	-	Moist loving	-	LC
-	Climber	-	T	-	LC
Anantamul	Climber	-	Moist loving	-	-
Black creeper	Climber	-	Moist loving	-	-
Rosy Milkweed Vine.	Climber	-	SA	Marshy	LC
Bread flower	Climber	-	Moist loving	-	-
Lesser Centaury	Herb	-	Moist loving	-	LC

S.no	Plant Name (Botanical name)	Family	Order	Nativity
642	*Haldina cordifolia* (Roxb.) Ridsdale	Rubiaceae Juss.	Gentianales	Native
643	*Mitragyna parviflora* (Roxb.) Korth.	Rubiaceae Juss.	Gentianales	Native
644	*Neolamarckia cadamba* (Roxb.) Bosser	Rubiaceae Juss.	Gentianales	Native
645	*Oldenlandia biflora* L.	Rubiaceae Juss.	Gentianales	Native
646	*Morinda pubescens* Sm.	Rubiaceae Juss.	Gentianales	Native
647	*Oldenlandia corymbosa* L.	Rubiaceae Juss.	Gentianales	Native
648	*Oldenlandia herbacea* (L.) Roxb.	Rubiaceae Juss.	Gentianales	Native
649	*Spermacoce ocymoides* Burm.f.	Rubiaceae Juss.	Gentianales	Native
650	*Spermacoce articularis* L.f.	Rubiaceae Juss.	Gentianales	Native
651	*Gardenia latifolia* Aiton	Rubiaceae Juss.	Gentianales	Native
652	*Richardia scabra* L.	Rubiaceae Juss.	Gentianales	Exotic
653	*Scleromitrion verticillatum* (L.) R.J.Wang	Rubiaceae Juss.	Gentianales	Native
654	*Spermadictyon suaveolens* Roxb.	Rubiaceae Juss.	Gentianales	Native
655	*Wendlandia heynei* (Schult.) Santapau & Merchant	Rubiaceae Juss.	Gentianales	Native
656	*Dentella repens* (L.) J.R.Forst. & G.Forst.	Rubiaceae Juss.	Gentianales	Native
657	*Galium aparine* L.	Rubiaceae Juss.	Gentianales	Native
658	Bothriospermum zeylanicum (J.Jacq.) Druce	Boraginaceae Juss.	Gentianales	Native
659	*Cordia dicotoma* G. Forst.	Boraginaceae Juss.	Gentianales	Native
660	*Coldenia procumbens* L.	Boraginaceae Juss.	Gentianales	Native
661	*Cynoglossum lanceolatum* Forssk.	Boraginaceae Juss.	Gentianales	Native
662	*Heliotropium indicum* L.	Boraginaceae Juss.	Gentianales	Exotic
663	*Heliotropium ovalifolium* Forssk.	Boraginaceae Juss.	Gentianales	Native
664	*Heliotropium strigosum* Willd.	Boraginaceae Juss.	Gentianales	Native
665	*Trichodesma indicum* (L.) R. Br.	Boraginaceae Juss.	Gentianales	Native
666	Ehretia acuminata (DC.) R. Br.	Boraginaceae Juss.	Gentianales	Native
667	*Ehretia laevis* Roxb.	Boraginaceae Juss.	Gentianales	Native
668	Artemisia vulgaris L.	Asteraceae Bercht. & J.Presl	Asterales	Native
669	*Ageratum conyzoides* L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
670	Ageratum houstonianum Mill.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
671	*Acmella ciliata* (Kunth) Cass.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
672	*Acmella paniculata* (Wall. ex DC.) R.K.Jansen	Asteraceae Bercht. & J.Presl	Asterales	Native
673	*Bidens pilosa* L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
674	*Blumea axillaris* (Lam.) DC.	Asteraceae Bercht. & J.Presl	Asterales	Native
675	*Blumea lacera* (Burm.f.) DC.	Asteraceae Bercht. & J.Presl	Asterales	Native
676	*Blumea sinuata* (Lour.) Merr.	Asteraceae Bercht. & J.Presl	Asterales	Native
677	*Blumea oxyodonta* DC.	Asteraceae Bercht. & J.Presl	Asterales	Native
678	*Caesulia axillaris* Roxb.	Asteraceae Bercht. & J.Presl	Asterales	Native
679	Calyptocarpus vialis Less.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
680	*Chromolaena odorata* (L.) R.M.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
681	*Cirsium arvense* (L.) Scop.	Asteraceae Bercht. & J.Presl	Asterales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Haldu	Tree	-	T	-	-
Kalamb	Tree	-	T	-	-
Kadamb	Tree	-	T	-	-
Two flower mille graines	Herb	-	Moist loving	-	-
Aal	Tree	-	T		
Corymb diamond flower.	Herb	-	Moist loving	-	LC
Slender Diamond Flower	Herb	-	Moist loving	-	LC
Basil Buttonweed	Herb	-	Moist loving	-	-
Jointed Buttonweed	Herb	-	Moist loving	-	-
Indian Boxwood	Tree	-	T	-	-
Rough Mexican clover	Herb	-	Moist loving	-	-
	Herb	-	Moist loving	-	-
Forest Champa	Shrub	-	Moist loving	-	-
Heyne's Wendlandia	Tree	-	SA	Riparian	LC
Creeping Dentella	Herb	-	Moist loving	-	LC
Goose Grass, Cleavers	Herb	-	Moist loving	-	LC
-	Herb	-	Moist loving	-	-
Fragrant manjack	Tree	-	Moist loving	-	-
Creeping Coldenia	Herb	-	Moist loving	-	LC
Lanceleaf Forget-Me-Not	Herb	-	Moist loving	-	-
Indian heliotrope	Herb	-	Moist loving	-	-
Grey Leaf Heliotrope	Herb	-	Moist loving	-	LC
Bristly Heliotrope	Herb	-	Moist loving	-	-
Indian Borage	Herb	-	Moist loving	-	-
Koda Tree	Tree	-	Moist loving	-	LC
Chamror	Tree	-	Moist loving	-	DD
Common mugwort	Shrub	-	Moist loving	-	LC
Goatweed	Herb	-	Moist loving	-	LC
Blueweed	Herb	-	Moist loving	-	-
Toothache Plant	Herb	-	Moist loving	-	-
Panicled Spot Flower	Herb	-	Moist loving	-	LC
Beggar's Tick	Herb	-	Moist loving	-	-
Soft Blumea	Herb	-	Moist loving	-	-
Lettuce-Leaf Blumea	Herb	-	Moist loving	-	-
Sow-Thistle Blumea	Herb	-	Moist loving	-	-
Spiny Leaved Blumea	Herb	-	Moist loving	-	-
Pink node flower	Herb	-	SA	Marshy	LC
Creeping Cinderella-weed	Herb	-	Moist loving	-	-
Devil weed	Herb	-	Moist loving	-	-
Field Thistle	Herb	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
682	*Cirsium wallichii* DC. | Species	Asteraceae Bercht. & J.Presl	Asterales	Native
683	*Cichorium intybus* L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
684	*Cyanthillium cinereum* (L.) H.Rob.	Asteraceae Bercht. & J.Presl	Asterales	Native
685	*Cyathocline purpurea* (Buch.-Ham. ex D.Don) Kuntze	Asteraceae Bercht. & J.Presl	Asterales	Native
686	Dichrocephala integrifolia (L.f.) Kuntze	Asteraceae Bercht. & J.Presl	Asterales	Native
687	*Eclipta prostrata* (L.) L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
688	Elephantopus scaber L.	Asteraceae Bercht. & J.Presl	Asterales	Native
689	*Erigeron bonariensis* L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
690	Erigeron canadensis L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
691	*Eschenbachia japonica* (Thunb.) J.Kost. Syn. *Erigeron japonicus* Thunb.	Asteraceae Bercht. & J.Presl	Asterales	Native
692	*Erigeron sublyratus* Roxb. ex DC.	Asteraceae Bercht. & J.Presl	Asterales	Native
693	*Enydra fluctuans* Lour.	Asteraceae Bercht. & J.Presl	Asterales	Native
694	*Eupatorium adenophorum* Spreng.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
695	*Eupatorium riparium* Regel	Asteraceae Bercht. & J.Presl	Asterales	Exotic
696	*Pseudognaphalium luteoalbum* (L.) Hilliard & B.L.Burtt	Asteraceae Bercht. & J.Presl	Asterales	Native
697	*Gnaphalium pensylvanicum* Willd.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
698	*Gnaphalium polycaulon* Pers.	Asteraceae Bercht. & J.Presl	Asterales	Native
699	*Gnaphalium pulvinatum* Delile	Asteraceae Bercht. & J.Presl	Asterales	Native
700	*Grangea maderaspatana* (L.) Poir.	Asteraceae Bercht. & J.Presl	Asterales	Native
701	*Grangea minima* (L.) Dum.Cours.	Asteraceae Bercht. & J.Presl	Asterales	Native
702	*Galinsoga parviflora* Cav.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
703	*Gynura crepidioides* Benth.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
704	*Parthenium hysterophorus* L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
705	*Pluchea lanceolata* (DC.) Oliv. & Hiern	Asteraceae Bercht. & J.Presl	Asterales	Native
706	Pulicaria undulata (L.) C.A.Mey.	Asteraceae Bercht. & J.Presl	Asterales	Native
707	*Tridax procumbens* L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
708	*Launaea procumbens* (Roxb.) Ramayya & Rajagopal	Asteraceae Bercht. & J.Presl	Asterales	Native
709	*Mikania micrantha* Kunth	Asteraceae Bercht. & J.Presl	Asterales	Exotic
710	Oligochaeta ramosa (Roxb.) Wagenitz	Asteraceae Bercht. & J.Presl	Asterales	Native
711	*Sigesbeckia orientalis* L.	Asteraceae Bercht. & J.Presl	Asterales	Native
712	*Soliva anthemifolia* (Juss.) Sweet	Asteraceae Bercht. & J.Presl	Asterales	Exotic
713	*Sonchus asper* (L.) Hill	Asteraceae Bercht. & J.Presl	Asterales	Exotic
714	*Sonchus oleraceus* L.	Asteraceae Bercht. & J.Presl	Asterales	Exotic
715	*Sonchus wightianus* DC.	Asteraceae Bercht. & J.Presl	Asterales	Native
716	*Sphagneticola calendulacea* (L.) Pruski	Asteraceae Bercht. & J.Presl	Asterales	Native
717	*Sphaeranthus indicus* L.	Asteraceae Bercht. & J.Presl	Asterales	Native
718	*Xanthium strumarium* L.	Asteraceae Bercht. & J.Presl	Asterales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Wallich's Thistle	Herb	-	Moist loving	-	-
Chicory	Herb	-	Moist loving	-	LC
Little ironweed	Herb	-	Moist loving	-	-
Gangotra	Herb	-	Moist loving	-	LC
Bentham's Buttonweed	Herb	-	Moist loving	-	-
False daisy	Herb	-	Moist loving	-	LC
Prickly-leaved elephant's foot	Herb	-	Moist loving	-	-
Flaxleaf Fleabane	Herb	-	Moist loving	-	-
Canadian fleabane	Herb	-	Moist loving	-	-
Dwarf lilyturf	Herb	-	Moist loving	-	-
-	Herb	-	Moist loving	-	-
Buffalo Spinach	Herb	-	A	FF	LC
Catweed	Herb	-	Moist loving	-	-
Mistflower	Herb	-	Moist loving	-	-
Weedy Cudweed	Herb	-	Moist loving	-	LC
Pennsylvania Cudweed	Herb	-	Moist loving	-	-
Many-Stemmed Cudweed	Herb	-	Moist loving	-	LC
Prostrate gnaphalium	Herb	-	Moist loving	-	DD
Madras carpet	Herb	-	Moist loving	-	LC
Spreading Sneeze Weed	Herb	-	Moist loving	-	-
Quick Weed	Herb	-	Moist loving	-	-
Redflower ragleaf	Herb	-	Moist loving	-	-
Carrot weed	Herb	-	Moist loving	-	-
Rasna	Herb	-	Moist loving	-	-
Desert Golden Daisy	Herb	-	Moist loving	-	-
Tridax daisy	Herb	-	Moist loving	-	-
Creeping Launaea	Herb	-	Moist loving	-	-
Bitter vine	Climber	-	Moist loving	-	-
Branched Sweet-Sultan	Herb	-	Moist loving	-	-
Indian-weed	Herb	-	Moist loving	-	-
Button Burrweed	Herb	-	Moist loving	-	LC
Prickly sow-thistle	Herb	-	Moist loving	-	-
Common sowthistle	Herb	-	Moist loving	-	-
Bitter Sow-Thistle	Herb	-	Moist loving	-	-
Chinese Wedelia	Herb	-	Moist loving	-	LC
East Indian Globe Thistle	Herb	-	Moist loving	-	LC
Common cocklebur	Herb	-	Moist loving	-	-

S.no	Plant Name (Botanical name)	Family	Order	Nativity
719	*Pentanema indicum* (L.) Y.Ling	Asteraceae Bercht. & J.Presl	Asterales	Native
720	*Youngia japonica* (L.) DC.	Asteraceae Bercht. & J.Presl	Asterales	Native
721	*Laggera crispata* (Vahl) Hepper & J.R.I.Wood	Asteraceae Bercht. & J.Presl	Asterales	Native
722	*Laggera aurita Benth.* ex C.B.Clarke syn., *Pseudoconyza viscosa* (Mill.) D'Arcy	Asteraceae Bercht. & J.Presl	Asterales	Native
723	*Jurinea heteromalla* (D.Don) N.Garcia, Herrando & Susanna	Asteraceae Bercht. & J.Presl	Asterales	Native
724	*Nymphoides cristata* (Roxb.) Kuntze	Menyanthaceae Dumort.	Asterales	Native
725	*Nymphoides indica* (L.) Kuntze	Menyanthaceae Dumort.	Asterales	Native
726	*Campanula dimorphantha* Schweinf.	Campanulaceae Juss.	Asterales	Native
727	*Lobelia alsinoides* Lam.	Campanulaceae Juss.	Asterales	Native
728	*Wahlenbergia marginata* (Thunb.) A.DC.	Campanulaceae Juss.	Asterales	Native
729	*Pittosporum napaulense* (DC.) Rehder & E.H.Wilson	Pittosporaceae R.Br.	Apiales	Native
730	*Centella asiatica* (L.) Urb.	Apiaceae Lindl.	Apiales	Native
731	*Cnidium monnieri* (L.) Cusson	Apiaceae Lindl.	Apiales	Native
732	*Daucus carota* L.	Apiaceae Lindl.	Apiales	Exotic
733	*Hydrocotyle sibthorpioides* Lam.	Apiaceae Lindl.	Apiales	Native
734	*Oenanthe javanica* (Blume) DC.	Apiaceae Lindl.	Apiales	Native
735	*Cyclospermum leptophyllum* (Pers.) Sprague ex Britton & P.Wilson	Apiaceae Lindl.	Apiales	Exotic
736	*Pinus roxburghii* Sarg.	Pinaceae Spreng. ex F.Rudolphi	Pinales	Native
737	Pinus wallichiana A.B.Jacks.	Pinaceae Spreng. ex F.Rudolphi	Pinales	Native
738	*Cedrus deodara* (Roxb. ex D.Don) G.Don	Pinaceae Spreng. ex F.Rudolphi	Pinales	Native
739	*Abies spectabilis* (D.Don) Mirb.	Pinaceae Spreng. ex F.Rudolphi	Pinales	Native
740	*Cupressus torulosa* D.Don ex Lamb.	Cupressaceae Bartlett	Cupressales	Native
741	*Juniperus chinensis* L.	Cupressaceae Bartlett	Cupressales	Native
742	*Juniperus semiglobosa* Regel	Cupressaceae Bartlett	Cupressales	Native
743	*Azolla pinnata* R.Br.	Salviniaceae Martinov	Salviniales	Native
744	*Salvinia natans* (L.) All.	Salviniaceae Martinov	Salviniales	Native
745	*Salvinia molesta* D.Mitch.	Salviniaceae Martinov	Salviniales	Exotic
746	*Marsilea minuta* L.	Marsileaceae Mirb.	Salviniales	Native
747	*Ceratopteris thalictroides* (L.) Brongn.	Pteridaceae E.D.M.Kirchn.	Polypodiales	Native

Common name	Habit	Grasses sub category	Habitat	Sub-catergory	IUCN status
Sonkadi	Herb	-	Moist loving	-	-
Oriental false hawksbeard	Herb	-	Moist loving	-	-
Curly Blumea	Herb	-	Moist loving	-	-
Sticky Blumea	Herb	-	Moist loving	-	-
Himalayan Thornless Thistle	Herb	-	Moist loving	-	-
Creasted floating heart	Herb	-	A	FF	LC
Water snow flake	Herb	-	A	FF	LC
Two formed bell flower	Herb	-	Moist loving	-	-
Chickweed Lobelia	Herb	-	SA	Marshy	LC
Asiatic Bellflower	Herb	-	Moist loving	-	-
Raini	Tree	-	SA	Riparian	LC
Asiatic pennywort	Herb	-	SA	Marshy	LC
Jashoshi	Herb	-	Moist loving	-	-
European wild carrot	Herb	-	Moist loving	-	LC
Water Pennywort	Herb	-	SA	Marshy	LC
Java waterdropwort	Herb	-	Moist loving		LC
Marsh Parsley	Herb	-	Moist loving	-	-
Chir pine	Tree	-	T	-	LC
-	Tree	-	T	-	LC
Deodar	Tree	-	T	-	LC
-	Tree	-	T	-	NT
Himalayan Cypress	Tree	-	T	-	LC
Chinese juniper	Tree	-	T	-	LC
Himalayan pencil juniper	Shrub	-	T	-	LC
Feathered mosquitofern	Herb	-	A	FF	LC
-	Herb	-	A	FF	LC
Giant salvinia	Herb	-	A	FF	NE
Dwarf waterclover	Herb	-	SA	Marshy	LC
Water sprite	Herb	-	SA	Marshy	LC



ANNEXURE II

List of Odonata species observed in the sampling sites of the Ganga River (Systematic position by Dijkstra et al. 2013)

Order: Odonata Fabricius, 1793

Suborder: Anisoptera Selys, 1854

Superfamily: Ghompoidae Rambur, 1842

Family: Ghomphidae Rampur, 1842

Ictinogomphus rapax Rambur, 1842- Indian Common Clubtail

Superfamily: Libelluloidae Leach, 1815

Family: Libellulidae Leach, 1815

Acisoma panorpoides Rambur 1842- Trumpet tail

Barchythemis contaminata Fabricius, 1793- Ditch Jewel

Crocothemis Servilia Drury, 1770 - Scarlet skimmer

Diplacodes trivialis Rambur, 1842-Blue ground Skimmer

Indothemis carnatica Fabricius, 1798- Light-tipped Demon

Orthetrum sabina Drury, 1770- Green Marsh Hawk

Orthetrum pruinosum Burmeister, 1839-Crimson-tailed Marsh Hawk

Pantala flavescens Fabricius, 1798-Wandering Glider

Palpopleura sexmaculata Fabricius, 1787-Blue-tailed Yellow Skimmer

Rhodothemis rufa Rambur, 1842- Rufous Marsh Glider

Tholymis tillarga Fabricius, 1798-Coral-tailed Clouding

Trithemis festiva Rambur, 1842- Black Stream Glider

Trithemis pallidinervis Kirby, 1889- Long-Legged Marsh Glider

Urothemis Signata Rambur, 1842- Great Crimson

Suborder: Zygoptera

Superfamily: Coenagrionoidea

Family: Coenagrionidae

Agriocnemis femina Brauer, 1868- Pruinosed Dartlet

Agriocnemis lacteol Selys, 1877- Milky Dartlet

Agriocnemis pygmaea Rambur, 1842- Pygmy Dartlet

Amphiallagma parvum Selys, 1876- Azure Dartlet

Ceriagrion cerinorubellum Brauer, 1865- Orange-tailed Marsh Dart

Ceriagrion coromandelianum Fabricius, 1798-Coromandel Marsh Dart

Ceriagrion cf chromothorax Joshi & Sawant, 2019- Sindhudurg Marsh

Ischnura forcipata Morton, 1907- Forcipate Dartlet

Ischnura nursei Morton, 1907- Pixie Dartlet

Ischnura rubilio Selys, 1876- Western Golden Dartlet

Paracercion calamorum Ris, 1916- Dusky Lilly-squatter

Pseudagrion decorum Rambur, 1842 -Three-lined Sprite

Pseudagrion rubriceps Selys, 1876-Saffron-faced Blue Sprite

Pseudagrion microcephalum Rambur, 1842 - Blue Sprite

Family: Platycnemididae

Calicnemia eximia Selys, 1863

ANNEXURE III

Checklist of the fish species recorded (previous and present studies) in the Ganga River

S. No.	Scientific name	Order	Family
1	*Carcharhinus leucas* (Valenciennes 1839)	Carcharhiniformes	Carcharhinidae
2	*Glyphis gangeticus* (Müller & Henle 1839)	Carcharhiniformes	Carcharhinidae
3	*Scoliodon laticaudus* Müller & Henle 1838	Carcharhiniformes	Carcharhinidae
4	*Brevitrygon walga* (Müller & Henle 1841)	Myliobatiformes	Dasyatidae
5	*Himantura marginata* (Blyth 1860)	Myliobatiformes	Dasyatidae
6	*Pastinachus sephen* (Fabricius 1775)	Myliobatiformes	Dasyatidae
7	*Chitala chitala* (Hamilton 1822)	Osteoglossiformes	Notopteridae
8	*Notopterus synurus* (Bloch & Schneider 1801)	Osteoglossiformes	Notopteridae
9	*Anguilla bengalensis* (Gray 1831)	Anguilliformes	Anguillidae
10	*Pisodonophis boro* (Hamilton 1822)	Anguilliformes	Ophichthidae
11	*Coilia dussumieri* Valenciennes 1848	Clupeiformes	Engraulidae
12	*Coilia ramcarati* (Hamilton 1822)	Clupeiformes	Engraulidae
13	*Setipinna brevifilis* (Valenciennes 1848)	Clupeiformes	Engraulidae
14	*Setipinna phasa* (Hamilton 1822)	Clupeiformes	Engraulidae
15	*Setipinna taty* (Valenciennes 1848)	Clupeiformes	Engraulidae
16	*Setipinna tenuifilis* (Valenciennes 1848)	Clupeiformes	Engraulidae
17	*Thryssa malabarica* (Bloch 1795)	Clupeiformes	Engraulidae
18	*Ilisha elongata* (Anonymous [Bennett] 1830)	Clupeiformes	Pristigasteridae
19	*Ilisha megaloptera* (Swainson 1839)	Clupeiformes	Pristigasteridae
20	*Pellona ditchela* Valenciennes 1847	Clupeiformes	Pristigasteridae
21	*Corica soborna* Hamilton 1822	Clupeiformes	Ehiravidae
22	*Anodontostoma chacunda* (Hamilton 1822)	Clupeiformes	Dorosomatidae
23	*Escualosa thoracata* (Valenciennes 1847)	Clupeiformes	Dorosomatidae
24	*Gonialosa manmina* (Hamilton 1822)	Clupeiformes	Dorosomatidae
25	*Gudusia chapra* (Hamilton 1822)	Clupeiformes	Dorosomatidae
26	*Gudusia variegata* (Day 1870)	Clupeiformes	Dorosomatidae
27	*Tenualosa ilisha* (Hamilton 1822)	Clupeiformes	Dorosomatidae
28	*Botia almorhae* Gray 1831	Cypriniformes	Botiidae
29	*Botia dario* (Hamilton 1822)	Cypriniformes	Botiidae
30	*Botia lohachata* Chaudhuri 1912	Cypriniformes	Botiidae
31	*Botia rostrata* Günther 1868	Cypriniformes	Botiidae
32	*Canthophrys gongota* (Hamilton 1822)	Cypriniformes	Cobitidae
33	*Lepidocephalichthys guntea* (Hamilton 1822)	Cypriniformes	Cobitidae
34	*Pangio pangia* (Hamilton 1822)	Cypriniformes	Cobitidae
35	*Aborichthys elongatus* Hora 1921	Cypriniformes	Nemacheilidae
36	*Nemacheilus corica* (Hamilton 1822)	Cypriniformes	Nemacheilidae
37	*Paracanthocobitis botia* (Hamilton 1822)	Cypriniformes	Nemacheilidae
38	*Paracanthocobitis mooreh* (Sykes 1839)	Cypriniformes	Nemacheilidae
39	*Paraschistura montana* (McClelland 1838)	Cypriniformes	Nemacheilidae
40	*Schistura devdevi* (Hora 1935)	Cypriniformes	Nemacheilidae
41	*Schistura doonensis* (Tilak & Husain 1977)	Cypriniformes	Nemacheilidae

Common Name	IUCN Status	Previous Studies	2019	2023	2024
Bull shark	VU	-	-	-	+
Ganges shark	CR	8,13,16,18	-	-	-
Spadenose shark	NT	2,4,5	-	-	-
Bengal whipray	NT	4,5	-	-	-
Blackedge whipray	DD	8,16	-	-	-
Cowtail stingray	NT	1,2,6,8,13,16,18	-	-	-
Clown knifefish	NT	1,2,3,4,5,6,7,8,10,11,12,14,15,16,17,18	+	+	+
Bronze featherback	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	-	+
Indian mottled eel	NT	1,2,3,4,5,8,10,12,13,16,18	+	-	-
Rice-paddy eel	LC	2,3,4,5,6,8,13,16,18	-	-	+
Goldspotted grenadier anchovy	LC	2,4,5,8,16	-	-	-
Ramcarat grenadier anchovy	DD	6,8,13,16,18	-	-	+
Short-hairfin anchovy	DD	2,3,4,5,8,12,13,14,17,18	+	-	-
Gangetic hairfin anchovy	LC	1,2,3,4,5,6,8,10,11,12,13,14,15,16,17,18	+	+	+
Scaly hairfin anchovy	LC	2,4,5,8,13,14,18	-	-	-
Common hairfin anchovy	DD	2,4,5	-	-	-
Hamilton's thryssa	LC	13,16,18	-	-	-
Elongate ilisha	LC	2,4,5,8,14	-	-	-
Bigeye ilisha	LC	1,2,3,4,5,6,8,10,13,18	-	-	-
Indian pellona	LC	2,4,5	-	-	-
Ganges river sprat	LC	2,3,4,5,6,8,11,13,16,18	-	-	-
Chacunda gizzard shad	LC	2,4,5,6,8,13,16,18	-	-	-
White sardine	LC	2,3,4,5,18	-	-	-
Ganges river gizzard shad	LC	1,2,3,4,5,6,8,10,12,13,14,16,18	+	+	+
Indian river shad	LC	1,2,3,4,5,6,8,10,11,12,13,14,15,16,17,18	+	+	+
Burmese river shad	LC	1,8	-	-	-
Hilsa shad	LC	1,2,3,4,5,6,8,10,11,12,13,14,15,16,17,18	+	-	+
Almorha loach	LC	7,8,9,12,13,16,18	-	-	-
Bengal loach	LC	1,2,3,4,5,6,8,9,10,11,12,13,16,17,18	-	-	+
Reticulate loach	LC	1,2,3,4,5,8,9,10,11,12,13,16,17,18	+	+	+
Gangetic loach	VU	1,2,3,4,5,7,8,9,10,11,13,16,17,18	+	-	-
Gongota loach	LC	6,10,16	-	-	-
Guntea loach	LC	1,2,3,4,5,6,7,8,10,11,12,13,16,17,18	+	-	+
Pangia coolie-loach	LC	2,3,4,5,6,11,16,17,18	+	-	-
-	LC	2,3,4,5,10,18	-	-	-
Stone Loach	LC	6,8,11,12,13,16,18	-	-	+
Mottled loach	LC	1,2,3,4,5,6,7,8,10,11,12,13,16,17,18	+	-	+
-	LC	12,18	-	-	+
-	NE	8,11,12,16	-	-	-
-	NT	18	-	-	-
-	DD	7,13,18	-	-	-

S. No.	Scientific name	Order	Family
42	*Schistura gangetica* (Menon 1987)	Cypriniformes	Nemacheilidae
43	*Schistura multifasciata* (Day 1878)	Cypriniformes	Nemacheilidae
44	*Schistura rupecula* McClelland 1838	Cypriniformes	Nemacheilidae
45	*Acoura savona* (Hamilton 1822)	Cypriniformes	Nemacheilidae
46	*Schistura scaturigina* McClelland 1839.	Cypriniformes	Nemacheilidae
47	*Psilorhynchus balitora* (Hamilton 1822)	Cypriniformes	Psilorhynchidae
48	*Psilorhynchus sucatio* (Hamilton 1822)	Cypriniformes	Psilorhynchidae
49	*Bangana dero* (Hamilton 1822)	Cypriniformes	Cyprinidae
50	*Barbodes binotatus* (Valenciennes 1842)	Cypriniformes	Cyprinidae
51	*Chagunius chagunio* (Hamilton 1822)	Cypriniformes	Cyprinidae
52	*Cirrhinus mrigala* (Hamilton 1822)	Cypriniformes	Cyprinidae
53	*Cirrhinus reba* (Hamilton 1822)	Cypriniformes	Cyprinidae
54	*Cyprinus carpio* Linnaeus 1758	Cypriniformes	Cyprinidae
55	*Garra annandalei* Hora 1921	Cypriniformes	Cyprinidae
56	*Garra gotyla* (Gray 1830)	Cypriniformes	Cyprinidae
57	*Garra lamta* (Hamilton 1822)	Cypriniformes	Cyprinidae
58	*Gymnostomus ariza* (Hamilton 1807)	Cypriniformes	Cyprinidae
59	*Labeo angra* (Hamilton 1822)	Cypriniformes	Cyprinidae
60	*Labeo bata* (Hamilton 1822)	Cypriniformes	Cyprinidae
61	*Labeo boga* (Hamilton 1822)	Cypriniformes	Cyprinidae
62	*Labeo boggut* (Sykes 1839)	Cypriniformes	Cyprinidae
63	*Labeo calbasu* (Hamilton 1822)	Cypriniformes	Cyprinidae
64	*Labeo catla* (Hamilton 1822)	Cypriniformes	Cyprinidae
65	*Labeo dyocheilus* (McClelland 1839)	Cypriniformes	Cyprinidae
66	*Labeo fimbriatus* (Bloch 1795)	Cypriniformes	Cyprinidae
67	*Labeo gonius* (Hamilton 1822)	Cypriniformes	Cyprinidae
68	*Labeo nandina* (Hamilton 1822)	Cypriniformes	Cyprinidae
69	*Labeo pangusia* (Hamilton 1822)	Cypriniformes	Cyprinidae
70	*Labeo rohita* (Hamilton 1822)	Cypriniformes	Cyprinidae
71	*Naziritor chelynoides* (McClelland 1839)	Cypriniformes	Cyprinidae
72	*Osteobrama cotio* (Hamilton 1822)	Cypriniformes	Cyprinidae
73	*Pethia conchonius* (Hamilton 1822)	Cypriniformes	Cyprinidae
74	*Pethia gelius* (Hamilton 1822)	Cypriniformes	Cyprinidae
75	*Pethia guganio* (Hamilton 1822)	Cypriniformes	Cyprinidae
76	*Pethia phutunio* (Hamilton 1822)	Cypriniformes	Cyprinidae
77	*Pethia ticto* (Hamilton 1822)	Cypriniformes	Cyprinidae
78	*Puntius chola* (Hamilton 1822)	Cypriniformes	Cyprinidae
79	*Puntius puntio* (Hamilton 1822)	Cypriniformes	Cyprinidae
80	*Puntius sophore* (Hamilton 1822)	Cypriniformes	Cyprinidae
81	*Puntius terio* (Hamilton 1822)	Cypriniformes	Cyprinidae
82	*Schizopyge curvifrons* (Heckel 1838)	Cypriniformes	Cyprinidae
83	*Schizothorax esocinus* Heckel 1838	Cypriniformes	Cyprinidae
84	*Schizothorax kumaonensis* Menon 1971	Cypriniformes	Cyprinidae
85	*Schizothorax plagiostomus* Heckel 1838	Cypriniformes	Cyprinidae

Common Name	IUCN Status	Previous Studies	2019	2023	2024
-	LC	3,7,13,18	+	-	-
-	LC	8,11,16,18	-	-	-
-	LC	8,11,12,13,16,18	-	-	+
-	LC	6,8,11,13,16,18	-	-	-
-	LC	3,8,11,18	-	-	+
Balitora minnow	LC	6,7,9,11,13,16,18	-	-	+
River stone carp	LC	6,9,13,16,18	-	-	-
Kalabans	LC	1,3,4,5,6,7,8,10,11,12,13,16,17,18	+	+	+
Spotted barb	LC	12,18	-	-	-
Chaguni	LC	2,3,4,5,6,8,9,10,11,12,13,16,17,18	+	-	+
Mrigal	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18	+	+	+
Reba carp	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18	+	+	+
Common carp	LC	2,3,4,5,8,10,12,17,18	+	+	+
Annandale garra	LC	1,8,9,11,16,18	-	-	-
Sucker head	LC	1,2,4,5,7,8,9,10,12,13,14,16,17,18	+	+	+
Lamta garra	LC	3,6,8,9,11,16,18	-	-	-
Reba	LC	6	-	-	-
Angra labeo	LC	2,3,4,5,6,8,9,11,12,13,18	-	-	-
Bata	LC	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Boga Labeo	LC	2,3,4,5,6,8,10,11,13,14,16,17,18	+	-	+
Boggut labeo	LC	8,10,12,13,16,18	-	-	-
Orangefin labeo	LC	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Catla	LC	1,2,3,4,5,7,8,9,10,11,12,13,15,16,17,18	+	+	+
Kali	LC	2,3,4,5,7,8,9,11,12,13,17,18	+	-	+
Fringed-lipped peninsula carp	LC	6,8,10,12,16,17,18	+	-	-
Kuria labeo	LC	1,2,3,4,5,6,8,10,11,12,13,14,16,17,18	+	+	+
-	NT	6,16	-	-	-
Pangusia labeo	NT	3,5,6,8,9,10,11,12,13,16,17,18	+	-	-
Roho labeo	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Dark mahseer	VU	7,8,9,11,12,16,17,18	+	-	+
Cotio	LC	1,2,3,4,5,6,8,9,10,11,12,13,16,17,18	+	+	+
Rosy barb	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,16,17,18	+	+	+
Golden barb	LC	2,4,5,6,9,11,13,16,18	-	-	-
Glass barb	LC	6,9,11,13,16,18	-	-	-
Spottedsail barb	LC	2,3,4,5,6,9,11,12,13,16,18	-	-	-
Ticto barb	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18	+	+	+
Swamp barb	LC	1,2,3,4,5,6,8,9,10,11,12,13,14,16,17,18	+	+	+
Puntio barb	NE	6,12,13,18	-	-	-
Pool barb	LC	1,2,3,4,5,6,8,10,11,12,13,14,15,16,17,18	+	+	+
Onespot barb	LC	3,6,9,11,12,13,16,17,18	-	-	-
Sattar snowtrout	LC	8,11,12,18	-	-	-
Chirruh snowtrout	VU	8,11,18	-	-	-
Kumaon snowtrout	DD	7,16,18	-	-	-
Snow trout	VU	8,11,12,17,18	+	-	-

S. No.	Scientific name	Order	Family
86	*Schizothorax progastus* (McClelland 1839)	Cypriniformes	Cyprinidae
87	*Schizothorax richardsonii* (Gray 1832)	Cypriniformes	Cyprinidae
88	*Systomus sarana* (Hamilton 1822)	Cypriniformes	Cyprinidae
89	*Tariqilabeo latius* (Hamilton 1822)	Cypriniformes	Cyprinidae
90	*Tor putitora* (Hamilton 1822)	Cypriniformes	Cyprinidae
91	*Tor tor* (Hamilton 1822)	Cypriniformes	Cyprinidae
92	*Amblypharyngodon microlepis* (Bleeker 1853)	Cypriniformes	Danionidae
93	*Amblypharyngodon mola* (Hamilton 1822)	Cypriniformes	Danionidae
94	*Barilius barila* (Hamilton 1822)	Cypriniformes	Danionidae
95	*Barilius vagra* (Hamilton 1822)	Cypriniformes	Danionidae
96	*Bengala elanga* (Hamilton 1822)	Cypriniformes	Danionidae
97	*Cabdio jaya* (Hamilton 1822)	Cypriniformes	Danionidae
98	*Cabdio morar* (Hamilton 1822)	Cypriniformes	Danionidae
99	*Chela cachius* (Hamilton 1822)	Cypriniformes	Danionidae
100	*Danio dangila* (Hamilton 1822)	Cypriniformes	Danionidae
101	*Danio rerio* (Hamilton 1822)	Cypriniformes	Danionidae
102	*Devario devario* (Hamilton 1822)	Cypriniformes	Danionidae
103	*Esomus danrica* (Hamilton 1822)	Cypriniformes	Danionidae
104	*Laubuka laubuca* (Hamilton 1822)	Cypriniformes	Danionidae
105	*Opsarius barna* (Hamilton 1822)	Cypriniformes	Danionidae
106	*Opsarius bendelisis* (Hamilton 1807)	Cypriniformes	Danionidae
107	*Opsarius shacra* (Hamilton 1822)	Cypriniformes	Danionidae
108	*Opsarius tileo* (Hamilton 1822)	Cypriniformes	Danionidae
109	*Raiamas bola* (Hamilton 1822)	Cypriniformes	Danionidae
110	*Rasbora daniconius* (Hamilton 1822)	Cypriniformes	Danionidae
111	*Rasbora rasbora* (Hamilton 1822)	Cypriniformes	Danionidae
112	*Salmostoma acinaces* (Valenciennes 1844)	Cypriniformes	Danionidae
113	*Salmostoma phulo* (Hamilton 1822)	Cypriniformes	Danionidae
114	*Salmostoma bacaila* (Hamilton 1822)	Cypriniformes	Danionidae
115	*Securicula gora* (Hamilton 1822)	Cypriniformes	Danionidae
116	*Ctenopharyngodon idella* (Valenciennes 1844)	Cypriniformes	Xenocyprididae
117	*Hypophthalmichthys molitrix* (Valenciennes 1844)	Cypriniformes	Xenocyprididae
118	*Hypophthalmichthys nobilis* (Richardson 1845)	Cypriniformes	Xenocyprididae
119	*Pterygoplichthys ambrosettii* (Holmberg 1893)	Siluriformes	Loricariidae
120	*Pterygoplichthys disjunctivus* (Weber 1991)	Siluriformes	Loricariidae
121	*Chaca chaca* (Hamilton 1822)	Siluriformes	Chacidae
122	*Plotosus canius* Hamilton 1822	Siluriformes	Plotosidae
123	*Rita rita* (Hamilton 1822)	Siluriformes	Ritidae
124	*Ailia coila* (Hamilton 1822)	Siluriformes	Ailiidae
125	*Ailiichthys punctata* Day 1872	Siluriformes	Ailiidae
126	*Clupisoma garua* (Hamilton 1822)	Siluriformes	Ailiidae
127	*Laides montanus* (Hora 1937)	Siluriformes	Ailiidae
128	*Eutropiichthys murius* (Hamilton 1822)	Siluriformes	Ailiidae
129	*Eutropiichthys vacha* (Hamilton 1822)	Siluriformes	Ailiidae
130	*Silonia silondia* (Hamilton 1822)	Siluriformes	Ailiidae

Common Name	IUCN Status	Previous Studies	2019	2023	2024
Dinnawah snowtrout	LC	7,8,12,13,16,18	-	-	+
Snowtrout	VU	2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18	+	-	+
Olive barb	LC	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Gangetic latia	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18	+	+	+
Putitor mahseer	EN	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Tor barb	DD	1,3,6,7,8,9,10,11,12,13,14,15,16,17,18	+	-	+
Indian carplet	LC	1,8,12,13,16,18	-	-	-
Mola carplet	LC	1,2,3,4,5,6,7,8,9,10,11,12,16,17,18	+	+	+
Barred baril	LC	2,3,4,5,6,7,8,9,11,12,13,16,18	-	-	+
Vagra baril	LC	2,3,4,5,6,7,8,9,11,12,13,16,17,18	+	+	+
Bengala barb	LC	2,3,4,5,6,8,12,13,16,18	-	-	-
Jaya	LC	1,3,6,8,9,10,11,12,13,16,17,18	+	-	-
Morari	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,16,17,18	+	+	+
Silver hatchet chela	LC	1,3,6,8,9,10,11,12,13,16,18	-	-	+
Dangila danio	LC	1,6,8,9,11,13,16,18	-	-	-
Zebra danio	LC	1,3,6,7,8,11,16,18	-	-	-
Sind danio	LC	1,2,3,4,5,6,8,9,11,12,13,16,17,18	+	-	+
Indian flying barb	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,16,18	-	-	-
Indian glass barb	LC	1,2,3,4,5,6,8,9,10,11,12,13,16,17,18	+	+	-
Barna baril	LC	2,3,4,5,6,8,9,10,11,12,13,16,18	+	-	+
Hamilton's barila	LC	1,2,3,4,5,6,7,8,9,11,12,13,16,17,18	+	-	+
Shacra baril	LC	3,6,9,11,13,16,18	-	-	-
Tileo baril	LC	2,3,4,5,6,8,12,13,16,18	-	-	-
Trout barb	LC	1,2,3,5,6,7,8,9,11,12,13,16,17,18	+	-	+
Slender rasbora	LC	2,3,4,5,6,7,8,9,10,11,12,13,16,17,18	+	-	+
Gangetic scissortail rasbora	LC	3,6,9,12,13,16,18	-	-	-
Silver razorbelly minnow	LC	2,4,5,11,16	-	-	-
Finescale razorbelly minnow	LC	2,3,4,5,6,8,11,12,13,14,16,17,18	-	-	-
Large razorbelly minnow	LC	1,2,3,4,5,6,8,9,10,11,12,13,16,17,18	+	+	+
Gora-chela	LC	1,2,3,4,5,6,8,9,10,11,12,13,16,17,18	+	-	+
Grass carp	LC	2,3,4,5,10,12,17,18	+	+	+
Silver carp	NT	2,3,4,5,8,10,12,17,18	+	+	+
Bighead carp	DD	2,3,4,5,10,12,17,18	+	-	+
Snow pleco	LC	12,18	-	-	-
Vermiculated sailfin catfish	LC	2,4,5	+	-	+
Squarehead catfish	LC	1,2,4,5,6,8,9,13,16,17,18	+	-	-
Gray eel-catfish	LC	6,8,13,14,16,18	-	-	-
Rita	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Gangetic ailia	NT	1,2,3,4,5,6,7,8,9,10,11,12,13,16,17,18	+	+	+
Jamuna ailia	DD	2,3,4,5,7	-	-	+
Garua bachcha	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18	+	+	+
Kocha garua	LC	7,8,9,11,18	-	-	+
Murius vacha	LC	2,3,4,5,6,8,10,12,13,16,17,18	+	+	+
Batchwa vacha	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Silond catfish	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	-	+

S. No.	Scientific name	Order	Family
131	*Pachypterus atherinoides* (Bloch 1794)	Siluriformes	Horabagridae
132	*Batasio batasio* (Hamilton 1822)	Siluriformes	Bagridae
133	*Hemibagrus menoda* (Hamilton 1822)	Siluriformes	Bagridae
134	*Mystus bleekeri* (Day 1877)	Siluriformes	Bagridae
135	*Mystus cavasius* (Hamilton 1822)	Siluriformes	Bagridae
136	*Mystus gulio* (Hamilton 1822)	Siluriformes	Bagridae
137	*Mystus tengara* (Hamilton 1822)	Siluriformes	Bagridae
138	*Mystus vittatus* (Bloch 1794)	Siluriformes	Bagridae
139	*Sperata aor* (Hamilton 1822)	Siluriformes	Bagridae
140	*Sperata lamarrii* (Valenciennes 1840)	Siluriformes	Bagridae
141	*Amblyceps mangois* (Hamilton 1822)	Siluriformes	Amblycipitidae
142	*Bagarius bagarius* (Hamilton 1822)	Siluriformes	Sisoridae
143	*Erethistes hara* (Hamilton 1822)	Siluriformes	Sisoridae
144	*Erethistes jerdoni* (Day 1870)	Siluriformes	Sisoridae
145	*Erethistes pusillus* Müller & Troschel 1849	Siluriformes	Sisoridae
146	*Erethistoides pipri* Hora 1950	Siluriformes	Sisoridae
147	*Gagata cenia* (Hamilton 1822)	Siluriformes	Sisoridae
148	*Gagata gagata* (Hamilton 1822)	Siluriformes	Sisoridae
149	*Gagata sexualis* Tilak 1970	Siluriformes	Sisoridae
150	*Glyptothorax alaknandi* Tilak 1969	Siluriformes	Sisoridae
151	*Glyptothorax annandalei* Hora 1923	Siluriformes	Sisoridae
152	*Glyptothorax botius* (Hamilton 1822)	Siluriformes	Sisoridae
153	*Glyptothorax brevipinnis* Hora 1923	Siluriformes	Sisoridae
154	*Glyptothorax cavia* (Hamilton 1822)	Siluriformes	Sisoridae
155	*Glyptothorax conirostris* (Steindachner 1867)	Siluriformes	Sisoridae
156	*Glyptothorax garhwali* Tilak 1969	Siluriformes	Sisoridae
157	*Glyptothorax gracilis* (Günther 1864)	Siluriformes	Sisoridae
158	*Glyptothorax horai* (Fowler 1934)	Siluriformes	Sisoridae
159	*Glyptothorax madraspatanus* (Day 1873)	Siluriformes	Sisoridae
160	*Glyptothorax pectinopterus* (McClelland 1842)	Siluriformes	Sisoridae
161	Glyptothorax telchitta (Hamilton 1822)	Siluriformes	Sisoridae
162	*Glyptothorax trilineatus* Blyth 1860	Siluriformes	Sisoridae
163	*Gogangra viridescens* (Hamilton 1822)	Siluriformes	Sisoridae
164	*Nangra nangra* (Hamilton 1822)	Siluriformes	Sisoridae
165	*Pseudecheneis sulcata* (McClelland 1842)	Siluriformes	Sisoridae
166	*Sisor rabdophorus* Hamilton 1822	Siluriformes	Sisoridae
167	*Pangasius pangasius* (Hamilton 1822)	Siluriformes	Pangasiidae
168	*Ompok bimaculatus* (Bloch 1794)	Siluriformes	Siluridae
169	*Ompok pabda* (Hamilton 1822)	Siluriformes	Siluridae
170	*Ompok pabo* (Hamilton 1822)	Siluriformes	Siluridae
171	*Wallago attu* (Bloch & Schneider 1801)	Siluriformes	Siluridae
172	*Clarias batrachus* (Linnaeus 1758)	Siluriformes	Clariidae
173	*Clarias magur* (Hamilton 1822)	Siluriformes	Clariidae
174	*Clarias gariepinus* (Burchell 1822)	Siluriformes	Clariidae
175	*Heteropneustes fossilis* (Bloch 1794)	Siluriformes	Clariidae

Common Name	IUCN Status	Previous Studies	2019	2023	2024
Indian potasi	LC	1,2,3,4,5,6,8,10,11,12,16,17,18	+	-	+
Tista batasio	LC	2,3,4,5,6,12,16,18	+	-	-
Menoda catfish	LC	1,2,4,5,6,8,9,12,13,16,18	-	-	-
Day's mystus	LC	1,2,3,4,5,8,9,10,11,12,13,14,15,16,17,18	-	-	+
Gangetic mystus	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	-	+
Long whiskers catfish	LC	2,3,4,5,6,8,13,14,15,16,18	-	-	-
Tengara catfish	LC	2,3,4,5,6,7,8,9,11,12,13,14,17,18	+	+	+
Striped dwarf catfish	LC	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Long-whiskered catfish	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18	+	+	+
-	NE	-	+	+	+
Indian torrent catfish	LC	2,4,5,6,7,8,9,11,12,13,16,17,18	+	-	-
Goonch	VU	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18	+	-	+
Kosi hara	LC	1,2,4,5,6,8,9,10,11,12,13,16,18	-	-	-
Sylhet hara	LC	9,11,13,16,18	-	-	-
-	LC	1,3,5,8,16,17,18	+	-	-
-	DD	16,17,18	-	-	-
Indian gagata	LC	1,2,3,4,5,6,7,8,9,11,12,13,16,17,18	+	+	+
Gangetic gagata	LC	2,3,4,5,6,8,9,13,14,16,18	-	-	-
Koel gagata	LC	3,7,9,11,13,17,18	+	-	-
-	LC	7,9,13,18	-	-	-
Patharchatta	LC	9,11,16,18	-	-	-
-	LC	6	-	-	-
	DD	11,12,13,18	-	-	-
River cat	LC	2,3,4,5,6,8,9,11,13,16,17,18	+	-	+
-	DD	8,9,11,16,18	-	-	-
-	LC	2,4,5,9,13,18	-	-	-
-	DD	7,8,9,13,16,17,18	+	-	-
-	LC	11,16	-	-	-
-	EN	8,11,18	-	-	-
River cat	LC	8,11,12,13,16,18	-	-	-
Telchitta	LC	3,6,8,9,11,12,16,18	-	-	+
Three-lined catfish	LC	8,11,18	-	-	-
Huddah nangra	LC	1,2,3,4,5,6,7,8,10,11,12,16	+	-	+
Kosi nangra	LC	1,6,7,8,9,11,12,13,16,18	-	-	-
Sucker throat catfish	LC	_	+	-	-
Sisor catfish	LC	1,2,3,4,5,6,7,8,9,10,12,13,16,18	+	-	-
Pangas catfish	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,18	-	-	-
Butter catfish	NT	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	-	+
Pabdah catfish	NT	2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Pabo catfish	NT	1,2,4,5,6,8,9,12,13,14,16,18	-	-	+
Wallago	VU	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Philippine catfish	LC	2,3,7,8,9,10,11,12,13,15,16,18	-	-	-
-	EN	4,5,6,17,18	-	+	-
North African catfish	LC	2,3,4,5,12,17,18	-	-	-
Stinging catfish	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+

S. No.	Scientific name	Order	Family
176	*Arius arius* (Hamilton 1822)	Siluriformes	Ariidae
177	*Arius gagora* (Hamilton 1822)	Siluriformes	Ariidae
178	*Batrachocephalus mino* (Hamilton 1822)	Siluriformes	Ariidae
179	*Hexanematichthys sagor* (Hamilton 1822)	Siluriformes	Ariidae
180	*Kyataphisa nenga* (Hamilton 1822)	Siluriformes	Ariidae
181	*Pseudosciades sona* (Hamilton 1822)	Siluriformes	Ariidae
182	*Oncorhynchus mykiss* (Walbaum 1792)	Salmoniformes	Salmonidae
183	*Salmo trutta* Linnaeus 1758	Salmoniformes	Salmonidae
184	*Harpadon nehereus* (Hamilton 1822)	Aulopiformes	Synodontidae
185	*Butis butis* (Hamilton 1822)	Gobiiformes	Eleotridae
186	*Eleotris fusca* (Bloch & Schneider 1801)	Gobiiformes	Eleotridae
187	*Apocryptes bato* (Hamilton 1822)	Gobiiformes	Oxudercidae
188	*Boleophthalmus boddarti* (Pallas 1770)	Gobiiformes	Oxudercidae
189	*Brachygobius nunus* (Hamilton 1822)	Gobiiformes	Oxudercidae
190	*Gobiopterus chuno* (Hamilton 1822)	Gobiiformes	Oxudercidae
191	*Odontamblyopus rubicundus* (Hamilton 1822)	Gobiiformes	Oxudercidae
192	*Periophthalmus weberi* Eggert 1935	Gobiiformes	Oxudercidae
193	*Pseudapocryptes elongatus* (Cuvier 1816)	Gobiiformes	Oxudercidae
194	*Stigmatogobius sadanundio* (Hamilton 1822)	Gobiiformes	Oxudercidae
195	*Trypauchen vagina* (Bloch & Schneider 1801)	Gobiiformes	Oxudercidae
196	*Amblyeleotris gymnocephala* (Bleeker 1853)	Gobiiformes	Gobiidae
197	*Glossogobius giuris* (Hamilton 1822)	Gobiiformes	Gobiidae
198	*Ichthyocampus carce* (Hamilton 1822)	Syngnathiformes	Syngnathidae
199	*Microphis cuncalus* (Hamilton 1822)	Syngnathiformes	Syngnathidae
200	*Microphis deocata* (Hamilton 1822)	Syngnathiformes	Syngnathidae
201	*Lepturacanthus pantului* (Gupta 1966)	Scombriformes	Trichiuridae
202	*Trichiurus gangeticus* Gupta 1966	Scombriformes	Trichiuridae
203	*Trichiurus lepturus* Linnaeus 1758	Scombriformes	Trichiuridae
204	*Macrognathus aculeatus* (Bloch 1786)	Synbranchiformes	Mastacembelidae
205	*Macrognathus aral* (Bloch & Schneider 1801)	Synbranchiformes	Mastacembelidae
206	*Macrognathus pancalus* Hamilton 1822	Synbranchiformes	Mastacembelidae
207	*Mastacembelus armatus* (Lacepède 1800)	Synbranchiformes	Mastacembelidae
208	*Monopterus albus* (Zuiew 1793)	Synbranchiformes	Synbranchidae
209	*Ophichthys cuchia* (Hamilton 1822)	Synbranchiformes	Synbranchidae
210	*Anabas cobojius* (Hamilton 1822)	Anabantiformes	Anabantidae
211	*Anabas testudineus* (Bloch 1792)	Anabantiformes	Anabantidae
212	*Trichogaster chuna* (Hamilton 1822)	Anabantiformes	Osphronemidae
213	*Trichogaster fasciata* Bloch & Schneider 1801	Anabantiformes	Osphronemidae
214	*Trichogaster labiosa* Day 1877	Anabantiformes	Osphronemidae
215	*Channa amphibeus* (McClelland 1845)	Anabantiformes	Channidae
216	*Channa barca* (Hamilton 1822)	Anabantiformes	Channidae
217	*Channa gachua* (Hamilton 1822)	Anabantiformes	Channidae
218	*Channa marulius* (Hamilton 1822)	Anabantiformes	Channidae
219	*Channa punctata* (Bloch 1793)	Anabantiformes	Channidae
220	*Channa stewartii* (Playfair 1867)	Anabantiformes	Channidae

Common Name	IUCN Status	Previous Studies	2019	2023	2024
Threadfin sea catfish	LC	2,4,5,6,8,13,16,18	-	-	-
Gagora catfish	NT	2,3,4,5,6,8,13,16,18	+	-	+
Beardless sea catfish	NE	6,8,16	-	-	-
Sagor catfish	NE	6,16	-	-	-
Engraved catfish	NE	2,4,5,6,16	-	-	-
Sona sea catfish	NE	6,8,16	-	-	-
Rainbow trout	LC	12,17,18	-	-	-
Sea trout	LC	-	+	-	+
Bombay-duck	NT	2,4,5,6,8,13,14,15,16,18	-	-	-
Duckbill sleeper	LC	6,16	-	-	-
Dusky sleeper	LC	2,3,4,5,8,14,16,18	+	-	-
-	LC	2,3,4,5,6,8,11,13,16,17,18	+	-	+
Boddart's goggle-eyed goby	LC	2,4,5,6,13,16,18	-	-	-
Bumblebee goby	NE	2,4,5,6,8,11,16	-	-	-
Glass goby	DD	6,8,14,16	-	-	-
Rubicundus eelgoby	LC	3,5,6,8,13,16,18	-	-	+
Weber's mudskipper	LC	-	-	-	+
-	LC	2,3,4,5,6,8,14,16,18	-	-	-
-	NE	6,8,13,16,18	-	-	-
Burrowing goby	LC	2,6,16	-	-	-
Masked shrimpgoby	LC	13,18	-	-	-
Tank goby	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18	+	+	+
Freshwater pipefish	LC	6,16	-	-	-
Crocodile-tooth pipefish	LC	2,4,5,6,8,13,16,18	-	-	-
Deocata pipefish	NT	6,16	-	-	-
Coromandel hairtail	DD	14,16	-	-	-
Ganges hairtail	NE	2,14	-	-	-
Largehead hairtail	LC	2,4,5,6,8,16	-	-	-
Lesser spiny eel	LC	1,6,8,11,16,18	-	-	+
One-stripe spinyeel	LC	2,3,4,5,8,9,12,13,14,15,17,18	+	-	-
Barred spiny eel	LC	1,2,3,4,5,6,8,9,10,12,13,14,15,16,17,18	+	-	+
Zig-zag eel	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Asian swamp eel	LC	12,18	-	-	-
Cuchia	LC	2,4,5,6,8,10,11,12,13,14,16,18	+	-	-
Gangetic koi	DD	6,9,13,18	-	-	-
Climbing perch	LC	1,2,3,4,5,7,8,9,10,11,12,13,16,17,18	+	-	+
Honey gourami	LC	2,3,4,5,6,7,8,10,11,13,16,17,18	+	-	+
Banded gourami	LC	1,2,3,4,5,6,7,8,11,12,13,16,17,18	+	-	+
Thick lipped gourami	LC	11,13,16,18	-	-	-
Borna snakehead	LC	9,13,18	-	-	-
Barca snakehead	DD	6,9,13,16,18	-	-	-
Red seam snakehead	LC	1,2,4,5,6,8,9,11,18	-	+	+
Great snake head	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18	+	+	+
Spotted snakehead	LC	1,2,3,4,5,6,7,8,9,11,12,13,15,16,17,18	+	-	+
Assamese snakehead	LC	8,9,12,13,16,18	-	-	-

S. No.	Scientific name	Order	Family
221	*Channa striata* (Bloch 1793)	Anabantiformes	Channidae
222	*Nandus nandus* (Hamilton 1822)	Anabantiformes	Nandidae
223	*Badis badis* (Hamilton 1822)	Anabantiformes	Badidae
224	*Lates calcarifer* (Bloch 1790)	Carangiformes	Latidae
225	*Eleutheronema tetradactylum* (Shaw 1804)	Carangiformes	Polynemidae
226	*Leptomelanosoma indicum* (Shaw 1804)	Carangiformes	Polynemidae
227	*Polynemus paradiseus* Linnaeus 1758	Carangiformes	Polynemidae
228	*Pseudorhombus arsius* (Hamilton 1822)	Carangiformes	Paralichthyidae
229	*Brachirus orientalis* (Bloch & Schneider 1801)	Carangiformes	Soleidae
230	*Cynoglossus cynoglossus* (Hamilton 1822)	Carangiformes	Cynoglossidae
231	*Cynoglossus lingua* Hamilton 1822	Carangiformes	Cynoglossidae
232	*Cynoglossus puncticeps* (Richardson 1846)	Carangiformes	Cynoglossidae
233	*Toxotes chatareus* (Hamilton 1822)	Carangiformes	Toxotidae
234	*Strongylura leiurus* (Bleeker 1850)	Beloniformes	Belonidae
235	*Strongylura strongylura* (van Hasselt 1823	Beloniformes	Belonidae
236	*Xenentodon cancila* (Hamilton 1822)	Beloniformes	Belonidae
237	*Hemiramphus far* (Fabricius 1775)	Beloniformes	Hemiramphidae
238	*Hyporhamphus limbatus* (Valenciennes 1847)	Beloniformes	Hemiramphidae
239	*Oryzias dancena* (Hamilton 1822)	Beloniformes	Adrianichthyidae
240	*Aplocheilus panchax* (Hamilton 1822)	Cyprinodontiformes	Aplocheilidae
241	*Etroplus suratensis* (Bloch 1790)	Cichliformes	Cichlidae
242	*Oreochromis mossambicus* (Peters 1852)	Cichliformes	Cichlidae
243	*Oreochromis niloticus* (Linnaeus 1758)	Cichliformes	Cichlidae
244	*Chelon parsia* (Hamilton 1822)	Mugiliformes	Mugilidae
245	*Moolgarda tade* (Fabricius 1775)	Mugiliformes	Mugilidae
246	*Mugil cephalus* Linnaeus 1758	Mugiliformes	Mugilidae
247	*Planiliza macrolepis* (Smith 1846)	Mugiliformes	Mugilidae
248	*Rhinomugil corsula* (Hamilton 1822)	Mugiliformes	Mugilidae
249	*Sicamugil cascasia* (Hamilton 1822)	Mugiliformes	Mugilidae
250	*Chanda baculis* Hamilton 1822	Mugiliformes	Ambassidae
251	*Chanda nama* Hamilton 1822	Mugiliformes	Ambassidae
252	*Chanda ranga* Hamilton 1822	Mugiliformes	Ambassidae
253	*Pseudambassis lala* (Hamilton 1822)	Mugiliformes	Ambassidae
254	*Terapon jarbua* (Fabricius 1775)	Centrarchiformes	Terapontidae
255	*Gerres setifer* (Hamilton 1822)	Acanthuriformes	Gerreidae
256	*Sillaginopsis domina* (Cuvier 1816)	Acanthuriformes	Sillaginidae
257	*Bahaba chaptis* (Hamilton 1822)	Acanthuriformes	Sciaenidae
258	*Johnius coitor* (Hamilton 1822).	Acanthuriformes	Sciaenidae
259	*Johnius gangeticus* Talwar 1991	Acanthuriformes	Sciaenidae
260	*Macrospinosa cuja* (Hamilton 1822)	Acanthuriformes	Sciaenidae
261	*Otolithoides biauritus* (Cantor 1849)	Acanthuriformes	Sciaenidae
262	*Otolithoides pama* (Hamilton 1822)	Acanthuriformes	Sciaenidae
263	*Panna microdon* (Bleeker 1849)	Acanthuriformes	Sciaenidae
264	*Acanthopagrus datnia* (Hamilton 1822)	Acanthuriformes	Sparidae
265	*Acanthopagrus latus* (Houttuyn 1782)	Acanthuriformes	Sparidae

Common Name	IUCN Status	Previous Studies	2019	2023	2024
Stiprd snakehead	LC	1,2,3,4,5,6,8,9,10,11,12,13,15,16,17,18	+	+	+
Gangetic leaffish	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	+	+	+
Badis	LC	1,2,3,4,5,6,8,9,11,13,16,17,18	+	-	-
Barramundi	LC	3,4,5,6,8,13,14,15,16,18	-	-	+
Fourfinger threadfin	NE	2,4,5,6,8,13,14,16,18	-	-	-
Indian threadfin	NE	6,14,16	+	-	-
Paradise threadfin	LC	2,4,5,6,8,14,15,16,18	-	-	+
Largetooth flounder	LC	6,16	-	-	-
Oriental sole	LC	3,8,18	-	-	-
Bengal tongue sole	LC	2,3,4,5,6,8,11,13,14,16,18	+	+	-
Long tongue sole	LC	2,4,5,6,8,13,14,16,18	-	-	-
Speckled tonguesole	LC	13,16,18	-	-	-
Spotted archerfish	LC	3,6,13,16,18	-	-	-
Banded needlefish	NE	3,13,18	-	-	-
Spottail needlefish	NE	3,8,14,16	-	-	-
Freshwater garfish	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18	+	+	+
Black-barred halfbeak	NE	18	-	-	-
Congaturi halfbeak	LC	1,2,4,5,8,12,13,18	-	-	-
Indian blue ricefish	LC	6,8,13,16,18	-	-	-
Blue panchax	LC	2,3,4,5,6,7,8,9,11,13,16,18	-	-	-
Pearlspot	LC	6,14,16,18	-	-	-
Mozambique tilapia	VU	10,12,17,18	-	-	-
Nile tilapia	LC	2,3,4,5,8,12,17,18	+	-	+
Goldspot mullet	NE	2,3,4,5,6,8,11,14,15,16	+	-	-
-	DD	4,5,8,13,14,16,18	-	-	-
Flathead grey mullet	LC	6,8,13,16,18	-	-	-
Largescale mullet	LC	8,13,16,18	-	-	-
Corsula	LC	1,2,3,4,5,6,8,10,11,12,13,14,15,16,17,18	+	+	+
Yellowtail mullet	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18	+	+	+
Himalayan glassy perchlet	LC	1,2,4,5,6,7,8,9,11,12,13,16,17,18	+	-	+
Elongate glass-perchlet	LC	1,2,3,4,5,6,8,9,10,11,12,13,16,17,18	+	+	+
Indian glassy fish	LC	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18	+	+	+
Highfin glassy perchlet	NT	2,3,4,5,6,8,17,18	+	-	-
Jarbua terapon	LC	2,4,5,6,8,13,14,16,18	-	-	-
Small Bengal silver-biddy	NE	6,8,16,18	-	-	-
Flathead sillago	NE	2,3,4,5,6,8,13,14,15,16,18	-	-	+
Chaptis bahaba	DD	6,16	-	-	-
Coitor croaker	LC	1,2,3,4,5,6,8,11,12,13,14,16,17,18	+	+	+
Gangetic bola	DD	2,3,4,5,8,10,12,13,14,17,18	+	-	+
Cuja bola	DD	6,16	-	-	-
Bronze croaker	DD	8,13,14,18	-	-	-
Pama croaker	DD	2,4,5,6,8,10,11,13,14,16,18	-	-	-
Pama croaker	LC	2,4,5,12,13,18	-	-	+
Bengal yellowfin seabream	DD	6	-	-	-
Yellowfin seabream	DD	8,13,18	-	-	-

S. No.	Scientific name	Order	Family
266	*Scatophagus argus* (Linnaeus 1766)	Acanthuriformes	Scatophagidae
267	*Chelonodon patoca* (Hamilton 1822)	Tetraodontiformes	Tetraodontidae
268	*Dichotomyctere fluviatilis* (Hamilton 1822)	Tetraodontiformes	Tetraodontidae
269	*Lagocephalus lunaris* (Bloch & Schneider 1801)	Tetraodontiformes	Tetraodontidae
270	*Leiodon cutcutia* (Hamilton 1822)	Tetraodontiformes	Tetraodontidae

Bilgrami (1991)[1], Das (2019)[2], Das et al. (2010)[3], Das et al. (2020)[4], Das et al. (2023)[5], Hamilton (1822)[6], Karmakar (2000)[7], Mathur et al. (2012)[8], Menon (1962)[9], Pathak & Tyagi (2010)[10], Payne & Temple (1996)[11], Sarkar et al. (2012)[12], Talwar (1991)[13], Vass et al. (2008)[14], Vass et al. (2010)[15], Venkateswarlu & Menon (1979)[16], WII-GACMC (2017)[17], WII-GACMC (2018)[18]; CE - Critically Endangered; DD - Data Deficiency; EN - Endangered; LC - Least Concern; NT - Near Threatened; NE - Not Evaluated; VU - Vulnerable.

Common Name	IUCN Status	Previous Studies	2019	2023	2024
Spotted scat	LC	2,3,4,5,6,8,13,14,15,16,18	+	-	-
Milkspotted puffer	LC	6,16	-	-	-
Green pufferfish	LC	1,6,8,12,13,16,18	-	-	-
Lunartail puffer	LC	4,5,16	-	-	-
Ocellated pufferfish	LC	1,2,3,4,5,6,8,10,11,12,13,16,17,18	+	-	-



Annexure IV Amphibians of Ganga River

Sl. No.	Common name	Scientific Name	IUCN Status	Present	Previous studies
		Order: Anura			
Family: Bufonidae					
1	Common Toad	*Duttaphrynus melanostictus* (Schneider, 1799)	LC	+	1,2,3
2	Marbled Toad	*Duttaphrynus stomaticus* (Lutken, 1864)	LC	+	1,2.3
3	Himalayan Toad	*Duttaphrynus himalayanus* (Gunther, 1864)	LC	+	1
Family: Dicroglossidae					
4	Indian Skipper Frog	*Euphlyctis cyanophlyctis* (Schneider, 1799)	LC	+	1,2,3
5	Indian Five-fingered Frog	*Euphlyctis hexadactyla* (Lesson, 1834)	LC	+	
6	Crab eating Frog	*Fejervarya cf. moodiei* (Taylor, 1920)	LC	+	
7	Orissa Frog	*Fejervarya orissaensis* (Dutta, 1997)	LC	+	
8		Fejervarya sp ?	NA	+	3
9	Indian Bull Frog	*Hoplobatrachus tigerinus* (Daudin, 1802)	LC	+	1,2,3
10	Jerdon's Bull Frog	*Hoplobatrachus crassus* (Jerdon, 1853)	LC	+	1
11	Granular Cricket Frog	*Minervarya cf. agricola* (Jerdon, 1853)	LC	+	
12	Pierrei Cricket Frog	*Minervarya cf. pierrei* (Dubois, 1975)	LC	+	
13	Sahyadri Cricket Frog	*Minervarya syhadrensis* (Annandale, 1919)	LC	+	1
14		Minervarya sp?	NA	+	
15	Carnatic Burrowing Frog	*Sphaerotheca breviceps* (Schneider, 1799)	LC	+	1,2,3
16	Western Burrowing Frog	*Sphaerotheca pashchima* Padhye, Dahanukar, Sulakhe, Dandekar, Limaye & Jamdade, 2017	LC	+	
17	Nepal Paa Frog	*Nanorana minica* (Dubois, 1975)	LC	+	1
18	Murree Frog	*Nanorana vicina* (Stoliczka, 1872)	LC	-	2
Family: Microhylidae					
19	Nilphamarai Chorus Frog	*Microhyla nilphamariensis* Howlader, Nair, Gopalan & Merila, 2015	LC	+	1, 2,3
20	Indian Balloon Frog	*Uperodon globulosus* (Günther, 1864)	LC	+	1
21	Variegated Balloon Frog	*Uperodon variegatus* (Stoliczka, 1872)	LC	+	
22	Marbled Balloon Frog	*Uperodon systoma* (Schneider, 1799)	LC	+	
23	Painted Balloon Frog	*Uperodon taprobanicus* (Parker, 1934)	LC	+	1
Family: Ranidae					
24	Yellow-striped Copper-back Frog	*Hylarana tytleri* (Theobald, 1868)	LC	+	1,3
25	Assam Sucker Frog	*Amolops formosus* (Günther, 1876)	LC	-	1
26	Jaunsari Stream Frog	Amolops jaunsari (Ray, 1995)	LC	+	1
Family: Rhacophoridae					
27	Assam Pigmy Tree Frog	*Chirixalus simus* (Annandale, 1915)	LC	+	
28	Brown Blotched Whipping Frog	*Polypedates bengalensis* Purkayastha, Das, Mondal, Mitra & Das, 2019	DD+		
29	Big-headed Whipping Frog	*Polypedates maculatus* (Gray, 1830)	LC	+	1,2,3
30	Assam Whipping Frog	*Polypedates taeniatus* (Boulenger, 1906)	LC	+	1,2,3

LC = Least Concern, DD= Data Deficient, NA = Not Available; + = Present, - = Absent; Previous studies (1- Boruah et al., 2020; 2- Kanaujia et al., 2017; 3- WII-NMCG, 2019)

Annexure V Presence and absence of Amphibians in the Ganga River.

Species	Upper Stretch			Middle Stretch									
	Dharasu	Byas Ghat	Haridwar	Bijnor	Tigri Ghat	Narora	Kachla	Farukkhabad	Kannauj	Kanpur	Bhitura	Manikpur	Prayagraj
Amolops jaunsari	0	1	0	0	0	0	0	0	0	0	0	0	0
Chirixalus sinus	0	0	0	0	0	0	0	0	0	0	0	0	0
Duttaphrynus himalayanus	0	1	0	0	0	0	0	0	0	0	0	0	0
Duttaphrynus melanostictus	0	0	1	1	0	1	1	1	1	1	1	1	1
Duttaphrynus stomaticus	1	0	1	1	1	1	1	1	1	1	1	1	1
Euphlyctis cyanophlyctis	0	0	1	1	0	1	1	1	0	1	1	1	1
Euphlyctis hexadactylus	0	0	0	0	0	0	0	0	0	0	0	0	0
Fejervarya cf. moodiei	0	0	0	0	0	0	0	0	0	0	0	0	0
Fejervarya orissaensis	0	0	0	1	0	1	1	1	0	0	0	0	0
Hoplobatrachus crassus	0	0	0	1	0	0	0	0	0	0	0	0	0
Hoplobatrachus tigerinus	0	0	1	1	1	1	1	1	1	1	1	1	1
Hylarana tytleri	0	0	0	0	0	0	0	0	0	0	0	0	0
Microhyla nilphmariensis	1	1	1	1	0	1	1	1	1	1	1	1	1
Minervarya cf. agricola	0	0	1	1	0	0	1	0	0	1	1	0	0
Minervarya cf. pierrei	0	0	0	0	0	0	0	1	0	0	1	0	0
Minervarya syhadrensis	1	0	1	0	1	1	1	1	1	1	1	1	1
Minervarya sp	0	0	0	1	0	0	0	0	0	0	0	0	0
Nanorana minica	0	1	0	0	0	0	0	0	0	0	0	0	0
Polypedates bengalensis	0	0	0	0	0	0	0	0	0	0	0	0	0
Polypedates maculatus	0	0	0	1	0	0	0	0	0	1	1	1	0
Polypedates taeniatus	0	0	0	1	1	1	1	1	1	0	0	0	0
Sphaerotheca breviceps	1	0	1	1	0	0	1	0	1	0	0	0	0
Sphaerotheca pashchima	0	1	0	0	1	0	0	0	1	1	1	1	1
Uperodon globulosus	0	0	0	0	0	0	0	0	0	0	0	0	0
Uperodon systoma	0	0	0	1	0	0	0	0	1	0	1	1	0
Uperodon taprobanicus	0	0	0	1	0	0	0	0	0	0	0	0	0
Uperodon variegatus	0	0	0	1	0	0	0	0	0	0	0	0	0

*1= presence; 0= absence)



Middle Stretch											Lower Stretch						
Bharatganj	Mirzapur	Varanasi	Gangabarar	Ballia	Chapra	Fatwah	Simaria	Munger	Kahalgaon	Sahibganj	Farakka	Jiaganj	Katwa	Nabadwip	Kalyani	Maheshtala	Haldia
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	1	0	1	1	0	1	1	0	1	1	1	1	1
0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	1	0	1	1	1	1	0	0	1	1	0	1	1	1	0	1
0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1
1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	1	1	1	0	1	0	0	1	0	1	1	1	1	0	0
0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	0	0
1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Annexure VI Relative abundance (%) of different Turtle groups in the Ganga River

Year	Pangshura	Nilssonia	Batagur	Chitra	Hamiltoni	Lissemys	Melanochelys
2018	96.32	2.37	0.57	0.39	0.21	0.10	
2019	98.72	1.17	0.07	0.03		0.01	
2020	99.25	0.21	0.14	0.01		0.05	0.34

ANNEXURE VII Checklist of water- and water-associated bird species in the Ganga River

SN	Order	Family	Common Name
1	Anseriformes	Anatidae	Bar-headed Goose
2	Anseriformes	Anatidae	Common Merganser
3	Anseriformes	Anatidae	Common Pochard
4	Anseriformes	Anatidae	Common Shelduck
5	Anseriformes	Anatidae	Common Teal
6	Anseriformes	Anatidae	Ferruginous Duck
7	Anseriformes	Anatidae	Gadwall
8	Anseriformes	Anatidae	Garganey
9	Anseriformes	Anatidae	Indian Spot-billed Duck
10	Anseriformes	Anatidae	Mallard
11	Anseriformes	Anatidae	Northern Pintail
12	Anseriformes	Anatidae	Northern Shoveler
13	Anseriformes	Anatidae	Red-crested Pochard
14	Anseriformes	Anatidae	Ruddy Shelduck
15	Anseriformes	Anatidae	Tufted Duck
16	Gruiformes	Rallidae	Eurasian Coot
17	Gruiformes	Rallidae	White-breasted Waterhen
18	Gruiformes	Gruidae	Common Crane
19	Gruiformes	Gruidae	Sarus Crane
20	Charadriiformes	Burhinidae	Great Thick-knee
21	Charadriiformes	Recurvirostridae	Black-winged Stilt
22	Charadriiformes	Recurvirostridae	Pied Avocet
23	Charadriiformes	Charadriidae	Grey-headed Lapwing
24	Charadriiformes	Charadriidae	Kentish Plover
25	Charadriiformes	Charadriidae	Little Ringed Plover
26	Charadriiformes	Charadriidae	Red-wattled Lapwing
27	Charadriiformes	Charadriidae	River Lapwing
28	Charadriiformes	Charadriidae	Tibetan Sand-Plover
29	Charadriiformes	Scolopacidae	Common Greenshank
30	Charadriiformes	Scolopacidae	Common Redshank
31	Charadriiformes	Scolopacidae	Common Sandpiper
32	Charadriiformes	Scolopacidae	Common Snipe
33	Charadriiformes	Scolopacidae	Eurasian Curlew
34	Charadriiformes	Scolopacidae	Green Sandpiper
35	Charadriiformes	Scolopacidae	Little Stint
36	Charadriiformes	Scolopacidae	Marsh Sandpiper
37	Charadriiformes	Scolopacidae	Ruff
38	Charadriiformes	Scolopacidae	Spotted Redshank
39	Charadriiformes	Scolopacidae	Temminck's Stint
40	Charadriiformes	Glareolidae	Small Pratincole
41	Charadriiformes	Laridae	Black-bellied Tern
42	Charadriiformes	Laridae	Black-headed Gull
43	Charadriiformes	Laridae	Brown-headed Gull

Scientific Name	Feeding Guild	IUCN	IWPA
Anser indicus (Latham, 1790)	H	LC	Sch.-II
Mergus merganser Linnaeus, 1758	C	LC	Sch.-II
Aythya ferina (Linnaeus, 1758)	H/C	VU	Sch.-I
Tadorna tadorna (Linnaeus, 1758)	C/H	LC	Sch.-II
Anas crecca Linnaeus, 1758	H	LC	Sch.-II
Aythya nyroca (Güldenstädt, 1770)	O	NT	Sch.-II
Mareca strepera (Linnaeus, 1758)	H/C	LC	Sch.-II
Spatula querquedula (Linnaeus, 1758)	H/C	LC	Sch.-II
Anas poecilorhyncha Forster, 1781	H/C	LC	Sch.-II
Anas platyrhynchos Linnaeus, 1758	H/C	LC	Sch.-II
Anas acuta Linnaeus, 1758	H/C	LC	Sch.-II
Spatula clypeata (Linnaeus, 1758)	C/H	LC	Sch.-II
Netta rufina (Pallas, 1773)	H/C	LC	Sch.-II
Tadorna ferruginea (Pallas, 1764)	O	LC	Sch.-II
Aythya fuligula (Linnaeus, 1758)	C/H	LC	Sch.-II
Fulica atra Linnaeus, 1758	H/C	LC	Sch.-II
Amaurornis phoenicurus (Pennant, 1769)	O	LC	Sch.-II
Grus grus (Linnaeus, 1758)	H/C	LC	Sch.-I
Antigone antigone (Linnaeus, 1758)	H/C	VU	Sch.-I
Esacus recurvirostris (Cuvier, 1829)	C	NT	Sch.-II
Himantopus himantopus (Linnaeus, 1758)	C/H	LC	Sch.-II
Recurvirostra avosetta Linnaeus, 1758	C	LC	Sch.-II
Vanellus cinereus (Blyth, 1842)	C	LC	Sch.-II
Anarhynchus alexandrinus (Linnaeus, 1758)	C	LC	Sch.-II
Thinornis dubius (Scopoli, 1786)	C	LC	Sch.-II
Vanellus indicus (Boddaert, 1783)	C	LC	Sch.-II
Vanellus duvaucelii (Lesson, 1826)	C	NT	Sch.-II
Anarhynchus atrifrons (Wagler, 1829)	C	LC	Sch.-II
Tringa nebularia (Gunnerus, 1767)	C	LC	Sch.-I
Tringa totanus (Linnaeus, 1758)	C	LC	Sch.-II
Actitis hypoleucos (Linnaeus, 1758)	C	LC	Sch.-II
Gallinago gallinago (Linnaeus, 1758)	C	LC	Sch.-II
Numenius arquata (Linnaeus, 1758)	C	NT	Sch.-II
Tringa ochropus Linnaeus, 1758	C	LC	Sch.-II
Calidris minuta (Leisler, 1812)	C/H	LC	Sch.-II
Tringa stagnatilis (Bechstein, 1803)	C	LC	Sch.-II
Calidris pugnax (Linnaeus, 1758)	C/H	LC	Sch.-II
Tringa erythropus (Pallas, 1764)	C	LC	Sch.-II
Calidris temminckii (Leisler, 1812)	C/H	LC	Sch.-II
Glareola lactea Temminck, 1820	C	LC	Sch.-II
Sterna acuticauda Gray, 1831	C	EN	Sch.-I
Chroicocephalus ridibundus (Linnaeus, 1766)	C	LC	Sch.-II
Chroicocephalus brunnicephalus (Jerdon, 1840)	C	LC	Sch.-II

SN	Order	Family	Common Name
44	Charadriiformes	Laridae	Indian Skimmer
45	Charadriiformes	Laridae	Pallas's Gull
46	Charadriiformes	Laridae	River Tern
47	Phoenicopteriformes	Phoenicopteridae	Greater Flamingo
48	Podicipediformes	Podicipedidae	Great Crested Grebe
49	Podicipediformes	Podicipedidae	Little Grebe
50	Ciconiiformes	Ciconiidae	Asian Openbill
51	Ciconiiformes	Ciconiidae	Asian Woolly-necked Stork
52	Ciconiiformes	Ciconiidae	Black Stork
53	Ciconiiformes	Ciconiidae	Black-necked Stork
54	Ciconiiformes	Ciconiidae	Lesser Adjutant
55	Ciconiiformes	Ciconiidae	Painted Stork
56	Suliformes	Anhingidae	Oriental Darter
57	Suliformes	Phalacrocoracidae	Great Cormorant
58	Suliformes	Phalacrocoracidae	Indian Cormorant
59	Suliformes	Phalacrocoracidae	Little Cormorant
60	Pelecaniformes	Threskiornithidae	Black-headed Ibis
61	Pelecaniformes	Threskiornithidae	Eurasian Spoonbill
62	Pelecaniformes	Threskiornithidae	Red-naped Ibis
63	Pelecaniformes	Ardeidae	Black-crowned Night Heron
64	Pelecaniformes	Ardeidae	Eastern Cattle-Egret
65	Pelecaniformes	Ardeidae	Great Egret
66	Pelecaniformes	Ardeidae	Grey Heron
67	Pelecaniformes	Ardeidae	Indian Pond-Heron
68	Pelecaniformes	Ardeidae	Intermediate Egret
69	Pelecaniformes	Ardeidae	Little Egret
70	Pelecaniformes	Ardeidae	Purple Heron
71	Pelecaniformes	Ardeidae	Striated Heron
72	Pelecaniformes	Pelecanidae	Great White Pelican
73	Accipitriformes	Pandionidae	Osprey
74	Accipitriformes	Accipitridae	Pallas's Fish Eagle
75	Accipitriformes	Accipitridae	Steppe Eagle
76	Coraciiformes	Alcedinidae	Common Kingfisher
77	Coraciiformes	Alcedinidae	Pied Kingfisher
78	Coraciiformes	Alcedinidae	Stork-billed Kingfisher
79	Coraciiformes	Alcedinidae	White-throated Kingfisher
80	Passeriformes	Hirundinidae	Barn Swallow
81	Passeriformes	Hirundinidae	Grey-throated Martin
82	Passeriformes	Motacillidae	Citrine Wagtail
83	Passeriformes	Motacillidae	White Wagtail
84	Passeriformes	Motacillidae	White-browed Wagtail

Scientific Name	Feeding Guild	IUCN	IWPA
Rynchops albicollis Swainson, 1838	C	EN	Sch.-I
Ichthyaetus ichthyaetus (Pallas, 1773)	C	LC	Sch.-II
Sterna aurantia Gray, 1831	C	VU	Sch.-I
Phoenicopterus roseus Pallas, 1811	C/H	LC	Sch.-II
Podiceps cristatus (Linnaeus, 1758)	C/H	LC	Sch.-II
Tachybaptus ruficollis (Pallas, 1764)	C	LC	Sch.-II
Anastomus oscitans (Boddaert, 1783)	C	LC	Sch.-II
Ciconia episcopus (Boddaert, 1783)	C	NT	Sch.-II
Ciconia nigra (Linnaeus, 1758)	C	LC	Sch.-II
Ephippiorhynchus asiaticus (Latham, 1790)	C	LC	Sch.-II
Leptoptilos javanicus (Horsfield, 1821)	C	NT	Sch.-I
Mycteria leucocephala (Pennant, 1769)	C	LC	Sch.-II
Anhinga melanogaster Pennant, 1769	C	LC	Sch.-II
Phalacrocorax carbo (Linnaeus, 1758)	C	LC	Sch.-II
Phalacrocorax fuscicollis Stephens, 1826	C	LC	Sch.-II
Microcarbo niger (Vieillot, 1817)	C	LC	Sch.-II
Threskiornis melanocephalus (Latham, 1790)	C	LC	Sch.-II
Platalea leucorodia Linnaeus, 1758	C	LC	Sch.-I
Pseudibis papillosa (Temminck, 1824)	C	LC	Sch.-II
Nycticorax nycticorax (Linnaeus, 1758)	C	LC	Sch.-II
Ardea coromanda (Boddaert, 1783)	C	LC	Sch.-II
Ardea alba Linnaeus, 1758	C	LC	Sch.-II
Ardea cinerea Linnaeus, 1758	C	LC	Sch.-II
Ardeola grayii (Sykes, 1832)	C	LC	Sch.-II
Ardea intermedia Wagler, 1829	C	LC	Sch.-II
Egretta garzetta (Linnaeus, 1766)	C	LC	Sch.-II
Ardea purpurea Linnaeus, 1766	C	LC	Sch.-II
Butorides striata (Linnaeus, 1758)	C	LC	Sch.-II
Pelecanus onocrotalus Linnaeus, 1758	C	LC	Sch.-II
Pandion haliaetus (Linnaeus, 1758)	C	LC	Sch.-I
Haliaeetus leucoryphus (Pallas, 1771)	C	EN	Sch.-I
Aquila nipalensis Hodgson, 1833	C	EN	Sch.-I
Alcedo atthis (Linnaeus, 1758)	C	LC	Sch.-II
Ceryle rudis (Linnaeus, 1758)	C	LC	Sch.-II
Pelargopsis capensis (Linnaeus, 1766)	C	LC	Sch.-II
Halcyon smyrnensis (Linnaeus, 1758)	C	LC	Sch.-II
Hirundo rustica Linnaeus, 1758	I	LC	Sch.-II
Riparia chinensis (Gray, 1830)	I	LC	Sch.-II
Motacilla citreola Pallas, 1776	C	LC	Sch.-II
Motacilla alba Linnaeus, 1758	C	LC	Sch.-II
Motacilla maderaspatensis Gmelin, 1789	C	LC	Sch.-II

Annexure VIII Relative Abundance of water and water-associated species during 2017-18 and 2024-25

Waterbirds	2017-18	2024-25
Bar-headed Goose	1.89	1.03
Common Merganser	0.01	0
Common Pochard	0.7	0
Common Shelduck	0.05	0
Common Teal	2.58	2.25
Ferruginous Duck	0	0.04
Gadwall	8.21	2.27
Garganey	0.18	0
Indian Spot-billed duck	0.1	0.54
Mallard	0.03	0.09
Northern Pintail	1.5	0.97
Northern Shoveler	1.22	0
Red-crested Pochard	0.4	0.67
Ruddy Shelduck	6.9	11.37
Tufted Duck	0.74	0
Eurasian Coot	0.37	0.29
White-breasted Waterhen	0	0.05
Common Crane	0	1.01
Sarus Crane	0.08	0.13
Great Thick-knee	0.01	0.25
Black-winged Stilt	0.89	3.51
Pied Avocet	1.3	0.36
Grey-headed Lapwing	0	0.52
Kentish Plover	0.05	2.07
Little Ringed Plover	0.17	0
Red-wattled Lapwing	0.04	0.22
River Lapwing	0.74	1.5
Tibetan Sand-Plover	0	0.47
Common Greenshank	2.96	4.41
Common Redshank	0.18	0.72
Common Sandpiper	0.21	0.5
Common Snipe	0.01	0
Eurasian Curlew	0.99	1.68
Green Sandpiper	0.32	0.25
Little Stint	0.95	0
Marsh Sandpiper	0.53	0
Ruff	0	0.36
Spotted Redshank	1.43	0.9
Temminck's Stint	0.1	1.28
Small Pratincole	22.5	0
Black-bellied Tern	0.3	0.22
Black-headed Gull	0.21	18.72
Brown-headed Gull	5.19	0.07

Waterbirds	2017-18	2024-25
Indian Skimmer	0	0.38
Pallas's Gull	0.55	0.85
River Tern	0.04	0.25
Greater Flamingo	0	0.04
Great Crested Grebe	0.49	0.59
Little Grebe	0.32	0
Asian Openbill	1.46	2.18
Asian Woolly-necked Stork	0.19	0.54
Black Stork	0.01	0
Black-necked Stork	0.03	0
Lesser Adjutant	0	0.02
Painted Stork	0.32	0.05
Oriental Darter	0.03	0.04
Great Cormorant	18.36	8.63
Indian Cormorant	0.63	0.04
Little Cormorant	0.49	0.83
Black-headed Ibis	0.16	0.72
Eurasian Spoonbill	0.85	0.29
Red-naped Ibis	1.16	3.04
Black-crowned Night Heron	0	0.22
Eastern Cattle-Egret	0.24	1.33
Great Egret	0.06	3.42
Grey Heron	1.09	2.74
Indian Pond-Heron	0.11	0.38
Intermediate Egret	0.05	0.56
Little Egret	0.61	2.36
Great White Pelican	0.01	0
Purple Heron	0	0.02
Striated Heron	0	0.02
Water-associated Birds	2017-18	2024-25
Osprey	0.07	0.04
Pallas's Fish-Eagle	0.01	0
Steppe Eagle	0.03	0
Common Kingfisher	0	0.05
Pied Kingfisher	0.12	0.36
Stork-billed Kingfisher	0	0.02
White-throated Kingfisher	0.06	0.16
Barn Swallow	0.37	0.32
Grey-throated Martin	7.83	10.77
Citrine Wagtail	0.01	0
White Wagtail	0.14	0
White-browed Wagtail	0.05	0.04





भारतीय वन्यजीव संस्थान
Wildlife Institute of India

NMCG

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GACMC/NCRR

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