NAMAMI GANGE

biodiversity profile of the ganga river

BIODIVERSITY PROFILE OF THE GANGA RIVER

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PREFACE

Freshwater ecosystems are the most vulnerable habitats in the current global change scenario. These ecosystems occupy less than 1% of the world's surface area, and provide shelter to many endemic and threatened species. Among the freshwater ecosystem, river ecosystems are more prone to large-scale modifications due to land use change along the rivers. River habitats are the embedded structures within the terrestrial ecosystem and the dispersal of organisms inhabiting these habitats are limited within the river basin network. Therefore, unlike terrestrial ecosystem, freshwater organisms have limited opportunities to move from disturbed to the ecologically healthy sites. Recent studies on aquatic systems showed that decline in the freshwater biodiversity is much faster than the terrestrial biodiversity. The Ganga River harbours globally significant portion of aquatic biodiversity, but evidences suggest declining trends in its biodiversity. This is largely due to high anthropogenic pressure and developmental activities that lead to flow modifications, riverbank alterations and untreated city and industrial discharges. In view of this, the Ministry of Water Resources, River Development and Ganga Rejuvenation through National Mission for Clean Ganga has entrusted the Wildlife Institute of India with the project 'Biodiversity Conservation and Ganga Rejuvenation' to restore the dwindling biodiversity of the Ganga River. This project aims to prepare a science based aquatic species restoration plan for Ganga River by involving multiple stakeholders. The present synthesis fulfils the requirement for one of the major objective of the project "Biodiversity Conservation and Ganga Rejuvenation: Planning Aquatic Species Restoration for Ganga River" which is to derive the state of biodiversity in the Ganga River. This book attempts to compile the current biodiversity profile of the Ganga River. Under this study, data from 32 intensive monitoring sites representing six habitat zones along the Ganga River has been synthesized. The book "Biodiversity profile of the Ganga River" contains the diversity profile for riverbank vegetation, odonates, fishes, reptiles, birds and mammals. The book also represents preliminary results of the study on physico-chemical parameters of river water and the genetic study taken up on selected fish species.

Vinod B. Mathur
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J. Antony Johnson
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Ruchi Badola

message

नितिन गडकरी
Nitin Gadkari

सत्यमेव जयते

मंत्री
जल संसाधन, नदी विकास, गंगा सरंक्षण,
सड़क परिवहन, राजमार्ग एवं पोत परिवहन
भारत सरकार
नई दिल्ली–110001

MINISTER
WATER RESOURCES, RIVER DEVELOPMENT,
GANGA REJUVENATION, ROAD TRANSPORT,
HIGHWAYS AND SHIPPING
GOVERNMENT OF INDIA
NEW DELHI-110001

It is my pleasure to write this message for the book "Biodiversity Profile of the Ganga River" prepared by the Wildlife Institute of India, Dehradun as part of the "Biodiversity Conservation and Ganga Rejuvenation" project, entrusted by the National Mission for Clean Ganga, Ministry of Water Resources, River Development and Ganga Rejuvenation.

The Ganga River is one of the longest transboundary rivers in Asia, with a high human density. In India, Ganga is not just a mere natural resource, but a symbol of faith, spirituality, culture and integrity. To ensure long-term sustainability of the Ganga River, it is crucial to restore the ecological integrity by conserving the aquatic species of the Ganga River. Biodiversity conservation is thus, an important component of the Namami Gange Program. This publication substantiates the commitment of the Government of India towards *Aviral* and *Nirmal dhara* of the Ganga River.

I appreciate and congratulate the efforts made by the Wildlife Institute of India in bringing out this book covering a wide range of taxa from plants to mammals across the length of the Ganga River.

(Nitin Gadkari)

message

डॉ. हर्ष वर्धन
Dr. Harsh Vardhan

सत्यमेव जयते

मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
भारत सरकार
नई दिल्ली–110003

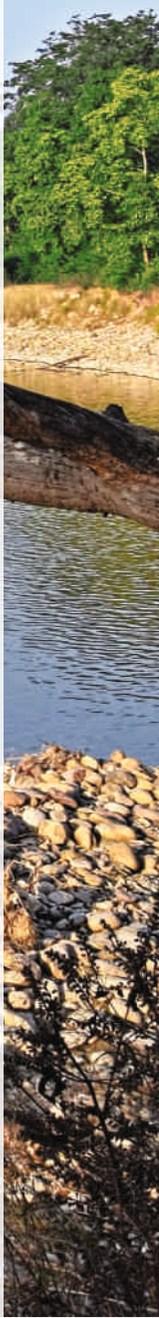
MINISTER
ENVIRONMENT, FOREST & CLIMATE CHANGE
GOVERNMENT OF INDIA
NEW DELHI-110003

The Ganga River, traversing through three biogeographic zones of India seeped deeply in socio-cultural and ecological values forms a lifeline for a very large section of humanity as well as aquatic biodiversity. However, centuries of resource exploitation has endangered this River system, which calls for a systematic conservation planning, as has been initiated under the project "Biodiversity Conservation and Ganga Rejuvenation" entrusted to the Wildlife Institute of India by the National Mission for Clean Ganga.

The findings of the intensive survey published in this book signifies the importance of Protected Areas as habitats for the conservation dependent species. The information provided in this book would aid in conservation planning and informed decision making required for restoring the river health.

I congratulate the Wildlife Institute of India in general and the project team in particular for an unprecedented effort put in for making this project a success and bringing out this publication.

(Harsh Vardhan)



message

सी.के.मिश्रा
C.K. Mishra

सत्यमेव जयते

सचिव
भारत सरकार
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
नई दिल्ली–110003

SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FOREST & CLIMATE CHANGE
NEW DELHI-110003

The Ganga River, traversing through diverse landscapes from its origin at Gaumukh to its confluence in Bay of Bengal at Ganga Sagar, nurtures populations of both human and the aquatic wildlife, spread across its basin covering 11 states of India. Alteration of river bank; unsustainable water abstraction, sand mining; agriculture along river bank and river islands; unsustainable fishing; and pollution due to industrial, domestic and agricultural wastes along with climate change are causing changes in the river's ecosystem. The gravity of the situation has necessitated holistic interventions, through combination of science, people and policy.

This book "Biodiversity Profile of the Ganga River" is an effort towards building the ecological knowledge of the current state of the diversity and presents the findings of the intensive study along the entire stretch of the mainstem Ganga River, emphasizing the role of Protected Areas as cornerstone for biodiversity conservation.

I congratulate the Wildlife Institute of India and its team for their commendable and significant contribution to the field of aquatic ecology and conservation.

C.K. Mishra

message

यू.पी. सिंह
U.P. Singh

सत्यमेव जयते

सचिव
भारत सरकार
जल संसाधन, नदी विकास एवं गंगा संरक्षण मंत्रालय
नई दिल्ली–110001

SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES, RIVER
DEVELOPMENT & GANGA REJUVENATION
NEW DELHI-110001

I am pleased to learn about the scientific work being carried out by the Wildlife Institute of India, Dehradun under the project "Biodiversity Conservation and Ganga Rejuvenation" entrusted by the National Mission for Clean Ganga, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India.

The Ganga River, apart from supporting the livelihoods of millions of people, harbours and nurtures diverse aquatic flora and fauna such as Gangetic river dolphin, gharial, mugger, otters, turtles, birds and fishes that are vital for maintaining the health of the river ecosystem. However, pollution, reduced water flow and over exploitation of riverine resources has led to habitat degradation causing decline in populations of these aquatic wildlife.

This book "Biodiversity Profile of the Ganga River" provides information on the synchronous distributional responses of studied taxa along the longitudinal gradient of the River. This repository of scientific knowledge will aid in achieving the mandate of NMCG for conservation of biodiversity of the Ganga River.

I sincerely appreciate the tremendous amount of efforts made by the Wildlife Institute of India in the field of aquatic wildlife conservation. I congratulate them on bringing out this book, which will contribute in strengthening the conservation initiatives of the Ganga River.

(Upendra Prasad Singh)

message

राजीव रंजन मिश्रा
Rajiv Ranjan Mishra

सत्यमेव जयते

महानिदेशक
भारत सरकार
जल संसाधन, नदी विकास एवं गंगा संरक्षण मंत्रालय
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नई दिल्ली–110002

DIRECTOR GENERAL
GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES, RIVER DEVELOPMENT & GANGA REJUVENATION
NATIONAL MISSION FOR CLEAN GANGA
NEW DELHI-110002

It gives me immense pleasure to learn that the Wildlife Institute of India, Dehra Dun has successfully prepared this book "Biodiversity Profile of the Ganga River", under the aegis of its NMCG-funded "Biodiversity Conservation and Ganga Rejuvenation" project.

The Ganga River provides habitat to a wide variety of aquatic flora and fauna. Conservation of this diversity is a challenging task considering the dependence of local communities on the resources of the Ganga River, and associated anthropogenic and development pressures. These pressures have disrupted natural processes and functions and have led to habitat degradation. The restoration and conservation of the river ecosystem needs a holistic approach wherein the scientific knowledge lays the foundation for long term conservation with the involvement of all the stakeholders. To accomplish this goal of biodiversity conservation of the Ganga River, NMCG has entrusted the Wildlife Institute of India with the project "Biodiversity Conservation and Ganga Rejuvenation" under the *Namami Gange*, an Integrated Ganga Conservation Mission.

This book "Biodiversity Profile of the Ganga River", presents the findings of the intensive study carried along the Ganga River, from origin to its mouth. The study emphasizes on the need of taxa-specific conservation approaches as distinct ecological responses were observed for the different groups of the studied taxa. I strongly believe that this book will contribute in framing strategic plans for conservation of the aquatic species and will further strengthen the ecological restoration of the Ganga River.

(Rajiv Ranjan Mishra)

message

सिद्धान्त दास
Siddhanta Das

सत्यमेव जयते

वन महानिदेशक एवं विशेष सचिव
भारत सरकार
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
नई दिल्ली–110003

DIRECTOR GENERAL OF FOREST & SPL. SECY
GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FOREST & CLIMATE CHANGE
NEW DELHI-110003

It is a matter of great satisfaction that the book "Biodiversity Profile of the Ganga River", has been prepared by the Wildlife Institute of India, Dehra Dun as part of the "Biodiversity Conservation and Ganga Rejuvenation" project, funded by the National Mission for Clean Ganga, Ministry of Water Resources, River Development and Ganga Rejuvenation.

The Ganga River traversing across diverse landscapes covering five states viz. Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal is a source of livelihood to millions of people residing along its banks and is thus aptly referred to as the "Lifeline of India". However, the growing population and developing economy is significantly impacting the ecological health of the Ganga River, which also endangers the livelihood of the people. Therefore, it becomes imperative to conserve the Ganga River and its resources. This book is a scientific documentation of the current distribution of the aquatic diversity along the mainstem Ganga River, and emphasizes the need for a systematic conservation planning with taxa-specific conservation approaches. The information provided in this book would also be useful for the long-term monitoring of the aqualife of Ganga River.

I congratulate the Wildlife Institute of India team for this comprehensive documentation of the biodiversity found in the Ganga River.

(Siddhanta Das)

message

एम. एस. नेगी
M.S. Negi

सत्यमेव जयते

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The Wildlife Institute of India, Dehra Dun has been conducting outstanding research work in the field of wildlife science and biodiversity conservation over last three decades. Engagement of the Wildlife Institute of India in the Namami Gange programme, has added a new dimension towards aquatic biodiversity conservation.

The book has been prepared on the basis of the intensive field surveys along the mainstem Ganga River and is a significant contribution to aquatic wildlife conservation in India. The book presents taxa specific distribution along the longitudinal gradient of the Ganga River and highlights the stretches of the River that need urgent conservation and management interventions. The information provided herein will be vital for decision making with regard to conservation prioritization and resource allocation for maintaining the river health and human well-being.

My best wishes and hearty congratulations to the Wildlife Institute of India and the project team for making valuable contribution to the cause of biodiversity conservation and Ganga rejuvenation.

(M.S. Negi)

INTRODUCTION TO FLORA AND FAUNA OF THE GANGA RIVER , ITS SIGNIFICANCE AND THE RATIONALE BEHIND BIODIVERSITY MONITORING

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ABSTRACT

The Ganga River traverses through diverse ecological conditions and is a home to numerous important flora and fauna. The aquatic habitats of the Ganga River are under threat due to rapidly increasing human population, deteriorating water quality and flow modifications. The assessment of biodiversity is a key step to make comprehensive conservation strategies for the restoration of aquatic species. Maintaining viable populations of the species inhabiting the Ganga River would ensure the integrity of the Ganga river ecosystem. Our monitoring surveys apply large-scale multi-taxa approach to prepare a baseline diversity profile for the Ganga River, which would assist the future conservation and management processes for restoring the river ecology.

Key words: River Restoration, Aquatic Biodiversity, Monitoring, National Mission, Clean Ganga

1

The Ganga is a Holy River of India, which is one of the centre of ancient human civilization. It is not only the most sacred river of India but also constitutes one of the most densely populated river basins of the world. The Ganga originates from Himalaya from its source tributaries Bhagirathi and Alaknanda, and also receives major tributaries of the north basin (e.g. Ramganga, Yamuna, Gomti, and Kosi) and the tributaries of south basin originating from the Vindhya ranges (e.g. Chambal, Sind, Betwa and Ken). The Ganga flows downhill through the west Himalayan mountain region, to the extended upper Gangetic plains till the north of West Bengal and then again starts to disintegrate into its sub-channels and forms lower Gangetic plains in India and Bangladesh. The Ganga basin harbours rich biodiversity due to its vastness which reflects the diversity of its physiographic, climatic, geological and hydrological characteristics. The entire course of the Ganga River can be characterized by a wide variety of ecological conditions and spans different climatic (temperate, tropical; both wet and dry), topographical (altitude, longitude and latitude) and geological zones (mountains, plains and estuary). The Ganga River basin has been classified in three biogeographical regions; the Western Himalaya, the upper and the lower Gangetic plains across its course in India (Rodgers et al., 2002). The Ganga River provides habitats for some of the most endangered and threatened species of the world and needs immediate attention for their conservation (Bashir et al., 2012; Hussain, 1999; Sarkar et al., 2012); these include the Gangetic dolphin (*Platanista gangetica*), smooth-coated otter (*Lutrogale perspicillata*), Eurasian otter (*Lutra lutra*) and the small clawed otter (*Aonyx cinereus*), the Gangetic ghariyal (*Gavialis gangeticus*), Indian skimmer (*Rynchops albicollis*), river tern (*Sterna aurantia*), red-crowned roofed turtle (*Batagur kachuga*), Gangetic shark (*Glyphis gangeticus*), freshwater catfish (*Wallago attu*), golden mahseer (*Tor putitora*), hilsa (*Tenualosa ilisha*) and Dudhwa tree frog (*Chiromantis dudhwaensis*). For the sustainable conservation of species and to make river habitats more resilient, it is required to bridge the gap between research and implementation that should include genuine collaborative involvement of concern stakeholders and managers. But this process needs to be assisted by ecologically sound data reflecting standardized and large-scale spatial efforts.

Freshwater ecosystems are under threat due to changing climatic conditions and human-caused disturbances, and its biodiversity is declining at an alarming rate faster than the terrestrial habitats (Dudgeon et al., 2006). The Ganga River is facing various kinds of anthropogenic interventions since the second half of the twentieth century in form of construction of dams with the emerging energy demand, diversion of water for agriculture, habitat alterations, human habitation along the banks and rapid urbanization-industrialization with increasing pollution levels which has resulted in degraded water quality. All these causal factors are a huge challenge for government agencies, relevant stakeholders and the entire scientific community in

order to maintain the ecological integrity of the river ecosystem. For a healthy river ecosystem, the river must be allowed to maintain its ecological flow by maintaining its longitudinal and lateral connectivity (Johnson et al., 2017). Especially, biodiversity plays a significant role in the functioning of a river ecosystem by providing different ecosystem services (Sinha, 2014). These services are not limited to just providing pure and clean water, maintaining inorganic cycles and carbon flow, but also include the assimilation of wastes from different human sources.

Recent studies suggested importance of baseline biodiversity data in designing conservation prioritization strategies in Indian tropical rivers (Bhat, 2017). In order to restore the ecological condition of Ganga River, the government of India has launched various river restoration programmes under National Mission on Clean Ganga (NMCG) programme. Acquiring the knowledge of diversity and species distribution along the river Ganga is an essential step and a fundamental approach in preserving the river's ecological integrity as to achieve the ecological state of *Nirmal Dhara* and *Aviral Dhara*. A plethora of literature exists for the flora and fauna of the River Ganga; e.g. published articles in journals, books, review articles, conference papers, environmental impact assessment reports and studies conducted by government agencies. Although, a very few studies conducted the surveys at large spatial scales along the main stem of the Ganga River. Some studies like Nautiyal et al., 2014, Murti, 1991 and the reports for "Ganga River Basin Environmental Management Plan" (Behera et. al., 2012; Mathur et al., 2012; Mathur et al., 2011) by seven Indian Institute of Technology (Bombay, Delhi, Guwahati, Kanpur, Kharagpur, Madras and Roorkee), are some significant contributions and give detailed taxonomic account and checklist of the reported species from the selected stretches of the Ganga River. The effectiveness of Clean Ganga programme can be easily validated through the physico-chemical and biological condition of river with reference to historical or past data. Regrettably, most of these studies conducted at different spatial scales, belong to different time domains, differ in magnitude and extent of data, and only focus on the selected stretch of the Ganga River. Moreover, due to lack of fixed monitoring stations, these findings lack the potential to be investigated in future for temporal trends in biodiversity with their associated

environmental conditions. These historical information are inadequate to establish the empirical relationship of environmental parameters with biodiversity status of Ganga.

With this as a background, a project on "Planning Aquatic Species Restoration for Ganga River" was launched in Wildlife Institute of India (Component 2 under WII-NMCG programme). One of the major objectives of this project is to derive the state of biodiversity in the Ganga River for provisioning of effective restoration plans. For the biodiversity conservation and rejuvenation of the Ganga River, we proposed to assess the occurrences and abundances of species across the river as a major step to proceed forward. This study not only provides the status of biodiversity along the main stem of the Ganga River, but also relates diversity with environmental conditions at selected monitoring stations. In this process, 32 permanent monitoring stations all along the main stem of the Ganga River (from Harsil to Ganga Sagar) were established, and information on status of aquatic

biodiversity and habitat conditions were generated. This document entails information on eight sub-components comprising of status of river bank vegetation, diversity and abundance of odonates, fishes, reptiles, birds and mammals, and status of toxicity level and genetic structure of aquatic organisms. This baseline document will also help to identify the indicator species and communities that would be used for monitoring the ecological health of the Ganga River. Here, our aim is to go beyond the preparation of taxonomic checklist of the biota comprising not only presence-absence information, but also setting up the baseline diversity profile with adaptation of sound ecological taxa-specific approaches so that future studies can utilize these results for provisioning of conservation processes and mitigation of anthropogenic alterations in habitats of the Ganga River.

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Photo Credit : Jeyaraj Antony Johnson

STUDY AREA AND SAMPLING STRATEGY

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ABSTRACT

The Ganga is the longest river in India which is divided into three distinct segments i.e. upper, middle and lower stretches. The different stretches of river pass through multiple environmental regimes. The upper stretch flows through hilly terrain, whereas the middle and lower stretch flow through alluvial plains. The river has been stratified in six habitat zones depending upon geomorphology, habitat condition, water availability and physical properties of water. The river is categorized in six habitat zones and each zone is represented by intensive monitoring sites of 5 km stretch with regular interval spacing of about 75 km between each site. The sites were fixed keeping in mind the logistics and feasibility of being able to cover all sampling sites in a given season i.e. within two months. Based on the above strategy, total of thirty-two intensive monitoring sites have been fixed by stratified sampling method with regular interval.

Key words: Ganga River , Habitat Zone, Monitoring Sites, Flood Plain.

2

2.1 SELECTION OF STUDY SITES, HABITAT ZONES AND RIVER STRETCHES

The holy Ganga travels through multiple environmental regimes of India. It originates from Gangotri glacier in Gaumukh (79°7´ E, 30°55´ N) at an elevation of 4100 meter (msl) and meets the Bay of Bengal in Ganga Sagar (88°4´ E, 21°38´ N). The river flows in three stretches; upper stretch from Gaumukh to Haridwar flows through the gorges of hilly terrain, middle stretch from Haridwar to Varanasi is mainly dense human populated areas with significant load of pollutants and lower stretch from Varanasi to Ganga Sagar is the part of flood plains.

In the upper segment, Ganga river flows through hilly gorge and its riverbed is characterised by bedrocks, pebbles and boulders. This stretch consists of fragile river ecosystem and has potential for generation of hydroelectricity.

The middle stretch is represented by numerous meandered channels comprising of fine sand. The river bed consists of gravels and pebbles at the initial part of this stretch but it turns to fine sand with its flow towards the lower stretch. The middle stretch experiences number of canals and industries that extract plenty of water from the river. Many populous cities like Kanpur, Fatehpur, Allahabad and Varanasi are situated along this stretch which introduce tremendous pollution load to the river system. Sand mining and river bed farming are common practices in this stretch.

The river enters the lower stretch with high sediment load and deposits till confluence which is the part of flood plains. Many tributaries meet the river in the lower stretch that leads to a high volume of water to flow. These tributaries contribute significant discharge in the monsoon season whereas rivers that originate from Himalayan region serve the Ganga river with significant water discharge throughout the year. However, the seasonal tributaries feed the Ganga river with fluctuated discharge depending upon the season. This segment deposits silts along the river mainly at the confluence which makes this area highly fertile. Three seasonal cropping patterns are common in this region. The lower part of this stretch experiences tidal effects which form a unique habitat with high salinity of soil and water. mangrove vegetation with halophilic biota forms a unique habitat in this part. Several large towns and cities, industries and agricultural areas lead to water extraction, contribute more nutrient load and pollutants. Encroachment of river bed for sand mining, agriculture etc. is also common in this stretch.

Depending upon the geomorphology, habitat condition, water, availability and physical properties of water the river is categorized in six habitat zones. The upper stretch from Gangotri to Haridwar sector has similar habitat condition. It is considered as Habitat Zone – 1. In the case of the middle stretch, it is quite long and has been stratified into three habitat zones: Haridwar to Narora, Narora to Kanpur and Kanpur to Varanasi, based on water availability and human pressure. The third stretch is Varanasi to Ganga Sagar stratified into two habitat zones based on the physico-chemical properties of water (Table: 2.1).

After stratification into six habitat zones, the intensive sampling sites were fixed by feasibly and

Habitat Zone	Stretch	Length (Km)	Number of Intensive Monitoring Sites
HZ-1	Gangotri - Haridwar	310	4
HZ-2	Haridwar - Narora	235	3
HZ-3	Narora - Kanpur	320	4
HZ-4	Kanpur - Varanasi	445	6
HZ-5	Varanasi - Farakka	685	8
HZ-6	Farakka - Ganga Sagar	530	7

Table 2.1: Six habitat zones and number of sampling sites in Ganga River

logistically covering all sampling sites in a given season i.e., within 2 months. Based on the reconnaissance survey at each location, a maximum of 3 days were required to cover all sampling sites considering logistic movement of team that can cover 32 sites per season i.e., in a two months period.

Based on the above strategy a total of thirty-two intensive monitoring sites have been fixed by stratified sampling method with regular interval spacing of about 75 km distance between each site. Each sampling site stretched about 5 km in length. Finalization of these selected sites was done by a reconnaissance survey and topographic maps. Suggestions from the local habitants regarding the suitability of sites for biodiversity monitoring were taken into consideration and the process was stabilized after the first intensive monitoring site survey during post monsoon season (October to November, 2017). Detailed information on site coordinates are given in Table 2.2.

Table 2.2: Zone-wise Intensive Monitoring Sites along with GPS coordinates

Habitat Zone	Site Name	Start Longitude	Latitude	End Longitude	Latitude
HZ-1	S1	78° 47' 14.203" E	31° 2' 26.826" N	78° 44' 17.802" E	31° 2' 18.524" N
	S2	78° 19' 41.724" E	30° 37' 16.495" N	78° 19' 34.235" E	30° 35' 24.136" N
	S3	78° 35' 29.603" E	30° 5' 4.478" N	78° 35' 29.226" E	30° 3' 57.795" N
	S4	78° 14' 3.714" E	30° 0' 23.712" N	78° 11' 44.776" E	29° 58' 41.743" N
HZ-2	S5	78° 1' 58.910" E	29° 26' 3.813" N	78° 2' 43.819" E	29° 23' 27.712" N
	S6	78° 9' 10.743" E	28° 49' 32.313" N	78° 8' 29.851" E	28° 46' 59.920" N
	S7	78° 21' 56.434" E	28° 14' 42.857" N	78° 23' 30.511" E	28° 12' 22.241" N
HZ-3	S8	78° 54' 48.913" E	27° 52' 0.631" N	78° 57' 21.261" E	27° 50' 44.719" N
	S9	79° 31' 29.863" E	27° 32' 34.978" N	79° 33' 17.570" E	27° 30' 39.288" N
	S10	79° 57' 45.873" E	27° 6' 33.916" N	79° 59' 36.032" E	27° 4' 23.108" N
	S11	80° 17' 52.290" E	26° 34' 10.649" N	80° 19' 9.271" E	26° 31' 49.392" N
HZ-4	S12	80° 44' 51.725" E	26° 4' 34.459" N	80° 47' 30.824" E	26° 3' 36.583" N
	S13	81° 18' 25.609" E	25° 49' 29.960" N	81° 20' 52.779" E	25° 48' 1.666" N
	S14	81° 46' 48.146" E	25° 28' 51.742" N	81° 49' 14.295" E	25° 29' 57.251" N
	S15	82° 11' 55.810" E	25° 12' 31.145" N	82° 13' 37.707" E	25° 10' 34.332" N
	S16	82° 36' 1.867" E	25° 13' 48.969" N	82° 38' 56.355" E	25° 13' 10.645" N
	S17	83° 8' 44.807" E	25° 19' 53.681" N	83° 10' 24.577" E	25° 22' 2.878" N
HZ-5	S18	83° 32' 19.484" E	25° 26' 14.692" N	83° 30' 42.141" E	25° 28' 31.762" N
	S19	84° 2' 30.646" E	25° 38' 11.238" N	84° 3' 44.128" E	25° 40' 38.347" N
	S20	84° 37' 35.046" E	25° 43' 38.649" N	84° 40' 14.716" E	25° 44' 47.440" N
	S21	85° 20' 23.707" E	25° 36' 35.007" N	85° 23' 18.186" E	25° 35' 50.492" N
	S22	85° 58' 56.400" E	25° 23' 53.643" N	86° 0' 33.385" E	25° 21' 37.268" N
	S23	86° 34' 9.965" E	25° 21' 12.411" N	86° 35' 35.503" E	25° 18' 51.670" N
	S24	87° 10' 45.546" E	25° 17' 27.833" N	87° 13' 4.366" E	25° 16' 50.390" N
	S25	87° 46' 27.555" E	25° 14' 38.771" N	87° 47' 28.945" E	25° 12' 5.429" N
HZ-6	S26	87° 55' 55.749" E	24° 37' 50.124" N	87° 58' 1.817" E	24° 35' 51.823" N
	S27	88° 15' 13.647" E	24° 15' 58.014" N	88° 15' 49.508" E	24° 13' 55.702" N
	S28	88° 11' 45.668" E	23° 45' 54.173" N	88° 10' 55.656" E	23° 43' 47.698" N
	S29	88° 21' 58.563" E	23° 27' 45.192" N	88° 22' 48.488" E	23° 25' 23.926" N
	S30	88° 27' 13.763" E	23° 2' 40.022" N	88° 25' 34.071" E	23° 0' 35.224" N
	S31	88° 14' 24.846" E	22° 32' 13.298" N	88° 12' 23.574" E	22° 30' 54.146" N
	S32	88° 11' 2.566" E	22° 3' 5.571" N	88° 9' 16.411" E	22° 0' 56.570" N

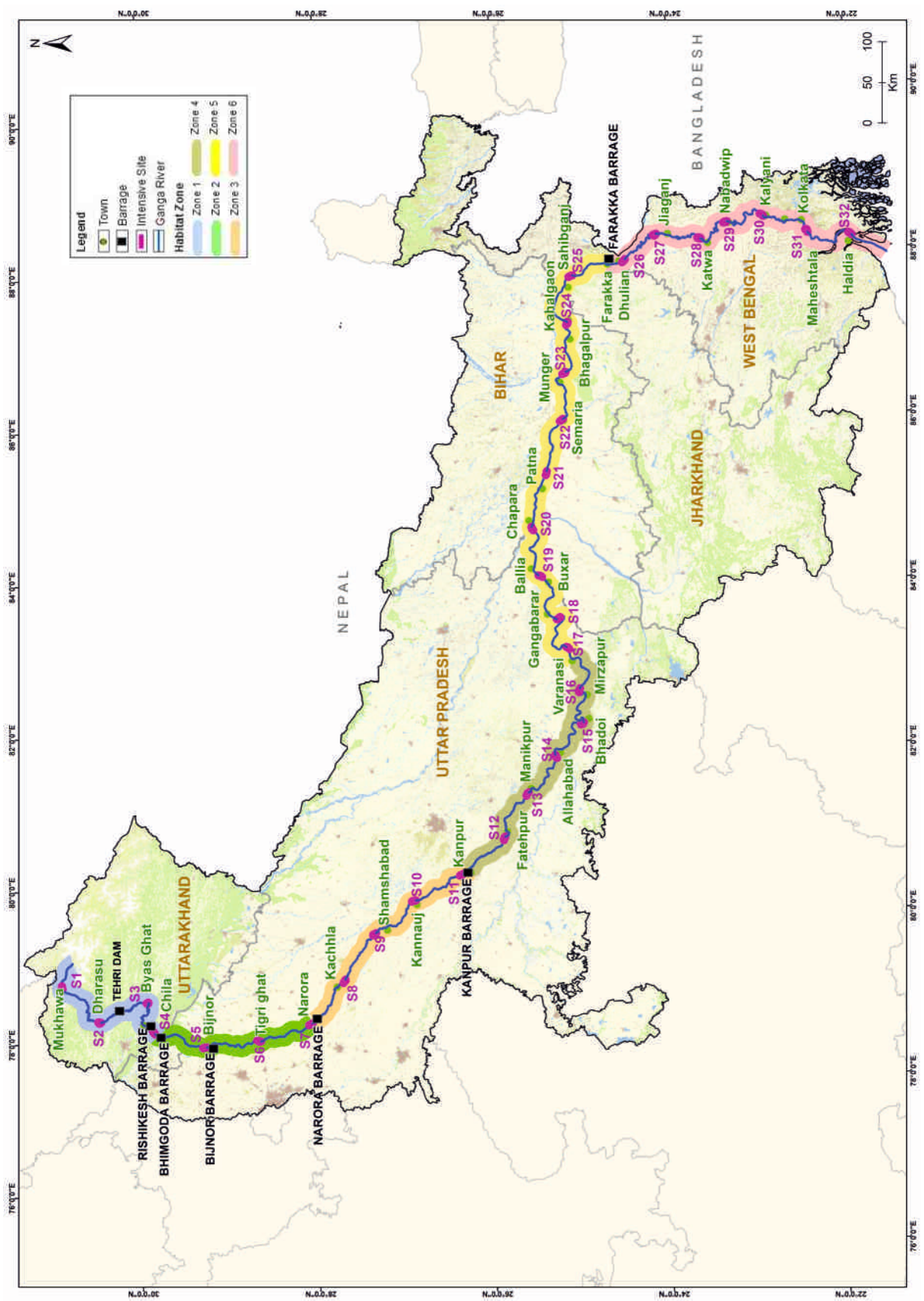

Figure 2.1: Map depicting six habitat zone and 32 Intensive Sampling Sites along the river Ganga

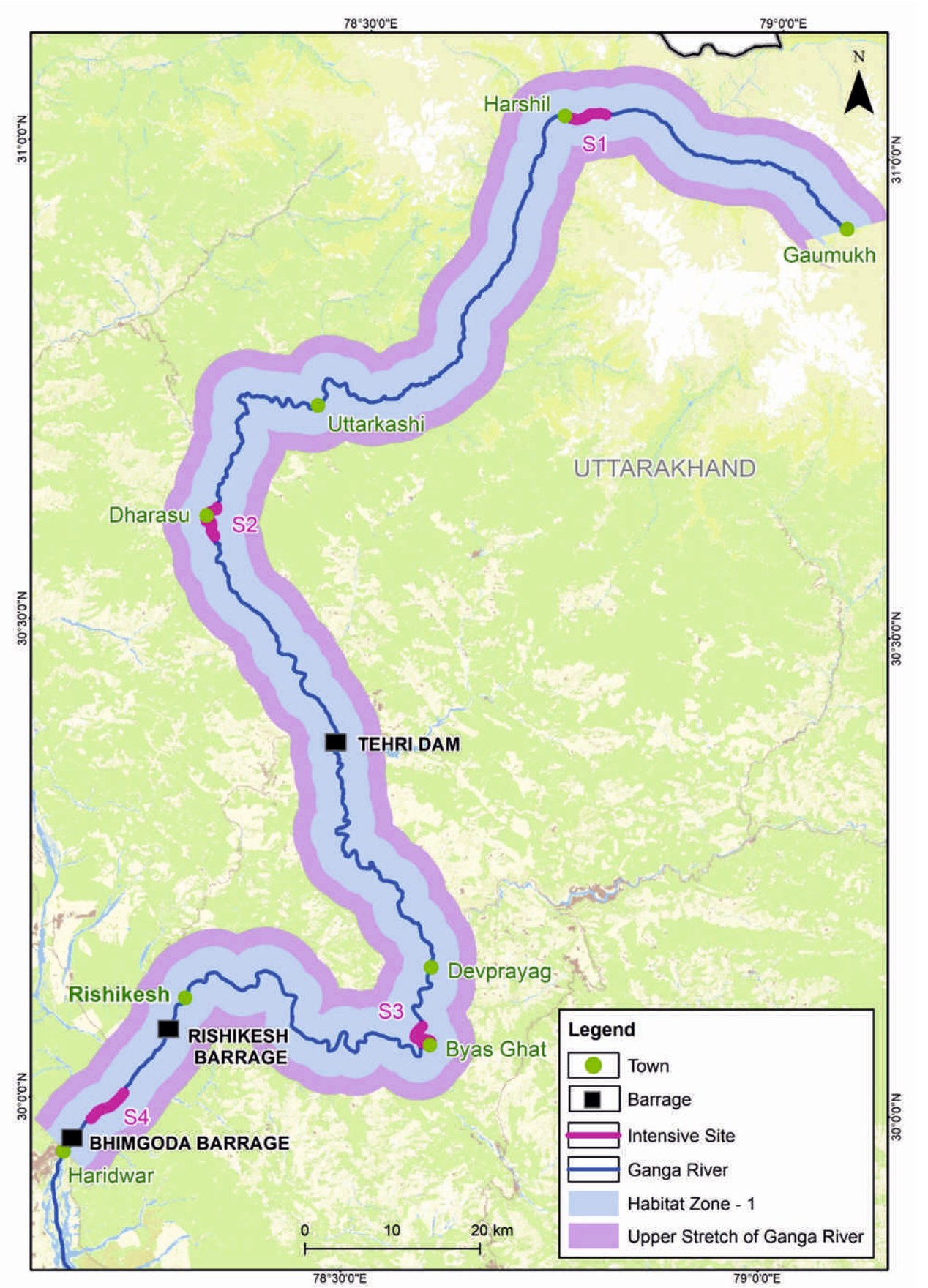

Figure 2.2: Map depicting one habitat zone along upper stretch of the Ganga River

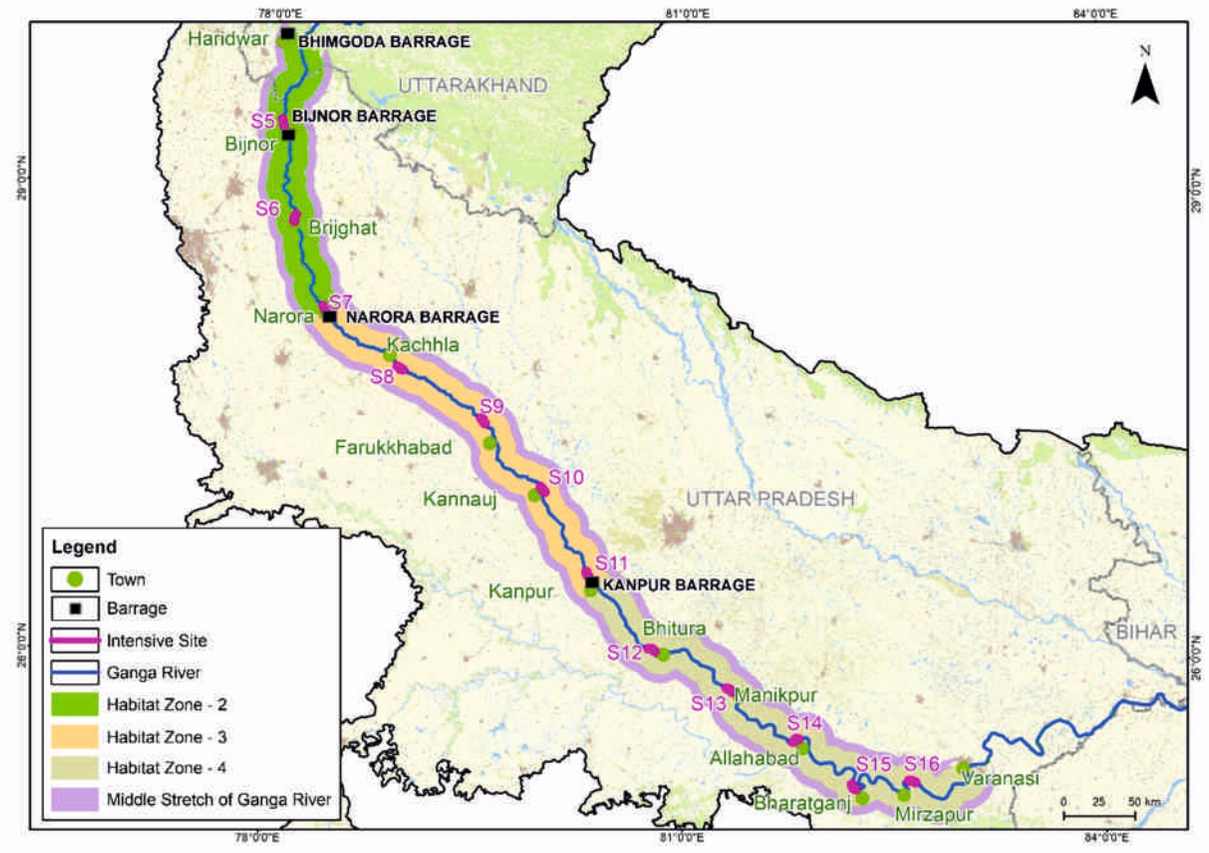

Figure 2.3: Map depicting three habitat zones along middle stretch of the Ganga River

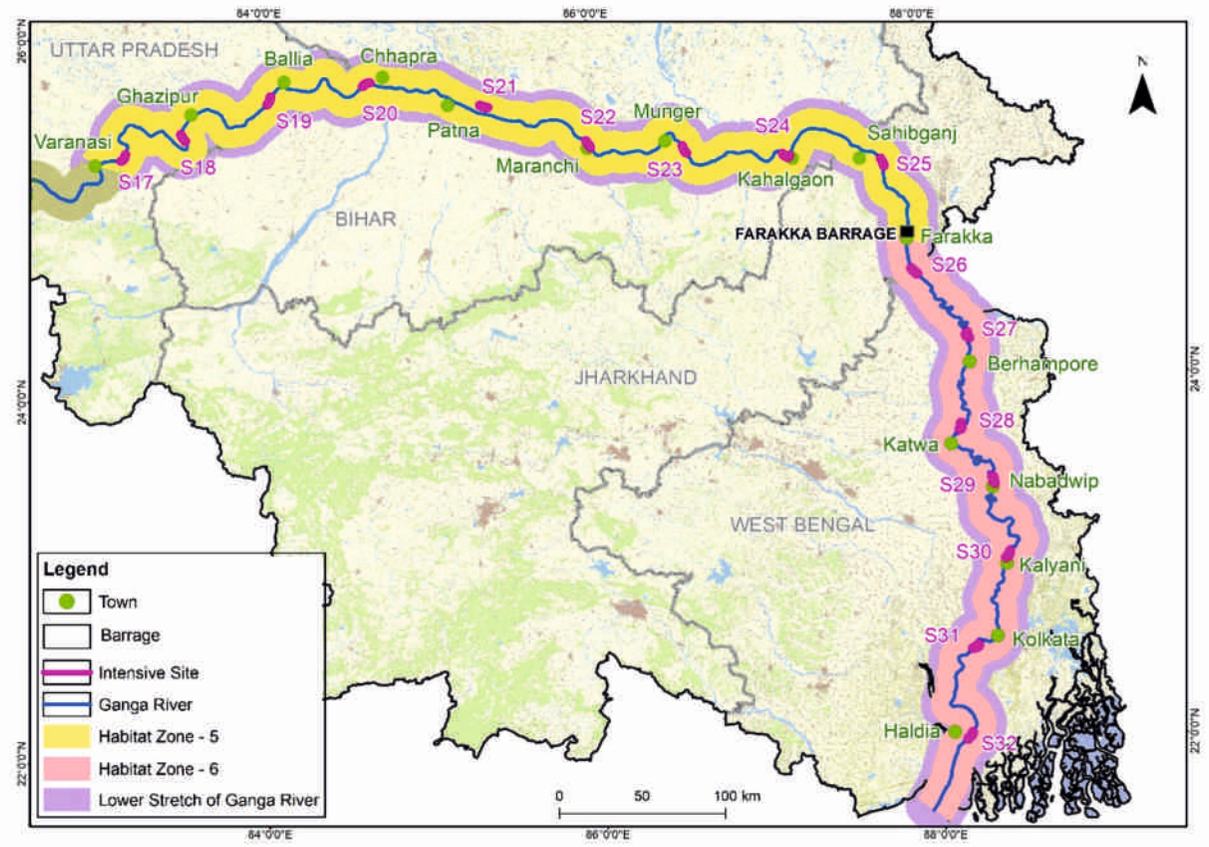

Figure 2.4: Map depicting three habitat zones along middle stretch of the Ganga River

2.2 CHARACTERISTICS OF THE SELECTED MONITORING SITES

The Intensive Monitoring Sites are river stretches of 5 km length with an interval of about 75 km. Each habitat zone is represented by number of Intensive Monitoring Sites. A detailed description of 32 sites is given below.

Site - S1

MUKHAWA

The first site lies in the Bhatwari Block, Uttarkashi District in Uttarakhand, along the Bhagirathi river. This stretch starts from 78°47'14.203" E, 31°2'26.826" N and ends at 78°44'17.802" E, 31°2'18.524" N. Mukhawa, Bagori village and Harshil township are located at the right bank, whereas Dharali village at left bank of the river along this site. National Highway 108 connects this area with district town Uttarkashi at a road distance of 75 km. This site is located at an altitude of 2500 m (msl). Mean depth of the river is 1.00 m. The river is characterised by high water flow with boulders and gravels at its bed. Apple farming is common on both sides of the river bank.

Figure 2.5: Location of study site Mukhawa in Google Earth map

Figure 2.6: Sampling location at Mukhawa

Site - S2

DHARASU

This site is located at Chinyalisaur Block, Uttarkashi District in Uttarakhand along the Bhagirathi river. This stretch starts from 78°19'41.724" E, 30°37'16.495" N and ends at 78°19'34.235" E, 30°35'24.136" N. Dharasu, Matoli, Badethi, Hidhara, Dhanpur, Nagri Bari villages are located at its right bank while Neli, Nagri Choti, Tulyara villages are located at the left bank of the river. This site is well connected with the district town Uttarkashi by National Highway 108 at a road distance of 32 km, and with Chinyalisaur town by National Highway 94 at a road distance of 9 km. The site is located at an altitude of 860 m (msl). Mean depth of the river is 1.0 m with cold water characterised by high water flow with boulders and gravels at the river bed. Dharasu hydroelectric power station is situated at its left bank. Terrace farming is a common agricultural practice around this area.

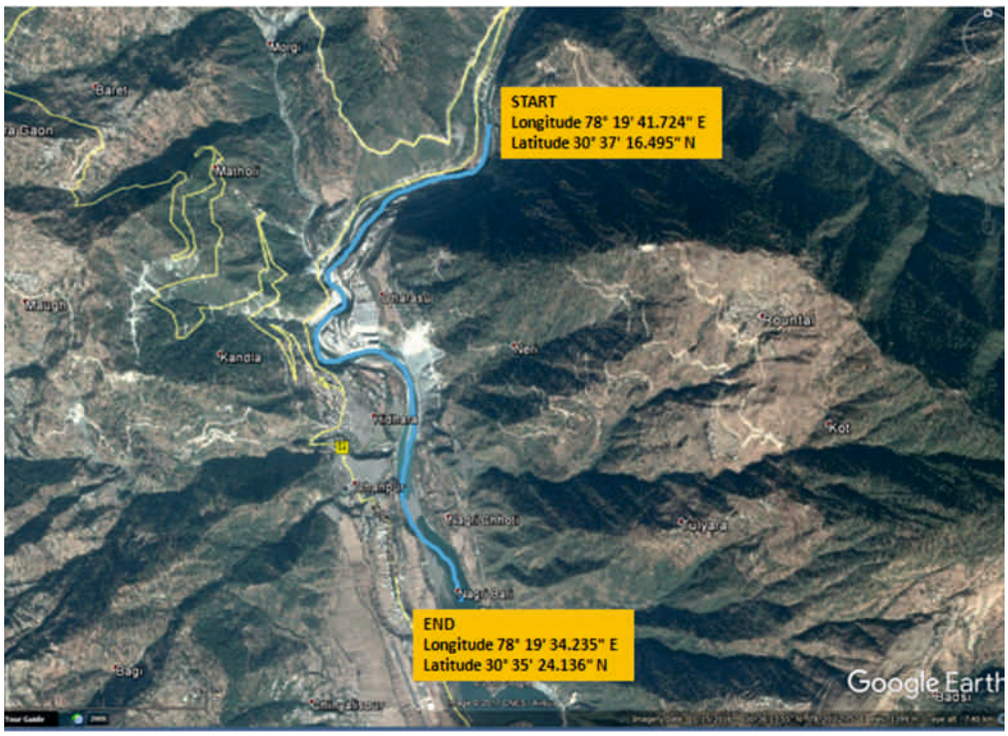

Figure 2.7: Study site Dharasu

Figure 2.8: Sampling location at Dharasu

Site - S3

BYAS GHAT

This site is situated 49 km downstream of Tehri Dam. The right bank of this river site is located at Devprayag Block, Tehri Garhwal District, whereas, left bank is located partly at Kot Block and Dwarikhal Block, Pauri Garhwal District in Uttarakhand along the Ganga River. Two major tributaries of Ganga River, Bhagirathi and Alakananda meet upstream of this site. The combined water of Bhagirathi and Alakananda river flows with name of Ganga River from Devprayag which is located 9 Km upstream. This segment lies between 78°35'29.603" E, 30°5'4.478" N and 78°35'29.226" E, 30°3'57.795" N. Simswara Malla, Pali Talli, Bibhairab villages are located at its right bank and Chandrabari, Kota Kunjali, Silsu Talla, Naugaon, Bagi villages are located at the left bank of the river along this site. The Byas Ghat is the location where Nayar River joins the Ganga River. National Highway 58 and a metalled road connect this area with the nearest town Devprayag from the right and the left bank of the river respectively. The altitude of this place is 460 m (msl). Mean depth of the river is 1.10 m. The water is cold and characterised by high water flow, boulders and gravels. Agriculture and livestock farming are the common livelihood practices in this area.

Figure 2.9: Google Earth map of study site at Byas Ghat

Figure 2.10: Sampling location at Byas Ghat

Site - S4

CHILLA

This Site is situated between two barrages; 11 km downstream of Veervadra Barrage, Rishikesh, and 7 km upstream of Bhimgoda Barrage, Haridwar. The river stretch is located partly at Yamkeshwar Block, Pauri Garhwal District and Doiwala Block, Dehradun District in Uttarakhand. This site starts from 78°14'3.714" E, 30°0'23.712" N and ends at 78°11'44.776" E, 29°58'41.743" N. Raiwala and Haripur villages are located along this site. National Highway 58 and 72 pass along this area that connect Rishikesh and Haridwar city. The altitude of this place is 315 m (msl), with cold river water characterised by less water flow, gravels and pebbles at its bed. This area comes under places of high religious value along the Ganga River. This stretch of the river is well protected as it is a part of Chilla-Motichur corridor of Rajaji Tiger Reserve. Mean depth of the river is 1.20 m. The river has braided channels with small mid river islands in this area. Water volume is comparatively low compared to upper reach due to diversion of water for Chilla hydroelectricity project. Forest, agriculture and major townships are the major land uses around this site.

Figure 2.11: Google Earth map of study site at Chilla

Figure 2.12: Sampling location at Chilla

Site - S5

GANGOLI KHADAR

This Site is situated 4 km upstream of Bijnor Barrage, Bijnor. It is a part of Hastinapur Wildlife Sanctuary. The right bank of the river site is located at Morna and Miranpur Block, Muzaffarnagar District, whereas the left bank is located at Mohammadpur Dewmal Block, Bijnor District in Uttar Pradesh. This segment lies between 78°1'58.910" E, 29°26'3.813" N and 78°2'43.819" E, 29°23'27.712" N. Rafiul Nagar, Gangoli Khadar, Nawalpur and Firozpur Darga are the villages located along this site. National Highway 119 connects the district town Bijnor at a distance of 11 km with an altitude of 222 m (msl). Mean depth of river is 1.40 m. The part of this site is comprised of a wetland or khadar which is the habitat of fish, turtle, birds, amphibians, reptiles and invertebrates. Water temperature is warmer than in the upper reach and the river is characterised with muddy water with gentle flow. Riverine forest patches, scrubs, grassland and agriculture are the major land uses in this area.

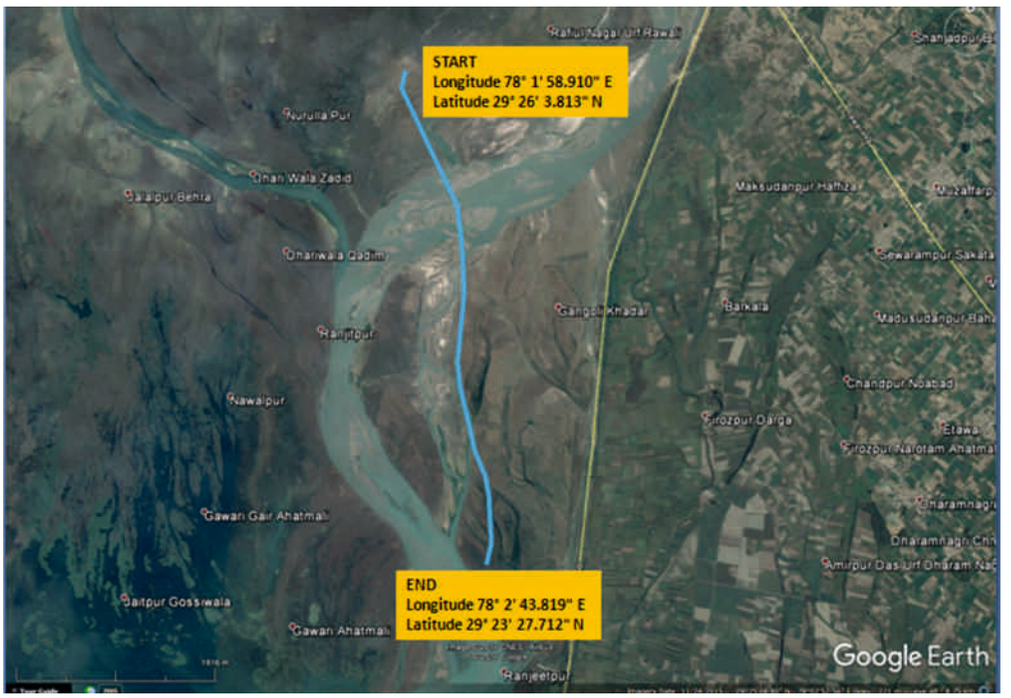

Figure 2.13: Google Earth map of study site at Gangoli Khadar

Figure 2.14: Sampling location at Chilla

Site - S6

TIGRI

This Site is situated at Tigri Ghat, which is a part of Ramsar site. This area comes under Gajraula Block, Amroha District in Uttar Pradesh and lies between 78°9'10.743" E, 28°49'32.313" N and 78°8'29.851" E, 28°46'59.920" N. Tigri, Faridpur, Lathera and Gadbali villages are located along this site. This place is connected with Garhmukteshwar town, which is 8 Km away and Gauraula town which is 9 km away at the right and the left bank respectively by National Highway 24, located at an altitude of 202 m (msl). Mean depth of the river is 3.20 m. Habitat of this site is highly dynamic with multiple sandbar. The river is characterised with muddy water and gentle flow. Grassland and agriculture are the major land uses in the area.

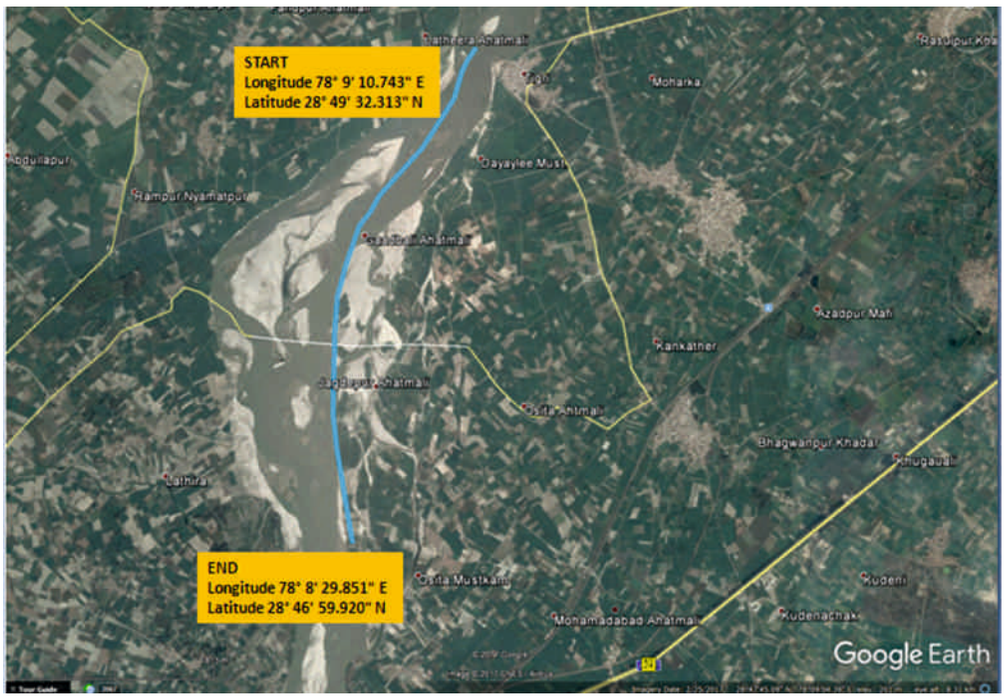

Figure 2.15: Google Earth map of study site at Tigri

Figure 2.16: Sampling location at Tigri

Site - S7

NARORA

This Site is situated between Narora Barrage and Rajghat, Narora. This area comes under Debai Block, Bulandsahar District in Uttar Pradesh. The site starts at 78°21'56.434" E, 28°14'42.857" N and ends at 78°23'30.511" E, 28°12'22.241" N. Nayabas Khadar, Rajghat Khadar, Udaigarhi Khadar, Naudai Khadar and Narora are located along this site. This place is close to Narora township and 6 km upstream of Narora Atomic power station. State highway 18 connects Narora with Dibai at the right bank and Barbala at the left bank of river. The altitude of this place is 182 m (msl). Mean depth of river is 3.30 m. The part of this site comprises of a large sandbar and river is characterised by muddy water with gentle flow. Grassland and agriculture are the major land uses character around the site. Anthropogenic pressure is also high in this area.

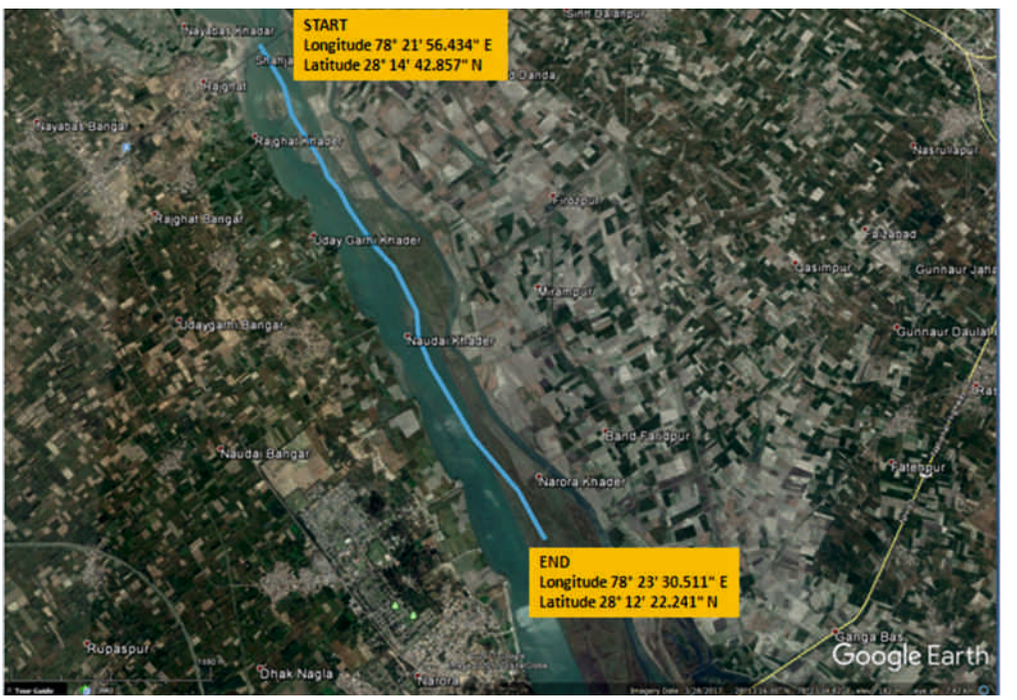

Figure 2.17: Google Earth map of Narora study site

Figure 2.18: Sampling location at Narora

Site - S8

SAHWAJPUR

The site is located near Kachhla. Its right bank is in Ganj Dundwara Block, Kasganj District and left bank is in Qadar Chowki Block, Budaun District in Uttar Pradesh. The site starts at 78°54'48.913" E, 27°52'0.631" N and ends at 78°57'21.261" E, 27°50'44.719" N. Sawazpur Kham, Ulai Khera and Kaithola villages are located along this site. This place is located downstream of Kachla town which is connected with district town Kasganj by National Highway-33. A village road connects the monitoring site with Kachla at a distance of 15 Km. The altitude of this place is 163 m (msl). Mean depth of the river is 1.10 m. The river is meandered with braided channels. Agriculture is the major land use of the site.

Figure 2.19: Google Earth map of Sahwajpur study site

Figure 2.20: Sampling location at Sahwajpur

Site - S9

AZIZABAD

The site is located at Samshabad Block, Farukkhabad District in Uttar Pradesh. The site starts at 79°31'29.863" E, 27°32'34.978" N and ends at 79°33'17.570" E, 27°30'39.288" N. Ajijabad, Narunagla, Champatpur villages are situated at the right bank whereas Mandra, Alampur and Katri Dundha villages at its left bank of the river. The district town Farukkhabad is located downstream of this site. Samshabad is well connected with Farukkhabad with road and railway line, located at an altitude of 145 m (msl). The mean depth of river is 1.40 m. The river is meandered with braided channels. Agriculture is the major land use at this site.

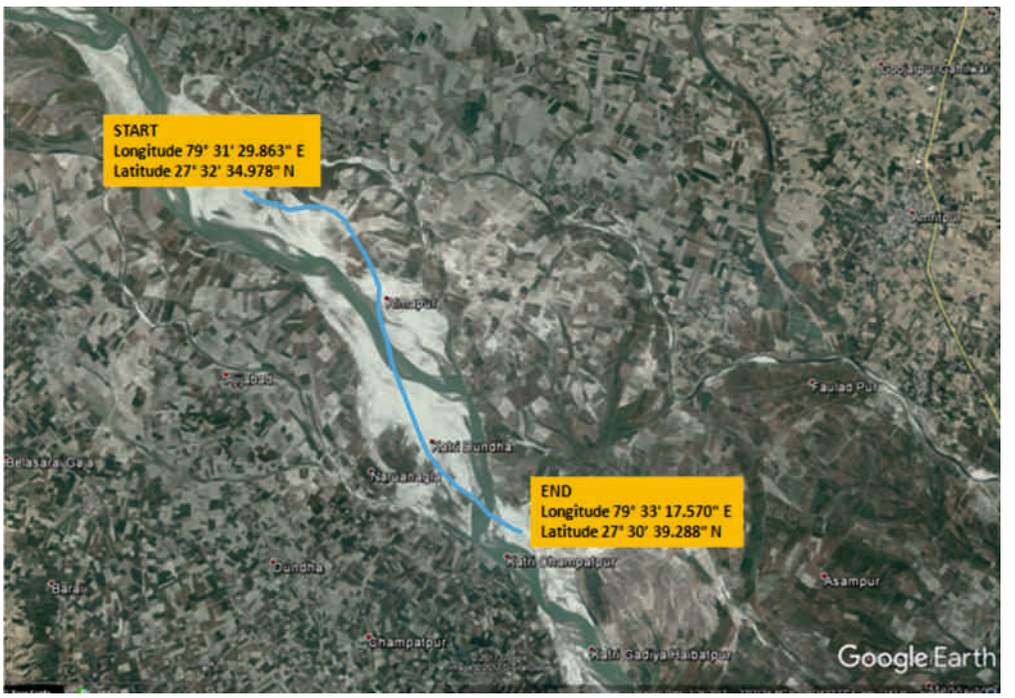

Figure 2.21: Google Earth map of study site at Azizabad

Figure 2.22: Sampling location at Azizabad

Site - S10

MEHENDIPUR

This site is located at Kannuj Block, Kannuj District at the right bank and Bilgram Block, Hardoi District in Uttar Pradesh. The site starts at 79°57'45.873" E, 27°6'33.916" N and ends at 79°59'36.032" E, 27°4'23.108" N. Katari Rampurlaraita, Katri Mahdeva, Katri Bichhuya, Bahuiya and Katri Kasimpur villages are situated along the river site. The district headquarter Kannuj is the nearest town which is connected by State Highway 21 with this area. Altitude of this place is 127 m (msl). The mean depth of river is 1.10 m. River is meandered with braided channels and sandbars. Agriculture is the major land use in the area.

Figure 2.23: Google Earth map of study site Sahwajpur

Figure 2.24: Sampling location at Mehendipur

Site - S11

KANPUR

This site is situated at 3 km upstream of Kanpur Barrage, Kanpur. The right bank of the river site is located at Kalyanpur Block, Kanpur Nagar District and the left bank at Sikandarpur Sarausi Block, Unnao District in Uttar Pradesh. This segment lies between 80°17'52.290" E, 26°34'10.649" N and 80°19'9.271" E, 26°31'49.392" N. Prithviganj, Pratapur Hari, Hindupur, Khyora Katari villages are located at its right bank and Katri Rautapur, Mirzapur, Katri Mirzapur at the left bank of river. National Highway 91 connects the site with district town Kanpur at a distance of 5 km. The altitude of this place is 116 m (msl). Mean depth of the river is 2.50 m. The city is known for industries which introduce high pollution load to the river. Water temperature is warmer and the river is characterised with muddy water with gentle flow. Agriculture and human settlement are the major land uses at this site.

Figure 2.25: Google Earth map of study site Kanpur

Figure 2.26: Sampling location at Kanpur

Site - S12

BHITURA

This site is located at transition of Fatehpur and Rae Bareli District in Uttar Pradesh. The right bank of the river site is situated at Bindki Block, Fatehpur District and the left bank at Sareni Block, Rae Bareli District. This segment lies between 80°44'51.725" E, 26°4'34.459" N and 80°47'30.824" E, 26°3'36.583" N. Kotiya, Rawatpur, Saraikhande and Gonda villages are located along this site. National Highway 2 connects the site with the nearest town Fatehpur at a road distance of 30 km. The altitude of this place is 106 m (msl). Mean depth of the river is 1.90 m. River water is characterised by high turbidity with gentle flow. Multiple mid river islands occur at this site. Agriculture and human settlement are the major land uses.

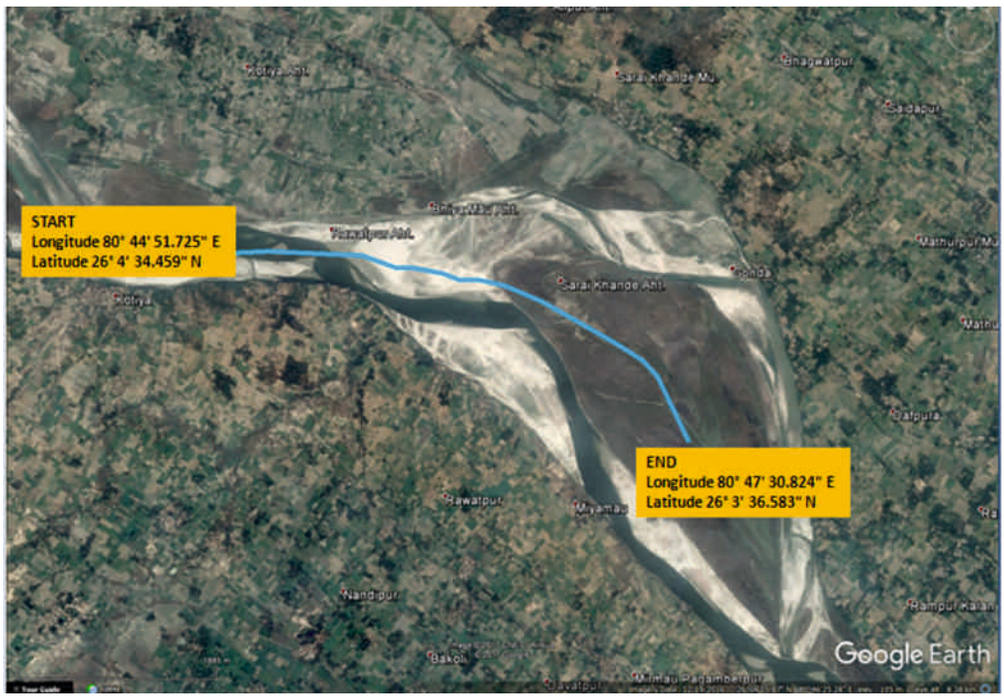

Figure 2.27: Google Earth map of study site at Bhitura

Figure 2.28: Sampling location at Bhitura

Site - S13

MANIKPUR

This site is located 10 km upstream of Manikpur town. The area lies at transition of Fatehpur, Kaushambi, Rae Bareli and Pratapgarh District in Uttar Pradesh. The right bank of the river site is situated partly at Airaya Block, Fatehpur District and Siraya Block, Kaushambi District and the left bank at Unchahar Block, Rae Bareli District and Kalakankar Block, Pratapgarh District. This stretch lies between 81°18'25.609" E, 25°49'29.960" N and 81°20'52.779" E, 25°48'1.666" N. Rasulpur Bhandra, Ekaunagarh and Afjalpur villages are located at the right bank and Malikpur Atmali, Kotra Bahadurganj and Sonamau Kachhar villages at left bank along this river site. National Highway 24B connects the site with the nearest town Manikpur. The altitude of this place is 95 m (msl). Mean depth of the river is 1.80 m. River water is characterised by high turbidity with meandering and gentle flow. Several sandbars occur along the site. Agriculture and human settlement are the major land uses.

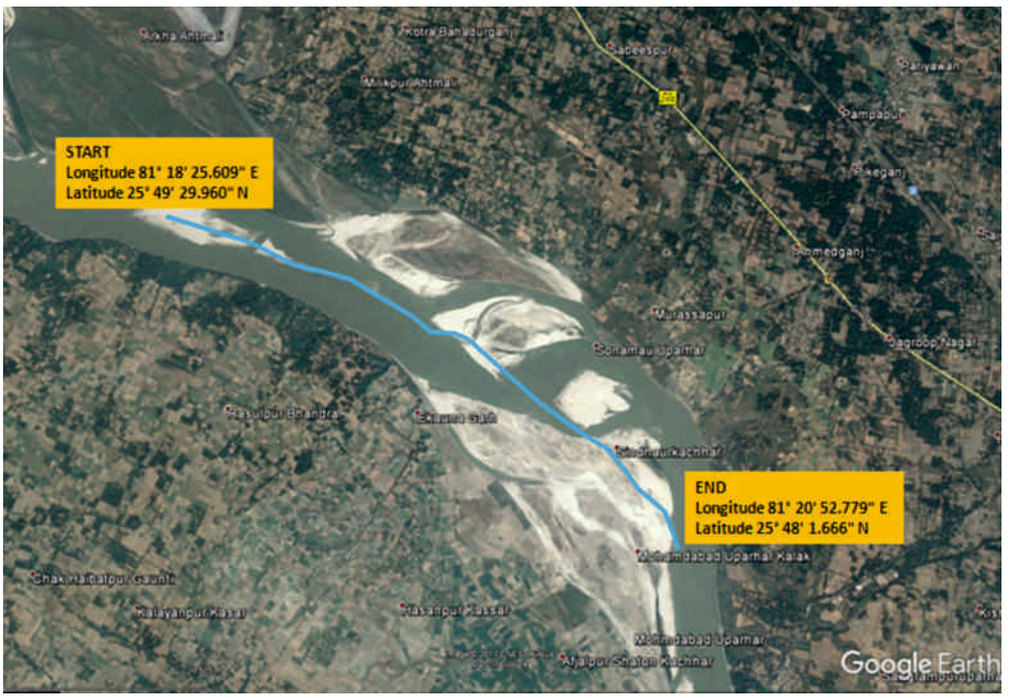

Figure 2.29: Google Earth map of study site at Manikpur

Figure 2.30: Sampling location at Manikpur

Site - S14

ALLAHABAD

This site is located in the vicinity of the pilgrim city Allahabad. It lies at Kaurihar Block, Allahabad District. This stretch lies between 81°18'25.609" E, 25°49'29.960" N and 81°20'52.779" E, 25°48'1.666" N. Chappri Kachhar, Chappri Uparhar, Fatoohpur Kachar villages are located along this river site. National Highway 2 and 24B connect Allahabad city with this site. Altitude of this place is 85 m (msl). Mean depth of river is 2.10 m. River water is characterised by high turbidity with meandering and gentle flow. Several sandbars occur along this site. Agriculture and human settlement are the major land uses. Yamuna River meets the Ganga River at 12 km downstream of this site.

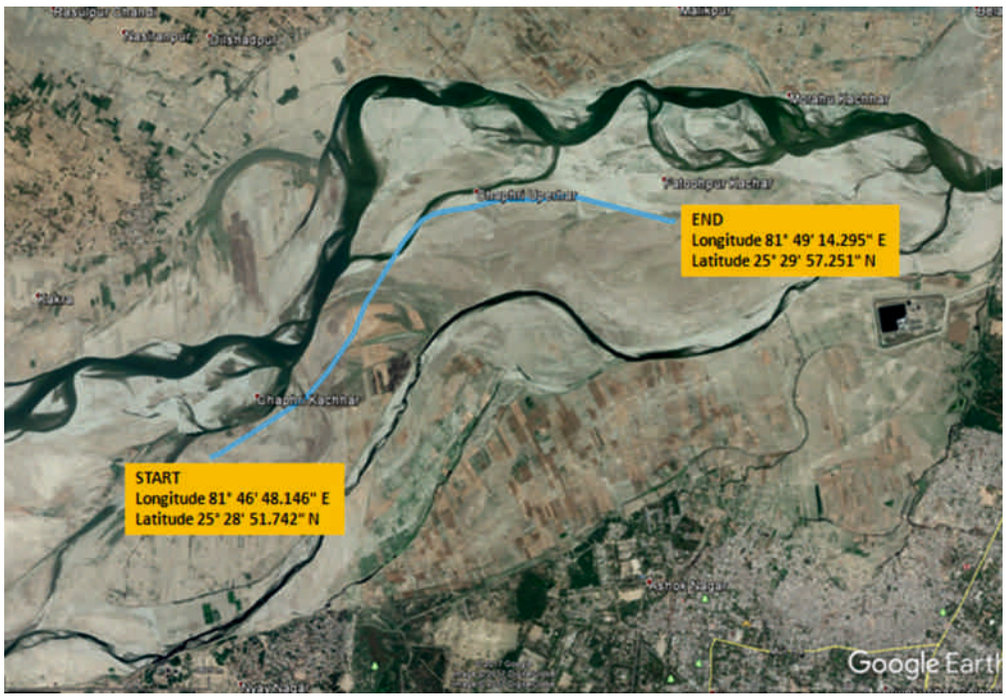

Figure 2.31: Google Earth map of study site at Allahabad

Figure 2.32: Sampling location at Allahabad

Site - S15

TELA

This site is located at a meandered part of river. Right bank of this stretch is situated at Uruwan and Manda Block, Allahabad District whereas left bank is situated at Digh Block, Bhadohi District in Uttar Pradesh. This stretch lies between 82°11'55.810" E, 25°12'31.145" N and 82°13'37.707" E, 25°10'34.332" N. Achola Kachar, Chaukatha Kachar, Narvar Kachar, Kushwaha Uperhar, Umapur Kalan villages are located at the right bank and Kundi Kala Tari, Kundi Khurd Tari, Poorepurva Tari, Bahapura Tari, Tehri Tari, Kusmaha Kachar villages are located at left bank of the river site. The area is connected with nearest town Bharatganj by National Highway 2. Altitude of this place is 82 m (msl). Mean depth of river is 9.50 m. River water is characterised by high turbidity with meandering and moderate flow. Agriculture is the major land use around this area.

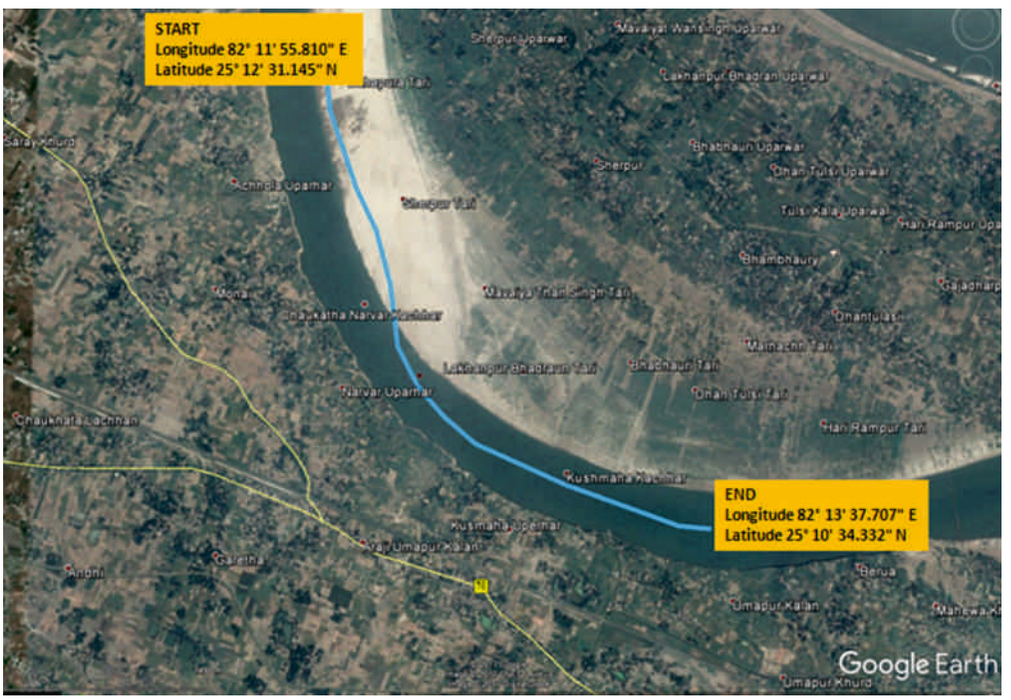

Figure 2.33: Google Earth map of study site at Tela

Figure 2.34: Sampling location at Tela

Site - S16

KOLHAR

This site is located 15 km downstream of Mirzapur town. The right bank of this stretch is situated at the transition of Majhwa and Nagar City Block, Mirzapur District and Aurai Block, Bhadohi District in Uttar Pradesh. This stretch lies between 82°36'1.867" E, 25°13'48.969" N and 82°38'56.355" E, 25°13'10.645" N. Gegarau, Shivrani, Gaharwani, Itawa Tani, Itawa Uparhar, Kolahalpur Tari, Garauli villages are located along the site. The area is connected with the nearest town Mirzapur by National Highway 2 and 7. The altitude of this place is 72 m (msl). Mean depth of the river is 5.90 m. River water is characterised by high turbidity with sand deposited areas. Agriculture is the major land use.

Figure 2.35: Google Earth map of study site at Kolhar

Figure 2.36: Sampling location at Kolhar

Site - S17

MUSTAFABAD RAMCHANDRAPUR

This site is located 18 Km downstream of Varanasi city. The right bank of this stretch is situated at the Chahaniya Block, Chandauli District and left bank in Chiraigaon Block, Varanasi District in Uttar Pradesh. This stretch lies between 83°8'44.807" E, 25°19'53.681" N and 83°10'24.577" E, 25°22'2.878" N. Gokulpur, Kali, Salempur, Bhosawali, Kharra, Derwan Kala, Maharura villages are located at the right bank and Ramchandipur, Gobrha villages at left bank. The area is connected with the nearest town Varanasi by Sakaldiha-Padao Road. The altitude of this site is 62 m (msl). Mean depth of the river is 4.10 m. River water is characterised by high turbidity. Deposition at river bank and mid river sand bars are major riverbed characteristics here. Agriculture and scrubland are the major land uses around this area.

Figure 2.37: Google Earth map of study site at Manikpur

Figure 2.38: Sampling location at Mustafabad Ramchandrapur

Site - S18

ZAMANIA GANGBARAR

This Site is located 13 km upstream of Ghazipur city. The right bank of this stretch is situated at the Zamania Block and left bank at Karanda Block, Ghazipur District in Uttar Pradesh. This stretch lies between 83°32'19.484" E, 25°26'14.692" N and 83°30'42.141" E, 25°28'31.762" N. Zamanai, Kalanpur, Tajpur Majha, Gangbarar Chitawan, Gangbarar Manjhari, Gangbarar Matsa villages are located at right bank and Puraina, Bayepur, Kasera, Barharia, Sidharipur, Noorampur, Harampah villages at the left bank of the river segment. The area is connected with the nearest town Ghazipur by National Highway 97 and Ghazipur-Chochakpur Road.The altitude of this site is 62 m (msl). Mean depth of the river is 2.80 m. River water is characterised by high turbidity. Sand deposition at river bank and mid river sand bars are major riverbed characteristics of this site. Agriculture is the major land uses.

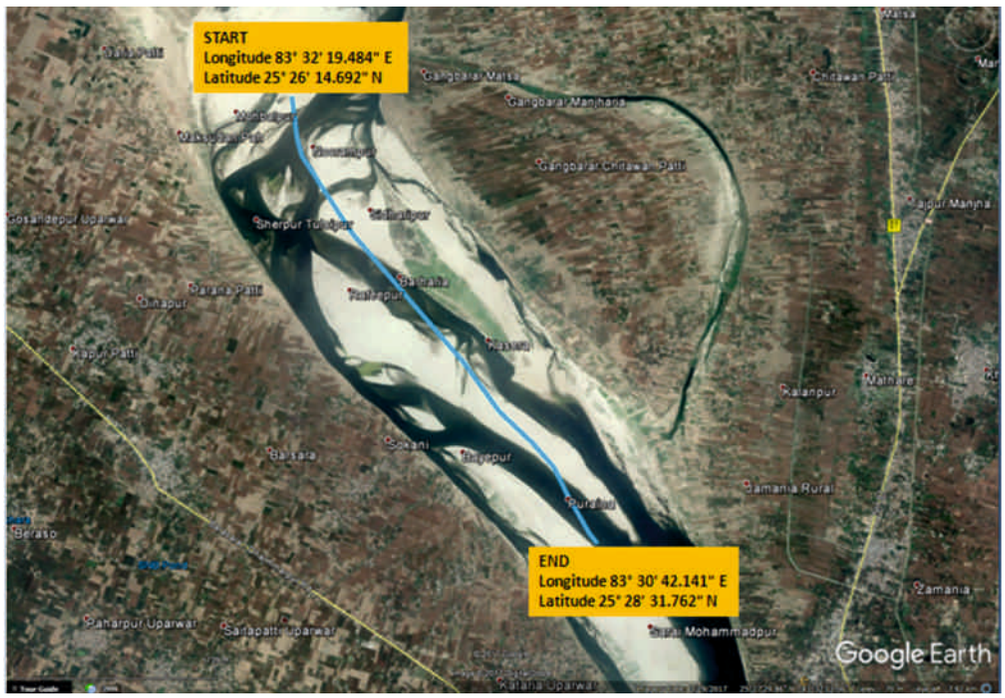

Figure 2.39: Google Earth map of study site at Zamania Gangabarar

Figure 2.40: Sampling location at Zamania Gangbarar

Site - S19

PIPRA

This site is located between Ballia and Buxar town. The stretch is located in Sohan Block, Ballia District in Uttar Pradesh. It lies between 84°2'30.646" E, 25°38'11.238" N and 84°3'44.128" E, 25°40'38.347" N. Umarpur Diara, Umarpur Nowbarar, Kesharpur, Kulhria, Gangbarar Shahpur villages are located along the site. The area is connected with National Highway 84 and 19 with Ballia and Buxar towns respectively. The altitude of this site is 62 m (msl). Mean depth of the river is 3.10 m. River water is characterised by high turbidity. Sand deposition at river bank and mid river islands are major characteristics of this site. Agriculture is the main land use around this area.

Figure 2.41: Google Earth map of study site at Pipra

Figure 2.42: Sampling location at Pipra

Site - S20

RAVELGANJ

This site is located 9 km upstream of Chhapra town in Murli Chhapra Block, Ballia District in Uttar Pradesh and Ravelganj Block, Saran District in Bihar. It lies between 84°37'35.046" E, 25°43'38.649" N and 84°40'14.716" E, 25°44'47.440" N. Korrha Nobarar, Sitab Diara, Uttarwar Chowki villages are located at the right bank and Digri Sudha, Naubarar Baiju, Loha Tola villages at the left bank of the site along river. The area is connected with National Highway 19 with Chappra town. The altitude of this place is 54 m (msl). Mean depth of the river is 2.90 m. River water is characterised by high turbidity. Sand deposition at river bank and mid river islands are major characteristics. Agriculture and human settlement are the main land uses in this area.

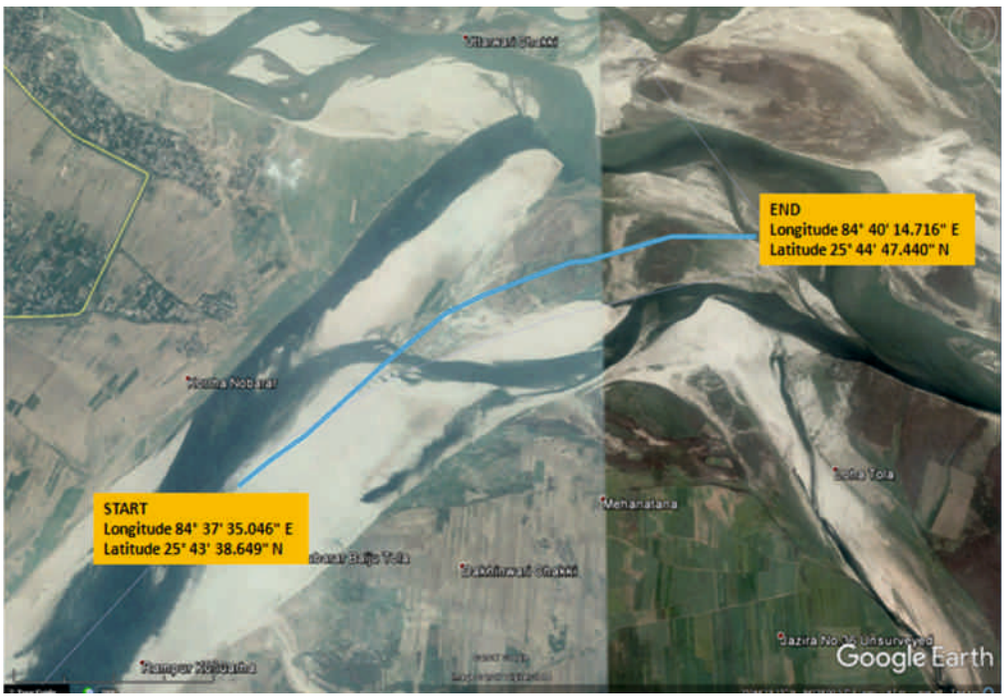

Figure 2.43: Google Earth map of study site at Ravelganj

Figure 2.44: Sampling location at Bhitura

RAGHUPUR

This site is located 15 km downstream of Patna town. It is in Bidupur Block, Vaishali District in Bihar. It starts from 85°20'23.707" E, 25°36'35.007" N and 85°23'18.186" E, 25°35'50.492" N. Bishnupr maniari, Etwarpur, Rampur, Fatehpur villages are located at the right bank and Jahangirphuli, Abdullahpur, Chechar, Chowkruhela, Munimchak villages at the left bank of the site. The area is connected by National Highway 31 and state Highway 93 with Patna and Hajipur cities respectively. The altitude of this area is 54 m (msl). Mean depth of the river is 3.20 m. River water is characterised by high turbidity. Large mid river island is formed between braided channels. Agriculture and human settlements are the main land use pattern around this area.

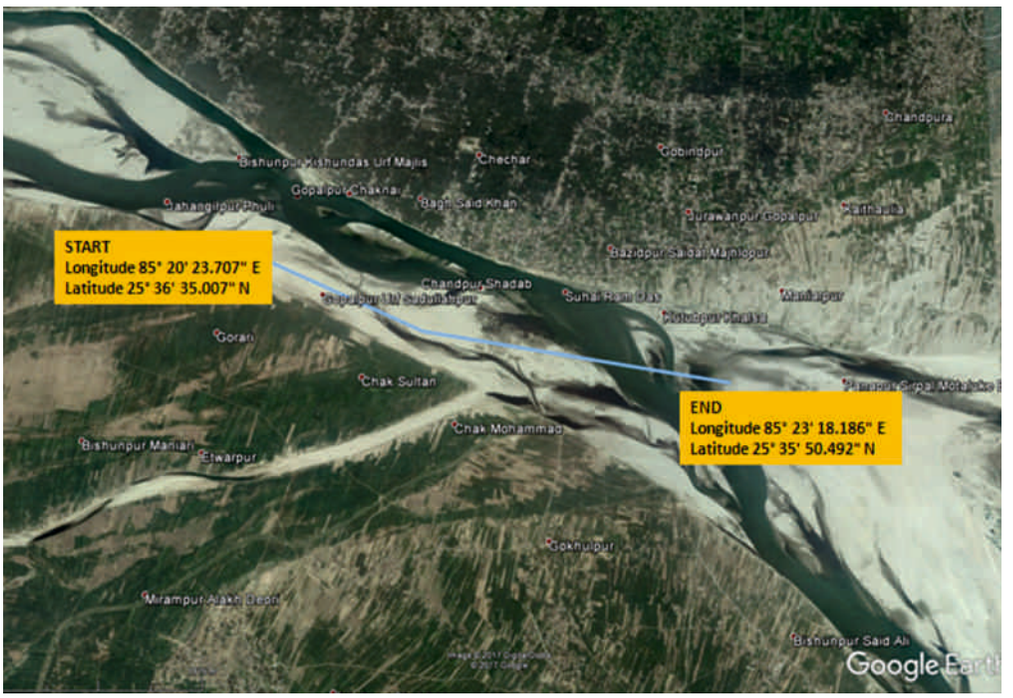

Figure 2.45: Google Earth map of study site of Raghupur

Figure 2.46: Sampling location at Raghupur

Site - S22

MARANCHI

This site is located 17 km upstream of Begusarai town. The right bank is located at Mokameh Block, Patna District and the left bank is in Barauni Block, Begusarai District in Bihar. It starts from 85°58'56.400" E, 25°23'53.643" N and 86°0'33.385" E, 25°21'37.268" N. Dariapur, Hathdeh, Hatidah Buzurg, Maranchi villages are located at the right bank and Semaria, Malhipur, Diara Maranchi villages at the left bank. This area is connected with Begusarai town by state Highway 55. The altitude of this area is 46 m (msl). Mean depth of the river is 3.40 m. River water is characterised by high turbidity and low water flow. Agriculture is the main land use pattern around this area.

Figure 2.47: Google Earth map of study site at Maranchi

Figure 2.48: Sampling location at Maranchi

Site - S23

TILAKPUR

This site is located 16 km downstream of Munger town. The right bank is located at Munger Block and left bank in Bariapur Block, Munger District in Bihar. It starts from 86°34'9.965" E, 25°21'12.411" N and 86°35'35.503" E, 25°18'51.670" N. Tarapur Diara and Binda Diara villages are located along river. This area is connected with Munger town by National Highway 80. The altitude of this place is 40 m (msl). Mean depth of the river is 6.20 m. River water is characterised by high turbidity and moderate water flow. Agriculture is the main land use pattern around this area.

Figure 2.49: Google Earth map of study site at Tilakpur

Figure 2.50: Sampling location at Tilakpur

Site - S24

KAHALGAON

This site is located at Kahalgaon, which is 25 km downstream of Bhagalpur city. The right bank is located at Ismailpur Block and left bank in Gopalpur Block, Bhagalpur District in Bihar. It starts from 87°10'45.546" E, 25°17'27.833" N and 87°13'4.366" E, 25°16'50.390" N. Kamalpur, Budhuchak villages are located at the right bank and Saidpur Dabra, Tintaganj villages are located at the left bank of river. This area is connected with Bhagalpur town by National Highway 80. The altitude of this place is 36 m (msl). Mean depth of the river is 3.30 m. River water is characterised by high turbidity and moderate water flow. Agriculture is the main land use pattern around this area.

Figure 2.51: Google Earth map of study site at Kahalgaon

Figure 2.52: Sampling location at Kahalgaon

Site - S25

MAHARAJPUR

This site is located 12 km downstream of Sahibganj town, partly at Rajmahal Block, Sahibganj District in Jharkhand and Manikchak Block, Maldah District in West Bengal. The site lies between 87°46'27.555" E, 25°14'38.771" N and 87°47'28.945" E, 25°12'5.429" N. Sahibganj, Rajmahal and Gadai villages are located along river. This area is connected with Sahibganj town by National Highway 80. The altitude of this place is 30 m (msl). Mean depth of the river is 2.90 m. River water is characterised by high turbidity and moderate water flow. Agriculture is the main land use pattern around this area.

Figure 2.53: Google Earth map of study site in Maharajpur

Figure 2.54: Sampling location at Maharajpur

Site - S26

CHANDPUR

This site is located 18 km downstream of Farakka barrage along the feeder canal of Hooghly river at Samserganj and Suti-II Block, Murshidabad District in West Bengal. The site lies between 87°55'55.749" E, 24°37'50.124" N and 87°58'1.817" E, 24°35'51.823" N. Dogachi, Bhagalpur villages are located at the right bank and Laskarpur, Mahisathali, Baliaghati villages at the left bank. This area is connected with Farakka by Dhulian-Pakur Road followed by National Highway 34. The altitude of this place is 24 m (msl). Mean depth of the river is 9.80 m. River water is characterised by high turbidity and moderate water flow. Agriculture is the main land use pattern around this area.

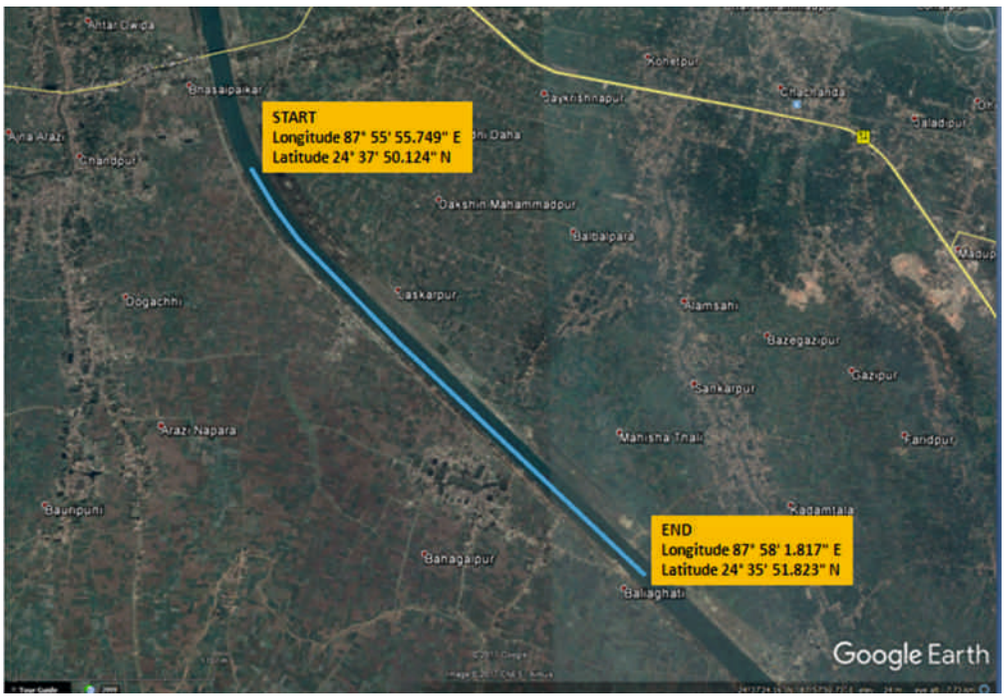

Figure 2.55: Google Earth map of study site in Chandpur

Figure 2.56: Sampling location at Chandpur

JIAGANJ - AZIMGANJ

This site is adjacent to Jiaganj-Azimganj town. It is located partly at Sagardighi and Jiaganj Block, Murshidabad District in West Bengal. The site lies between 88°15'13.647" E, 24°15'58.014" N and 88°15'49.508" E, 24°13'55.702" N. Pardiar, Baranagar villages are located at the right bank and Jiaganj-Azimganj Municipal at both the banks of this site. This area is connected with Jiaganj and Azimganj town by Jiaganj-Murshidabad road. The altitude of this place is 22 m (msl). Mean depth of the river is 6.00 m. River water is characterised by high turbidity and moderate water flow here. Agriculture and human settlements are the main land use patterns around this area.

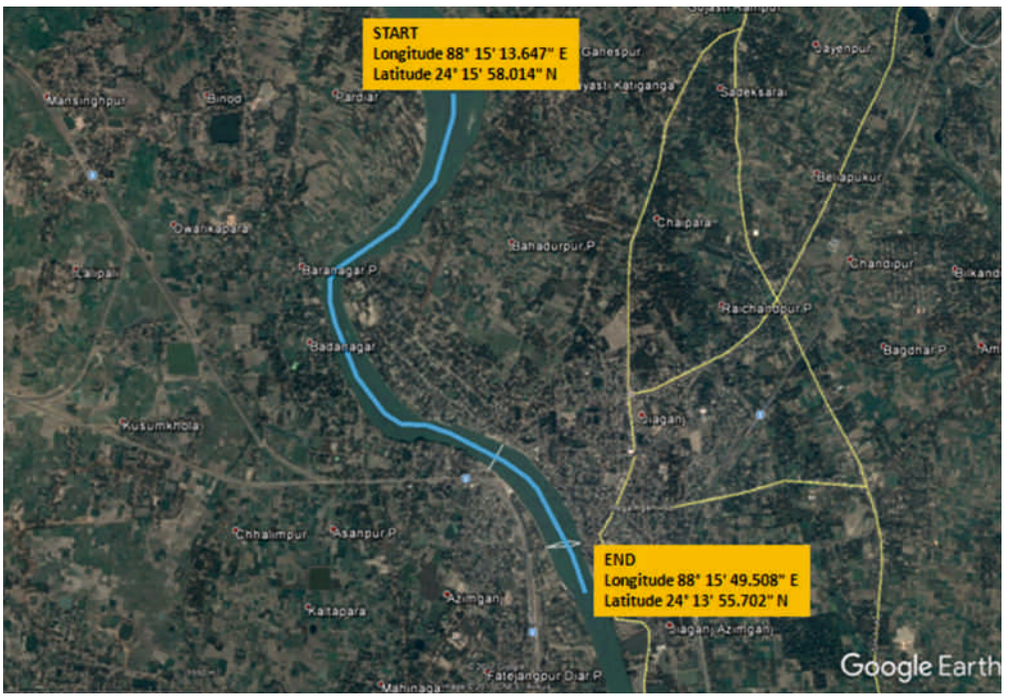

Figure 2.57: Google Earth map of study site at Jiaganj-Azimganj

Figure 2.58: Sampling location at Jiaganj-Azimganj

Site - S28

NALIAPUR

This site is located 12 km upstream of Katwa town. The right bank is located at Ketugram-II Block, Barddhaman District and Kaliganj Block, Nadia District in West Bengal. The site lies between 88°11'45.668" E, 23°45'54.173" N and 88°10'55.656" E, 23°43'47.698" N. Maugram, Natungram, Char Narayanpur villages are located at the right bank and Char Gopalpur, Char Manikdihi, Narayanpur, Raghupur villages at the left bank of the stretch. This area is connected with Katwa town by National Highway 34 and State Highway 6. The altitude of this place is 16 m (msl). Mean depth of the river is 6.10 m. River water is characterised by high turbidity and moderate salinity as tidal effect is prevalent at the site. Ajay River meets the Ganga River at this place. Agriculture is the main land use pattern around the area.

Figure 2.59: Google Earth map of study site at Naliapur

Figure 2.60: Sampling location at Naliapur

RUDRAPURA NABADWIP

This site is located 3 km upstream of Nabadwip town. It is located partly at Purbashali-II Block, Barddhaman District, Krishnanagar-II Block and Nabadwip Block, Nadia District in West Bengal. It lies between 88°21'58.563" E, 23°27'45.192" N and 88°22'48.488" E, 23°25'23.926" N. Kasthasali, Indrakpur villages are located at the right bank, and Charbehala, Charkasthasali, Rudrapura villages at the left bank of the stretch. The altitude of this place is 14 m (msl). Mean depth of the river is 6.80 m. River water is characterised by high turbidity and moderate water flow. The river water is saline due to tidal effect. Agriculture, riverine vegetation patches are the main land use patterns around this area.

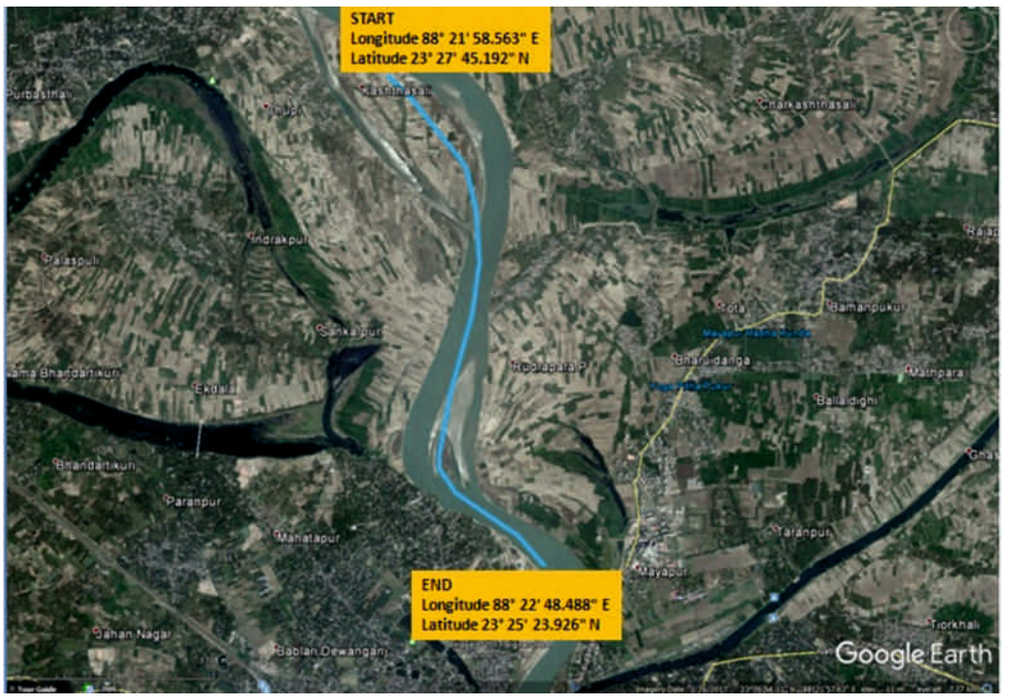

Figure 2.61: Google Earth map of study site at Rudrapura Nabadwip

Figure 2.62: Sampling location at Rudrapura Nabadwip

Site - S30

RANINAGAR KALYANI

This site is located 4 km upstream of Kalyani town. The right bank is located at Balagarh Block, Hooghly District and the right bank at Chakdah Block, Nadia District in West Bengal. The site lies between 88°27'13.763" E, 23°2'40.022" N and 88°25'34.071" E, 23°0'35.224" N. Aschitpur, Dumurdahatham, Raninagar, Naosarai, Raghunathpur villages are located at the right bank and Sukhsagar, Kalipur, Durgapur, Tarinipur, Sarati, Ganga Manoharpur villages at the left bank of the stretch. Madanpur-Kalyani road connects this site with Kalyani. Altitude of this place is 8 m (msl). Mean depth of the river is 10.10 m. River water is characterised by high turbidity and moderate water flow. Mid river islands are present with riparian vegetation at this place. Agriculture and human settlements are the main land use pattern in this area.

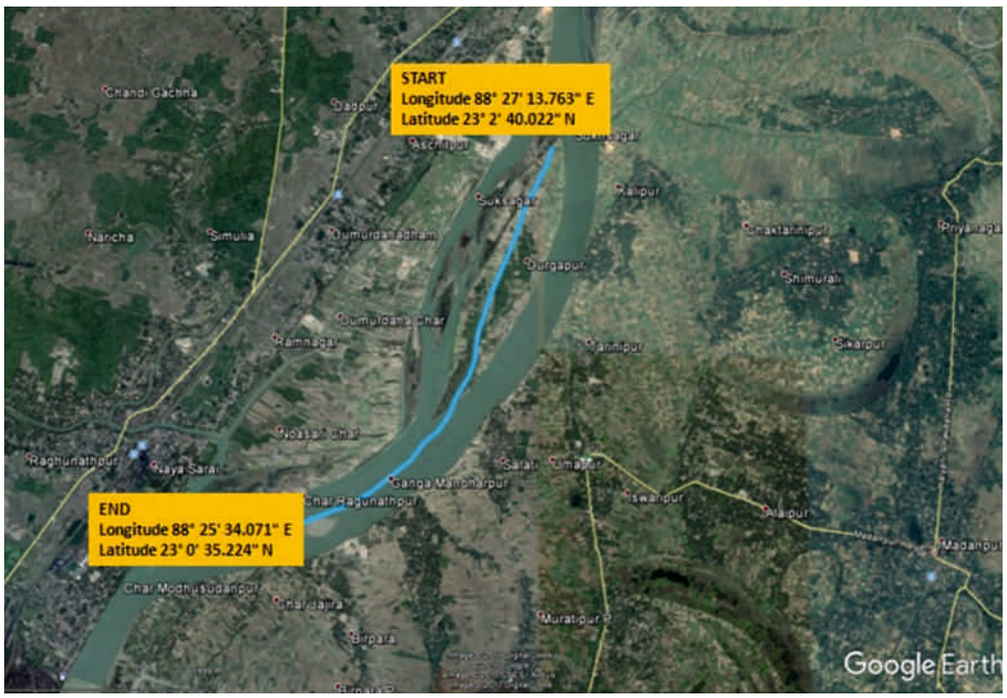

Figure 2.63: Google Earth map of study site at Raninagar Kalyani

Figure 2.64: Sampling location at Raninagar Kalyani

Site - S31

MAHESHTALA

This site is located 15 Km downstream of Kolkata city. The right bank is located at Sankrail Block, Howrah District and left bank at Thakurpukur Maheshtala Block, South 24 Parganas District in West Bengal. The site lies between 88°14'24.846" E, 22°32'13.298" N and 88°12'23.574" E, 22°30'54.146" N. Budge Budge Trunk Road connects this site with Kolkata. The altitude of this place is 4 m (msl). Mean depth of the river is 12.50 m. River water is characterised by high turbidity and salinity. Tidal influence is predominant here and it is a part of Kolkata Port river transport route. Agriculture and human settlements are the main land use patterns around this area.

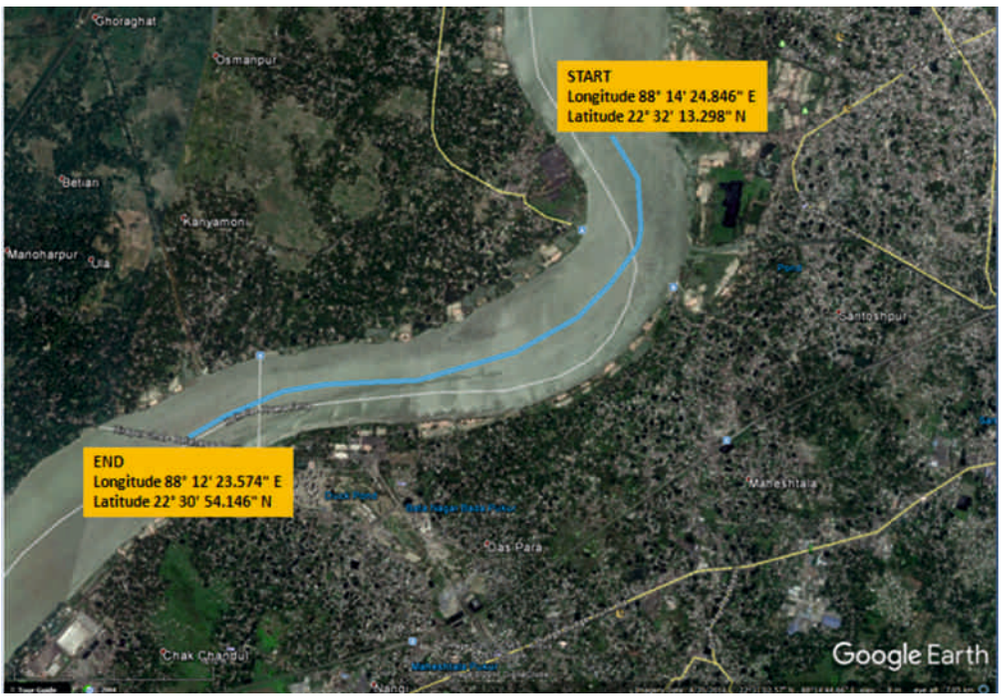

Figure 2.65: Google Earth map of study site at Maheshtala

Figure 2.66: Sampling location at Maheshtala

Site - S32

HALDIA – DIAMOND HARBOUR

This site is located at Haldia town and 15 km upstream of Ganga Sagar island. The right bank is located partly at Sutahata and Haldia Block whereas left bank at partly at Kulpi and Kakdwip Block, South 24 Parganas District in West Bengal. It lies between 88°11'2.566" E, 22°3'5.571" N and 88°9'16.411" E, 22°0'56.570" N. Haldia Municipal area located at right bank and Tyangrachar, Uttar Chandan Nagar villages are located at left bank of the stretch. National Highway 47 connects this site with Haldia from the right bank whereas National Highway 117 connects this site with Kolkata and Kakdwip from the left bank. The altitude of this place is 1 m (msl). Mean depth of the river is 12.80 m. River water is characterised by high turbidity. Salinity of water is very high owing to river confluence. Tidal influence is predominant in this site and it is a part of Kolkata Port river transport route. Mid river island is present at this site along with riparian vegetation. Agriculture and human settlements are the main land use pattern around this area.

Figure 2.67: Google Earth map of study site at Haldia-Diamond Harbour

Figure 2.68: Sampling location at Haldia – Diamond Harbour

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FLORAL ASSEMBLAGES AND VEGETATION PATTERNS ALONG THE GANGA RIVER

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ABSTRACT

Floral assemblages along the riparian land of the river are excellent indicators of both upland and aquatic plant communities, which help to assess the health of river in a particular area. Any changes in the dynamics of the riparian habitat can have a knock-on effect on aquatic and river dependent faunal diversity viz., resident and migratory birds, amphibians, fishes, invertebrates, aquatic mammals, and affect the river infrastructure, flood cycle, agriculture, and local communities along the river basins. The Ganga River is classified into 6 habitat zones, represented by 32 intensive sampling sites, each of length 5 km which comprise of various habitats viz. wetland, grassland, agricultural land, riverine forest, mangrove etc. The traditional quadrat method was used to assess the status and

3

distribution of riparian and aquatic flora of the Ganga River, using which ecological parameters like density, frequency, diversity, richness and prominence values were calculated. A systematic survey of the flora recorded 289 plant species (56 % herbs, 10 % shrubs, 21 % trees, 6 % climbers and 7% grasses, reeds and sedges) belonging to 88 families and 219 genera with 67% nativity. The dominant families were Asteraceae (30 species), Poaceae (16 species), Euphorbiaceae, Fabaceae, Polygonaceae (12 species each) and Solanaceae (11 species). Species with high prominence values are *Cynodon dactylon* (5.3), *Saccharum spontaneum* (2.0), *Parthenium hysterophorus* (1.4), *Ziziphus nummularia* (1.2), *Typha angustata* (1.1) and *Eichhornia crassipes* (1.1). The diversity was found in the following order: Zone I (Dharasu, Byas-ghat and Haridwar) > Zone V (Ballia, Kahalgaon and Sahibganj) > Zone VI (Farakka and Jiaganj) > Zone II (Bijnor) > Zone IV (Gangabarar, Fatehpur and Allahabad) > Zone III (Kanpur). In future, the study will be continued for evaluating the health of riparian habitat along the river, using riparian vegetation index (RVI) and mitigatory measures will be suggested for the restoration of degraded habitats.

Key words: The Ganga River, Riparian Vegetation, Flora, Exotic Species, Diversity

3.1 INTRODUCTION

Plant communities have been a major focus for investigation since time immemorial. The Gangetic biodiversity, due to its representativeness, richness and uniqueness, has attracted several people from different parts of the globe. The Gangetic ecosystem forms an important environment for aquatic, semi-aquatic and hydrophilic floral and faunal associations. Vegetation composition and assemblages of an area form a significant habitat that contribute to the structure and function of such ecosystems. In recent decades, rapidly changing climate conditions have shifted the focus of vegetation studies towards identifying the vegetation pattern and composition and the impact of climate change on it.

Ganga River supports rich and biodiverse aquatic (instream) and riparian (streamside) ecosystems that contribute many valued environmental services. The vegetation pattern along the Ganga varies according to the season and flood levels. Species composition differs by function of water supply and different soil type, which has a sharp influence on plant species distribution. As aquatic vegetation plays an imperative role in bio-filtration by absorbing large amount of organic as well as inorganic nutrients from the eutrophic water bodies/nutrient enriched pollutant, through various dynamic processes, e.g. water cycle, nutrient cycle and food chain, they have been recognized as 'Kidneys of the Landscape' (Mitsch and Gossilink, 2000). The

vegetation formations in the riverine area of Ganga change wherever a road embankment or any anthropogenic activities occur, which forms a unique type like forested land on the flood-free ground, grasslands on seasonally flooded areas, and aquatic, semi-aquatic, submerged vegetation in water bodies. Several macrophytes (submerged, emergent and free-floating aquatic plants) are known to accumulate and bio-concentrate heavy metals producing an internal concentration several folds greater than their surroundings (Chen et al., 2008) and the areas saturated with water are crucial incubators, supporting high species diversity (Allen-Diaz et al., 2008).

Considering the available literature on the subject, an attempt has been made to review and analyze the work done zone wise, as the entire Indo-Gangetic plain is divisible into three major parts (i) Upper Ganga Plain, (ii) Middle Ganga Plain, and (iii) Lower Ganga Plain. Different aspects of biodiversity of the Ganga River, which have appeared in scientific publications during past few decades, broadly focus on floristic diversity, plant composition, vegetation assessment, nativity, and impact of disturbances on vegetation assemblages. J.F. Duthie (1903-1929) in his three volumes of 'Flora of the Upper Gangetic Plain and of the Adjacent Siwalik and Sub-Himalayan tracts', gives a description of several plants of Upper Ganga plain. A list of 171 species of aquatic angiosperms that grow commonly in fresh water, brackish water as well as marshy areas has been reported by Biswas (1954) in 'Handbook of common water and marshy plants of India and Burma'. Subramanyam (1974), in “Aquatic Angiosperms” gives a detailed description and distribution of 117 taxa belonging to 32 families of the commonly found aquatic and halophytic flowering plants of the Indian sub-continent. Babu (1977) in his book “Herbaceous Flora of Dehradun” deals with the systematic account of 1,230 species of Angiosperms belonging to 624 genera distributed over 115 families, which include records of some aquatic angiosperms. Cook (1996) in “Aquatic & wetland plants of India” provides a detailed description of vascular angiosperm and wetland plants of the Indian Sub-continent. Naskar (1993) in his two volumes of “Plant Wealth of the Lower Ganga Delta: An Eco-taxonomical Approach” and in “Aquatic and Semi-Aquatic Plants of the Lower Ganga Delta: Its Taxonomy Ecology and Economic Importance” (1990), describes the floristic diversity of lower Gangetic plain as well as the vegetation of mangrove vegetation of delta region.

Vegetation sampling

Although several scientific studies have been conducted on the floristic diversity of the Gangetic plains, yet these have been done in few stretches (fragments) of the river and its tributaries. Moreover, very few were focused specifically on the riverine vegetation composition of the Ganga River. The absence of this reliable and updated information, their conservation, restoration values, and socioeconomic importance has greatly hampered the development of policy, legislation and administrative interventions. Therefore, the present study aims to generate the complete baseline information on the floristic diversity, as well as floral composition and vegetation pattern along the Ganga River .

3.2 METHODOLOGY

The survey for vegetation sampling was carried out in two seasons: post-monsoon survey during September-November and post-winter survey during March-May. Out of the 32 pre-decided sampling sites, the systematic survey for floristic diversity was conducted in 25 sites of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal. In each of these sites, a 5 Km stretch along the river has been identified as an intensive sampling area, which, for the ease of vegetation sampling, was further sub-divided into six-point locations at an interval of 1 Km from each other. A belt transect of 100 $\times$ 50m was laid out on either of the river banks (Figure 3.1), depending on accessibility.

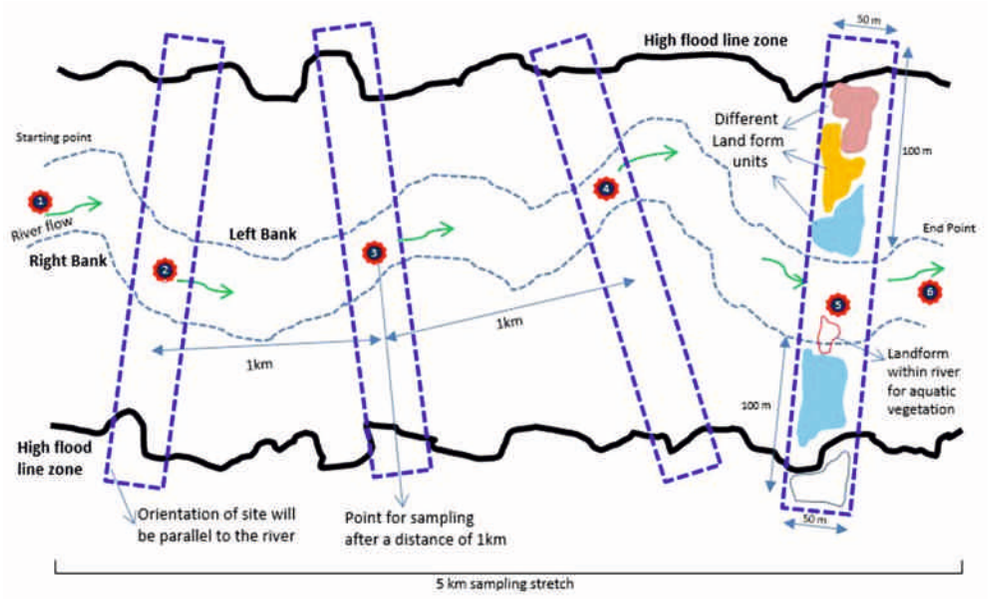

Figure 3.1: A pictorial representation of the sampling strategy for vegetation

Different landforms within this belt, like a riparian belt, wetland, grassland or agricultural land, were identified, and subsequently, quadrat sampling following the Cox, (1976) sampling protocol was done on each unique landform. Five quadrats, each of size 1×1m, were randomly laid onto the landforms and the plant individuals falling in this area were recorded in the datasheet. The species which could not be identified on spot were photographed, and collected for preparation of herbarium. The herbariums were used to identify plant species with the help of identification keys and resource persons.

The data was used to prepare a checklist of plants following Adhikari & Babu (2008). Plant identification was done with the help of various Floras and field identification guides such as Flora of the Upper Gangetic plains (Duthie, 1903-29), Herbaceous Flora of Dehradun (Babu, 1977), Aquatic and Semi Aquatic Plants of the Lower Ganga Delta (Naskar K, 1990), Common Indian Wild Flowers (Kehimkar, 2000), Flowers of the Himalaya (Polunin and Stainton, 1997), Plant Wealth of the Lower Ganga Delta (Naskar K ,Volume I and II, 1993) and Aquatic Wetland Plants of India (Cook, 1996). The plant habit type and nativity status were also listed, with the help of field guides, books, research papers and authentic websites like Gerber et al., (2004), Khuroo et al., (2012), Naidu, V. (2012), Reddy, C.S. (2008), Reddy et al., (2016), Singh et al., (2010). Ecological parameters like abundance, density, frequency, richness and Shannon's diversity were calculated following Misra (1968) and Magurran (1988). The Prominence Value (PV) for every species was also calculated following Henderson (1998).

$$PV = \left(\frac{\textit{Relative abundance of a species x in category}}{\textit{Sum of relative abundances of all species in category}} \right) + \left(\frac{\textit{Sum of relative abundances of all species in category}}{\textit{Sum of relative frequency of all species in category}} \right) \text{X100}$$

A matrix for the disturbance recorded visually at the survey sites was also prepared, using which disturbance index was calculated. Disturbance value of a site was calculated by totaling the presence of all disturbances occuring in a site.

$$\textit{Disturbance score} = \frac{\textit{Disturbance value of a site}}{\textit{Total number of disturbances}} \times 100$$

3.3 RESULTS

A total of 289 plant species including herbs, shrubs and trees, representing 88 families and 219 genera were recorded in the 25 intensive sampling sites. The plants are classified according to their habit types into herbs (aquatic, riparian and terrestrial), shrubs, trees, climbers, and grasses (including reeds and sedges). A checklist of the plant species encountered during the systematic survey is given in Appendix 1. The family Asteraceae was found to be the most dominant with 30 species, followed by Poaceae (16 species), Euphorbiaceae, Fabaceae and Polygonaceae (12 species each), Solanaceae (11 species), Amaranthaceae, Convolvulaceae, Lamiaceae, Malvaceae and Mimosaceae (9 species each) (Table 3.1).

Table 3.1: Distribution of 88 families encountered in the study

Dominant Family (Species Number)	Single Species
Asteraceae (30), Poaceae (16),	Agavaceae, Berberidaceae,
Euphorbiaceae, Fabaceae, Polygonaceae (12 in each) Solanaceae (11)	Bignoniaceae, Bombacaceae, Cactaceae, Cannabaceae, Capparaceae, Caricaceae, Caryophyllaceae, Casuarinaceae
Amaranthaceae, Convolvulaceae, Lamiaceae, Malvaceae, Mimosaceae (9 in each)	Ceratophyllaceae, Crassulaceae,, Elaeagnaceae, Equisetaceae,
Acanthaceae, Scrophulariaceae (7 in each)	Eriocaulaceae, Fumariaceae, Liliaceae
Verbenaceae (6)	Linaceae, Linderniaceae
Cyperaceae, Rubiaceae (5 in each)	Marsileaceae, Martyniaceae,
Araceae, Caesalpiniaceae, Cucurbitaceae	Menyanthaceae, Moringaceae
Moraceae, Myrtaceae (4 in each)	
Arecaceae, Brassicaceae, Commelinaceae, Nymphaeaceae, Plantaginaceae, Potamogetonaceae	
Rutaceae (3 in each)	
Anacardiaceae, Apiaceae, Apocynaceae, Asclepiadaceae, Boraginaceae, Chenopodiaceae, Combretaceae, Geraniaceae, Hydrocharitaceae, Lythraceae, Meliaceae, Pinaceae, Pontederiaceae, Ranunculaceae, Rhamnaceae, Rosaceae,	
Santalaceae, Sapindaceae, Urticaceae (2 in each)	

Habit and Habitat types

As mentioned above, the recorded plants were categorized into their respective habit and habitat types (Figure 2). The results indicate that a majority of the plants along the Ganga River were herbs (56%), which include aquatic (20%), as well as riparian and terrestrial plants (80%), followed by trees (21%) and shrubs (10%). The grass habit type including reeds and sedges contributed 7% of the total plant community observed, out of which 67% belong to the family Poaceae (Grasses), 24% belong to Cyperaceae (Sedge family) and the rest 9% belong to reeds category. Genus *Typha* and *Phragmites* were the two reed plants that were found in the study area.

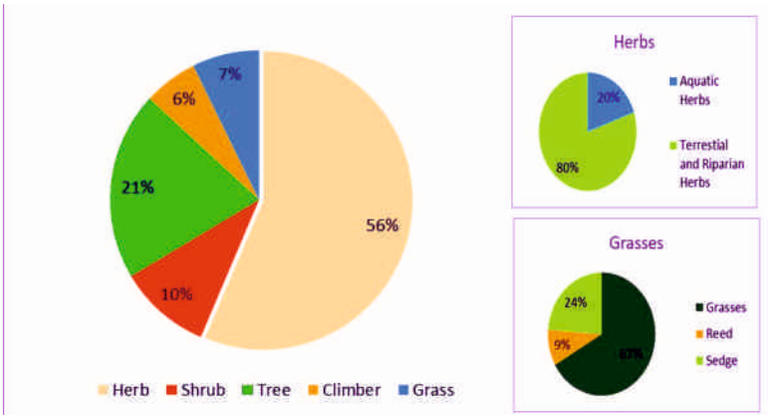

Figure 3.2: Plant habit and habitat types recorded along the Ganga River

Nativity

The nativity status of recorded plants showed, that 67% plants were native and the rest 33% were exotic, some of which have naturalized in India (Figure 3.3).

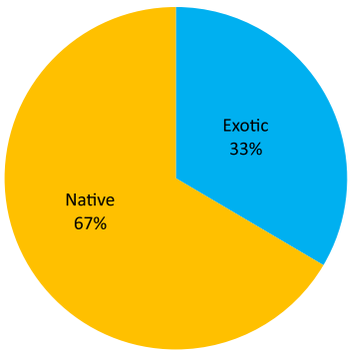

Figure 3.3: Percent composition of native and exotic plants species along the Ganga River

The nativities of the exotic plants were also examined. A majority of the plants (57%) have their origin from Tropical America followed by Tropical Africa (14%), Tropical South America and Europe (6% each) Australia, Central America and Brazil (3% each). The results indicate that plants from other tropical countries are more widespread in the Indo-Gangetic plain. (Figure 3.4)

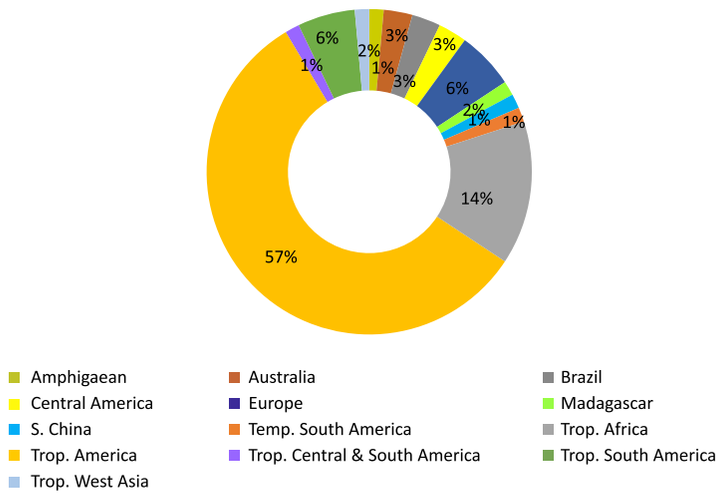

Figure 3.4: Percent contribution of the nativity of exotic plants along the Ganga River

Nativity status of the recorded plants, specific to the sampled sites was studied and the result is represented in the figure below (Figure 3.4). Allahabad was found to have maximum exotic species out of the total plants sampled in the area, followed by Kanpur, Ballia, Haldia and Kachla.

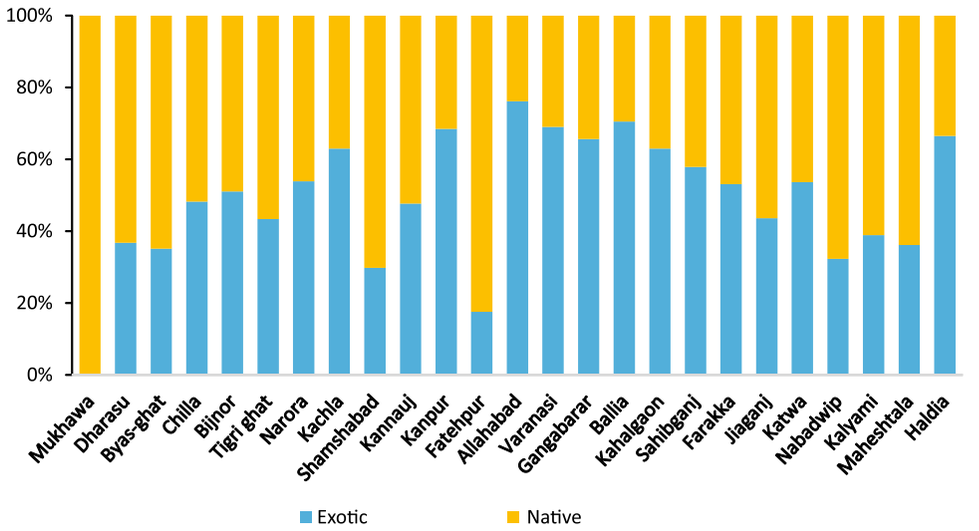

Figure 3.5: Percent contribution of native and exotic plant species at each sampled site

The same analysis was done for the six habitat zones, which indicated that maximum exotic species out of the total species in each zone, was observed in Zone 4 (Fatehpur to Varanasi) and Zone 5 (Gangabarar to Sahibganj) followed by Zone 3 (Kachla to Kanpur).

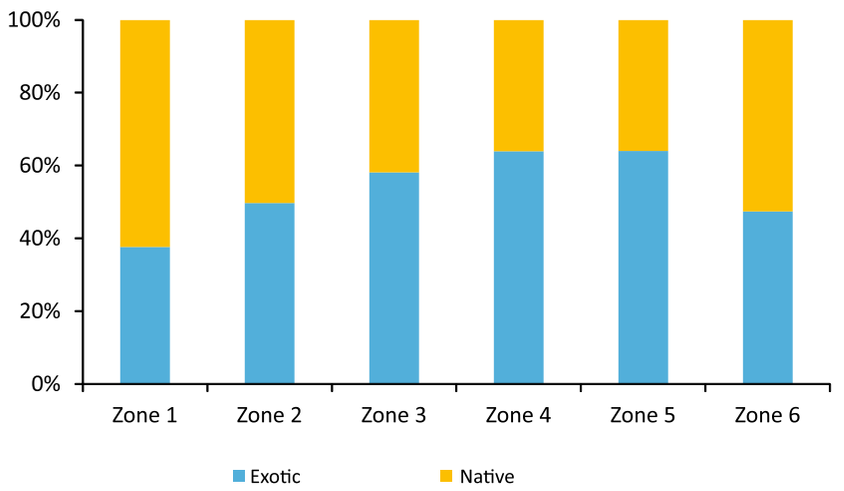

Figure 3.6: Percent contribution of native and exotic plant species at each habitat zone

Density

Cynodon dactylon showed maximum density (22.1%) for the entire river stretch, followed by *Saccharum spontaneum* (3.1%), *Eichhornia crassipes* (2.6%), *Parthenium hysterophorus* (2.4%), *Alternanthera philoxeroides* (2.4%) and *Sida acuta* (2.3%).

Zone specific analysis shows that *Equisetum diffusum* has a maximum density (7.01%) in zone 1, followed by *Cynodon dactylon* (5.3%) which exhibited maximum values in zone 2, zone 3, zone 4 and zone 5 (24.4%, 34.4%, 64.2%, and 16.6% respectively). *Tamarix gallica* var. *indica* (4.8%) in zone 1; Sida acuta (13.8%), *Parthenium hysterophorus* (9.4%) in zone 2; *Saccharum*

spontaneum (20.5%), *Alternanthera philoxeroides* (13.1%) in zone 3; *Setaria* sp.(12.0%), *Rungia pectinata* (2.7%) in zone 4; *Lippia alba* (10.4%), *Urena lobata* (4.7%) in zone 5 and *Eichhornia crassipes* (6.7%), *Coix lacryma-jobi* (6.0%), *Typha angustata* (4.5%) in zone 6 are other species which show high density values in the respective zones.

Measurement of tree girth

Frequency

The frequency of plant species, recorded throughout the river stretch and specific to each habitat zone was calculated. The results indicate that *Parthenium hysterophorus* is the most frequently occurring species, followed by *Phyla nodiflora, Hydrilla verticillata, Cynodon dactylon, Grangea maderaspatana, Stuckenia pectinata, Croton bonplandianum, Ranunculus sceleratus, Ageratum conyzoides, Mikania micrantha, Xanthium strumarium,* and *Ipomoea carnea.*

Zone specific analysis indicates that zone 1, which is the hilly stretch of the Ganga River, has a different trend of frequently occurring species in comparison to other zones. *Rumex nepalensis, Verbascum Thapsus, Equisetum diffusum, Tamarix gallica var. indica, Fumaria indica, Cirsium wallichii, Parthenium hysterophorus* and *Veronica anagallis-aquatica* are the species that show the higher frequency in zone 1, some of which are also representative of high altitude vegetation. *Cynodon dactylon* showed high frequency in the remaining zones (2, 3, 4 and 5). Other plant species which displayed high frequency are: *Sida acuta*, *Saccharum spontaneum* and *Parthenium hysterophorus* in zone 2; *Saccharum spontaneum, Crotalaria juncea* and *Ziziphus nummularia* in zone 3; *Setaria* sp., *Croton bonplandianum* and *Lippia alba* in zone 4; *Lippia alba, Parthenium hysterophorus* and *Grangea maderaspatana* in zone 5; *Coix lacryma-jobi, Eichhornia crassipes, Typha angustata* and *Ipomoea carnea* in zone 6.

Prominence Value

The Prominence Value (inclusive of relative frequency and relative density) of plant species, recorded throughout the river stretch, and specific to each habitat zone was calculated. The results indicate that the species with high prominence values for the entire river stretch are *Cynodon dactylon* (5.3), *Saccharum spontaneum* (2.0), *Parthenium hysterophorus* (1.4), *Ziziphus nummularia* (1.2), *Typha angustata* (1.1) and *Eichhornia crassipes* (1.1).

The species with high prominence values for zone 1 are *Equisetum diffusum* (6.8), *Rumex nepalensis* (4.4), *Verbascum Thapsus* (3.7), *Tamarix gallica* var. *indica* (3.6), *Fumaria indica* (3.2), *Parthenium hysterophorus* (3.1), *Cirsium wallichii* (2.7) and *Veronica anagallis-aquatica* (2.3). *Cynodon dactylon* showed high prominence value in the remaining zones (2, 3, 4 and 5). Other plant species which displayed high prominence values are: *Sida acuta* (8.7), *Saccharum spontaneum* (8.1) and *Parthenium hysterophorus* (7.8) in Zone 2; *Saccharum spontaneum* (16.9), *Crotalaria juncea* (12.1) and *Ziziphus nummularia* (12.0) in zone 3; *Setaria* sp. (0.1), *Croton bonplandianum* (0.04) and *Lippia alba* (0.04) in zone 4; *Lippia alba* (7.5), *Parthenium hysterophorus* (4.7) and *Grangea maderaspatana* (4.1) in zone 5; *Coix lacryma-jobi* (7.0), *Eichhornia crassipes* (5.0), *Typha angustata* (4.8) and *Ipomoea carnea* (4.6) in zone 6.

Species richness and diversity

The species richness and diversity values calculated for the sampled sites as well as the habitat zones show a uniform trend. The values of species richness for the 25 sampling sites range from 71 in Dharasu to 4 in Shamshabad and Kannauj, while Shannon's diversity index values range from 3.95 in Dharasu to 1.22 in Kannauj.

The sites with high richness are Dharasu (71), Chilla (45), Byas-ghat (38), Jiaganj (37), Farakka (32) and Bijnor (31). Least richness is recorded in Kannauj (4), Shamshabad (4) and Maheshtala (5).

The sites with high diversity are Dharasu (3.9), Chilla (3.6), Byas-ghat (3.4), Jiaganj (3.3), Farakka (3.2), Sahibganj (3.0), Kahalgaon (2.9) and (Bijnor (2.8). Least diversity is recorded in Kannauj (1.2), Shamshabad (1.2) and Maheshtala (1.4).

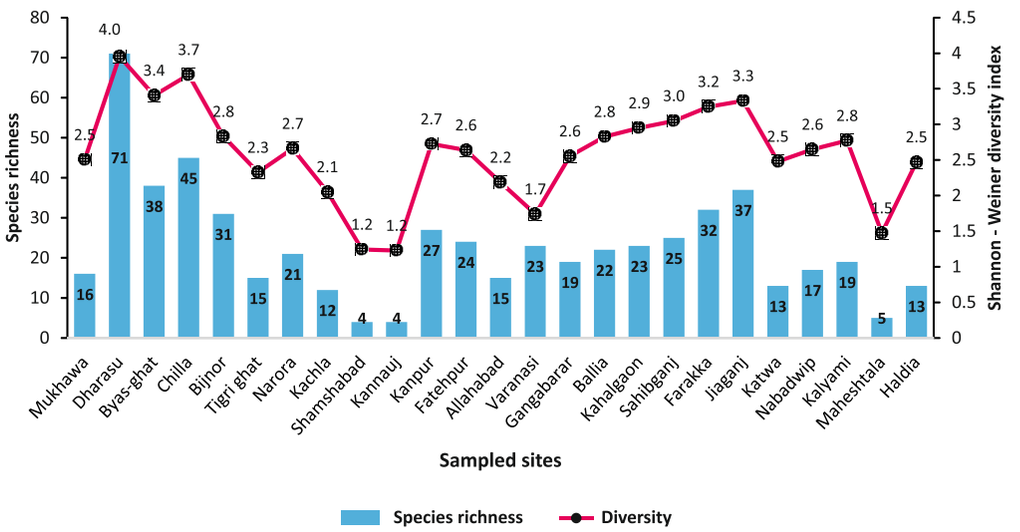

Figure 3.7: Species richness and diversity (H') along river Ganga

The species richness and diversity values for habitat zones are highest for zone 1, which is the hilly stretch of the Ganga River. The species richness for Habitat zones in decreasing order is: Zone 1 > Zone 6 > Zone 2 > Zone 5 > Zone 4 > Zone 3. Whereas the order for species diversity is: Zone 1 > Zone 5 > Zone 6 > Zone 2 > Zone 4 > Zone 3. Zone 3 (Kachla to Kanpur) is the least rich and diverse zone of all the six habitat zones.

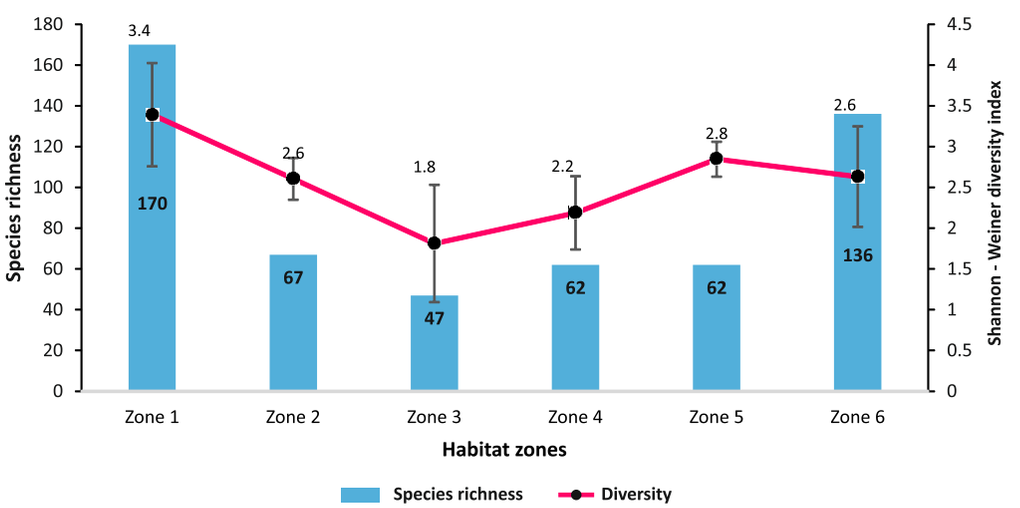

Figure 3.8: Species richness and diversity across various habitat zones

Disturbance Index

A matrix of the disturbances present on each site was prepared and quantified for the purpose of identifying the most prominent disturbances in the study area as well as estimating the contribution of disturbance in each sampling site.

Out of the fourteen identified disturbance variables, human-habitation (settlements) and human activities like fishing, bathing, washing clothes near the river have been identified as the most common disturbances, present in 22 out of 25 sampled sites. Grazing by livestock followed by ghats (ferry/boat), riverbed agriculture, religious activities and presence of motorable road near the riparian area have been identified as other significant disturbances, which are present in the sampling sites.

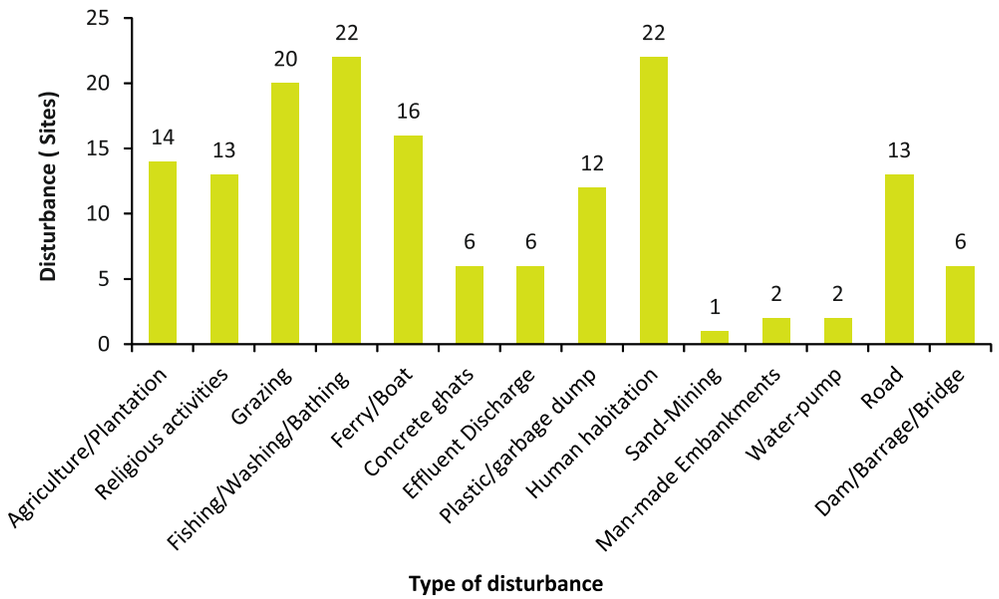

Figure 3.9: Various types of disturbances identified across the Ganga River

A disturbance index for the sampled sites was calculated, which indicates that Varanasi was the most disturbed site. Kahalgaon, Nabadwip, Kalyani, Haldia and Jiaganj, all in zone 5 and 6 are other highly disturbed stretches of the river. On the other hand Mukhawa, Dharasu, Shamshabad and Fatehpur are comparatively less disturbed sites of the river.

A zone wise comparison of the same shows similar results. The habitat zones of disturbance in decreasing order can be represented as: Zone 6 > Zone 5 > Zone 4 > Zone 3 > Zone 1 > Zone 2.

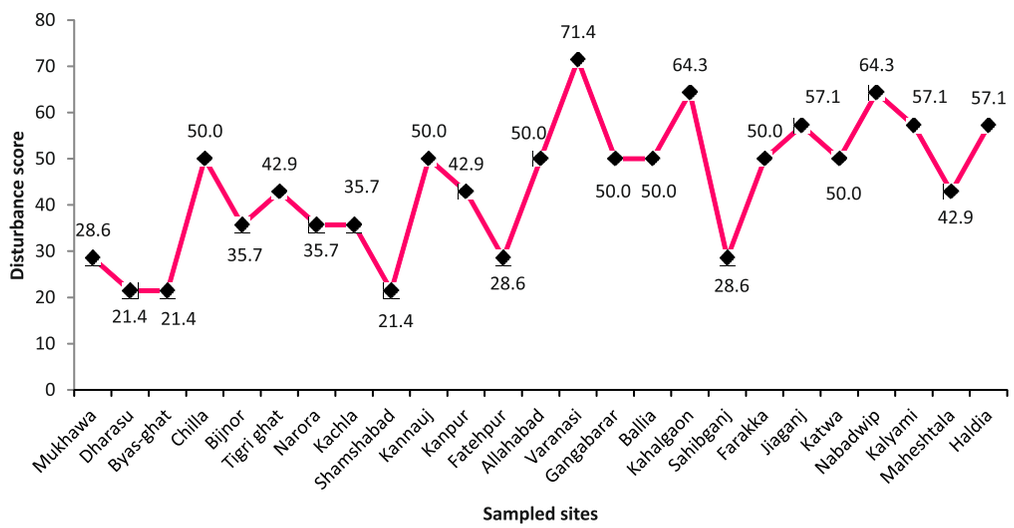

Figure 3.10: A graphical representation of the disturbance index for each sampled site

3.4 DISCUSSION

A rapid survey of the vegetation composition of the Ganga River indicates that out of the 298 plant species recorded, the majority of the plants along the river were herbs. The total number of aquatic species recorded in a survey out of 163 herbs were 32, which is low due to less number of wetlands falling within the sampling areas. The stretches where diversity and richness are found extremely low, like Shamshabad and Kachla, are highly impacted by riverbed agriculture. Varanasi also shows low diversity (1.73) because it is a highly disturbed site with 71% of the total disturbances recorded for the entire Ganga River. Other stretches, which show high diversity like Dharasu, Chilla, Baghi Village, Farakka and Sahibganj, are comparatively less disturbed sites. However, it is observed that some sites with high diversity like Kahalgaon, Jiaganj, Ballia, Kanpur, Haldia and Allahabad are also sites with high disturbances. It was found that these sites have a high percentage (>50%) of exotic species out of the total plants recorded. The disturbances in the sites have possibly promoted the growth of invasive and tolerant species replacing the native ones. This is supported by the results of density and frequency, which indicate that throughout the river stretch, the most densely and frequently occurring plant species like *Saccharum spontaneum, Eichhornia crassipes, Parthenium hysterophorus, Alternanthera philoxeroides, Sida acuta, Urena lobata* and *Typha angustata* are exotic as well as invasive weeds. These plant species are dominant in the areas which are disturbed.

In terms of habitat zones, the highest diversity is recorded in zone 1 (Mukhawa to Haridwar), which also has the least composition of exotic plant species and is less disturbed (5th position in decreasing order of disturbance). zone 2 (Bijnor to Narora) is the least disturbed site, has a low composition of exotic plant species (5th position in decreasing order of exotic species composition) and has moderate diversity (4th position in decreasing order of diversity). The high diversity, less disturbance and low composition of exotic species in zone 1 and 2 can be attributed to the fact that some parts of the two protected areas, Rajaji National Park and Hastinapur Wildlife Sanctuary respectively fall in the sampling sites. Zone 4 (Fatehpur to Varanasi) has the maximum composition of exotic plant species, is less diverse (5th position in decreasing order of diversity) and moderately disturbed (3rd position in decreasing order of disturbance).

Further studies

We know that the floral communities along the riparian land of the river are important, as they indicate the health of the river system in a particular area. The further study will hence be carried out for calculating the Riparian Vegetation Index (RVI) and estimating the health of riparian habitat along the river. Planning for restoring degraded habitats will be suggested based on the health of the riparian vegetation. Along with this, the seven survey sites that could not be sampled will be surveyed and the results will be incorporated into the assessment of a complete biodiversity profile of the 32 intensive sampling sites.

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Appendix 1: Checklist of plant species encountered during the systematic survey across river Ganga (Mukhawa to Haldia). Habit: H - Herb; S - Shrub, T – Tree, C - Climber, G - Grass, Aq -Aquatic, Sg - Sedge and R - Reed; Status: E - Exotic and N - Native; Nativity: Trop. - Tropical, Temp. - Temperate, C - Central, S - South, Ind. - Indian Oriental

Family	Species name	Habit	Status	Nativity
Acanthaceae	*Acanthus ilicifolius* L.	S	N	Ind.
	Barleria cristata L.	S	N	Ind.
	Barleria prionitis L.	S	N	Ind.
	Dicliptera roxburghiana Nees	H	N	Ind.
	Justicia adhatoda L.	H	N	Ind.
	Peristrophe paniculata (Forssk.) Brummitt	H	E	Trop. America
	Rungia pectinata (L.) Nees	H	N	Ind.
Agavaceae	*Agave angustifolia* Haw.	S	E	Ind.
Amaranthaceae	*Achyranthes aspera* L.	H	N	Ind.
	Aerva sanguinolenta (L.) Blume	H	N	Ind.
	Alternanthera philoxeroides (Mart.) Griseb.	H	E	Trop. America
	Alternanthera sessilis (L.) R. Br. ex DC.	H	E	Trop. America
	Amaranthus sp. 1	H	—-	—-
	Amaranthus sp. 2	H	—-	—-
	Amaranthus spinosus L.	H	E	Trop. America
	Celosia argentea var *spicata*	H	E	Trop. Africa
	Chenopodium album Linn.	H	E	Europe
Anacardiaceae	*Mangifera indica* L.	T	N	Ind.
	Toxicodendron parviflorum Kuntze	S	N	Ind.
Apiaceae	*Centella asiatica* (L.) Urb.	H	N	Ind.
	Coriandrum sativum L.	H	N	Ind.
Apocynaceae	*Alstonia scholaris* (L.) R. Br.	T	N	Ind.
	Carissa bispinosa Desf. ex Brenan	S	N	Ind.
Araceae	*Colocasia* sp. 1	H	—-	—-
	Colocasia esculenta (L.) Schott	H	N	Ind.
	Pistia stratiotes L.	Aq	E	Trop. America
	Spirodela polyrhiza (L.) Schleid.	Aq	N	Ind.
Arecaceae	*Borassus flabellifer* L.	T	E	Trop. Africa
	Cocos nucifera L.	T	N	Ind.
	Phoenix dactylifera L.	T	N	Ind.
Asclepiadaceae	*Calotropis gigantea* (L.) R.Br.	S	E	Trop. Africa
	Calotropis procera (Ait.) R.Br.	H	E	Trop. Africa
Asteraceae	*Ageratum conyzoides* L.	H	E	Trop. America
	Anaphalis sp.1	H	--	--
	Anaphalis sp.2	H	--	--
	Artemisia sp. 1	H	--	—-
	Artemisia sp. 2	H	--	—-
	Artemisia sp. 3	H	--	—-
	Aster bellidioides Buch.-Ham. ex D. Don	H	N	Ind.
	Caesulia axillaris Roxb.	H	N	Ind.
	Cirsium heteromallum (D. Don) Spreng.	H	N	Ind.
	Cirsium wallichii Dc.	H	N	Ind.
	Crassocephalum crepidioides (Benth.) Moore	H	E	Trop. America
	Eclipta alba (L.) Hassk.	H	E	Trop. America
	Erigeron bonariensis L.	H	N	Ind.
	Eupatorium adenophora Spreng.	H	E	C. America
	Gnaphalium pensylvanicum Willd.	H	E	Trop. America
	Gnaphalium sp.	H	--	—-
	Grangea maderaspatana (L.) Poir.	H	E	Trop. S. America
	Inula sp.	H	--	—-

Family	Species name	Habit	Status	Nativity
	Inula indica L.	H	N	Ind.
	Launaea procumbens (Roxb.) Ramayya & Rajagopal	H	N	Ind.
	Mikania micrantha Kunth	C	E	Trop. America
	Parthenium hysterophorus L.	H	E	Trop. America
	Sphaeranthus indicus L.	H	N	Ind.
	Synedrella nodiflora (L.) Gaertn.	H	E	Trop. America
	Taraxacum officinale F.H. Wigg.	H	N	Ind.
	Tridax procumbens L.	H	E	C. America
	Vernonia cinerea Less.	H	E	Amphigaean
	Wedelia trilobata (L.) Hitchc.	H	E	Trop. America
	Xanthium strumarium L.	H	E	Trop. America
	Youngia japonica (L.) DC.	H	E	Trop. S. America
Berberidaceae	*Berberis aristata* Sims	S	N	Ind.
Bignoniaceae	*Jacaranda* sp.	T	E	Brazil
Bombacaceae	*Bombax ceiba* L.	T	N	Ind.
Boraginaceae	*Ehretia laevis* Roxb.	T	N	Ind.
	Heliotropium indicum L.	H	N	Ind.
Brassicaceae	*Capsella bursa-pastoris* (Linn.) Medik	H	E	Europe
	Lepidium virginicum L.	H	E	Trop. America
	Rorippa nasturtium-Aquaticum (L.) Hayek	Aq	N	Ind.
Cactaceae	*Opuntia stricta* (Haw.) Haw.	S	E	Trop. America
Caesalpiniaceae	*Bauhinia vahlii* Fern.-Vill.	C	N	Ind.
	Cassia fistula L.	T	N	Ind.
	Delonix regia (Bojer ex Hook.) Raf.	T	E	Madagascar
	Senna occidentalis (L.) Link	H	E	Trop. S. America
Cannabaceae	*Cannabis sativa* Linn.	H	E	C. Asia
Capparaceae	*Capparis decidua* (Forssk.) Edgew.	S	N	Ind.
Caricaceae	*Carica papaya* L.	T	N	Ind.
Caryophyllaceae	*Polycarpon prostratum* (Forssk.)	Aq	N	Ind.
Casuarinaceae	*Casuarina equisetifolia* L.	T	N	Ind.
Ceratophyllaceae	*Ceratophyllum demersum* L.	Aq	E	Trop. America
Chenopodiaceae	*Chenopodium* sp.	H	--	—-
	Chenopodium ambrosioides L.	H	E	Trop. America
Combretaceae	*Terminalia* sp.	T	--	—-
	Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	T	N	Ind.
Commelinaceae	*Commelina axillaris* L.	H	N	Ind.
	Commelina benghalensis L.	H	N	Ind.
	Cyanotis cristata (L.) D. Don	H	N	Ind.
Convolvulaceae	*Convolvulus pluricaulis* Choisy	H	N	Ind.
	Ipomoea aquatica Forssk.	H	N	Ind.
	Ipomoea carnea Jacq.	S	E	Trop. America
	Ipomoea eriocarpa R. Br.	C	E	Trop. Africa
	Ipomoea obscura (L.) Ker Gawl.	C	E	Trop. Africa
	Ipomoea pes-tigridis L.	C	E	Tropical Africa
	Ipomoea purpurea (L.) Roth	C	E	Trop. S. America
	Merremia hederacea (Burm. f.) Hallier f.	C	N	Ind.
	Operculina turpethum (L.) Silva Manso	C	N	Ind.
Crassulaceae	Sedum sp.	H	--	—-
Cucurbitaceae	*Coccinia grandis* (L.) Voigt	C	N	Ind.
	Lagenaria siceraria (Molina) Standl.	C	N	Ind.
	Mukia maderaspatana (L.) M. Roem.	C	E	NA
	Trichosanthes cucumerina L.	C	N	Ind.
Cyperaceae	*Cyperus* sp. 1	Sg	--	—-
	Cyperus sp. 2	Sg	--	—-
	Cyperus sp. 3	Sg	--	—-

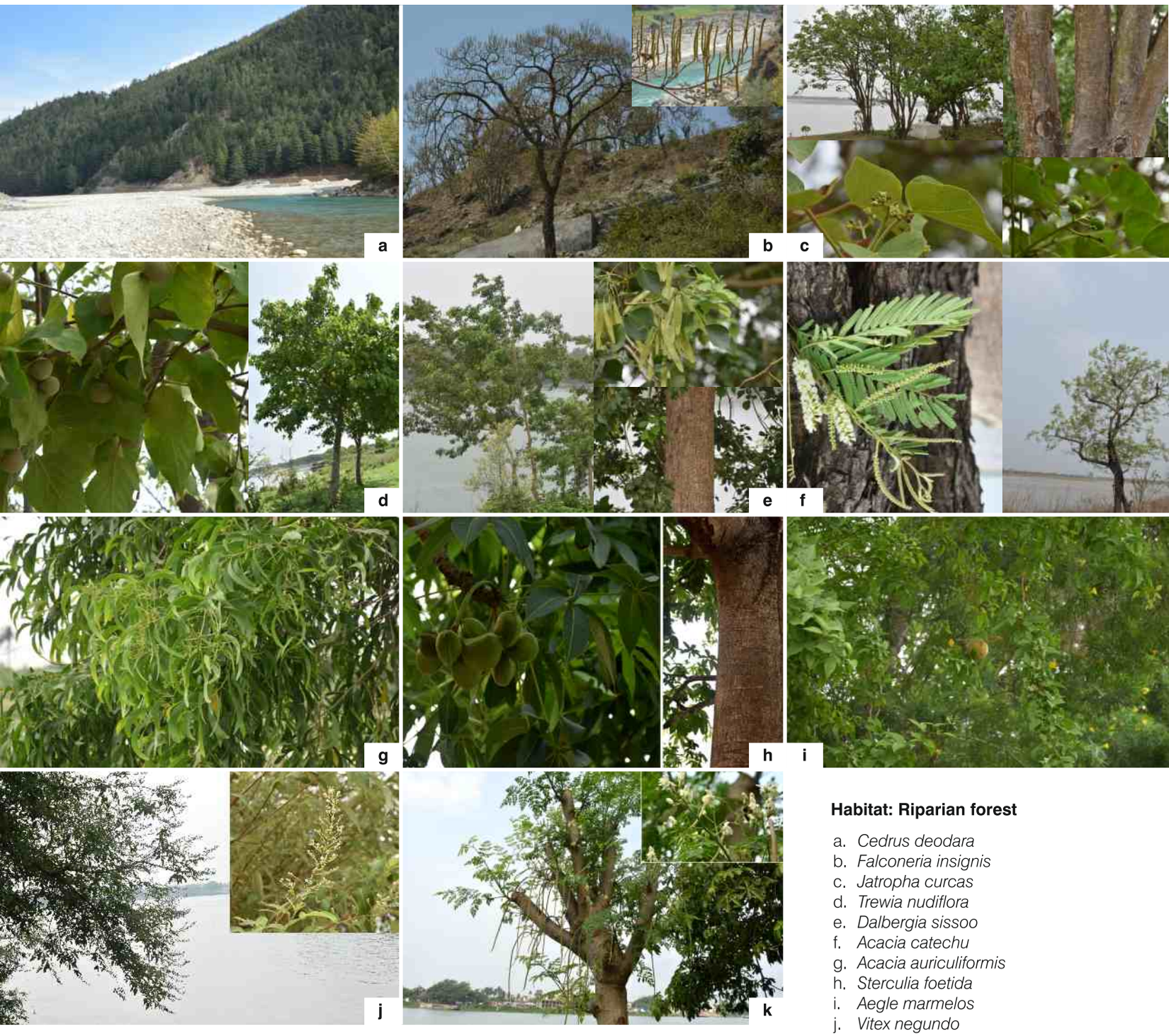
Family	Species name	Habit	Status	Nativity
	Cyperus sp.4	Sg	--	--
	Schoenoplectus mucronatus (L.) Palla	Sg	N	Ind.
Elaeagnaceae	*Hippophae salicifolia* D. Don	S	N	Ind.
Equisetaceae	*Equisetum diffusum* D. Don	H	N	Ind.
Eriocaulaceae	*Eriocaulon* sp.	H	N	Ind.
Euphorbiaceae	*Acalypha indica* L.	H	N	Ind.
	Chrozophora rottleri (Geiseler) A. Juss. ex Spreng.	H	E	Trop. Africa
	Croton bonplandianus Baill.	H	E	Temp. S. America
	Euphorbia cyathophora Murray	H	E	Trop. America
	Euphorbia hirta L.	H	E	Trop. America
	Euphorbia royleana Boiss.	S	N	Ind.
	Euphorbia thymifolia L.	H	N	Ind.
	Falconeria insignis Royle	T	N	Ind.
	Jatropha curcas L.	T	E	C. America
	Mallotus philippensis (Lam.) Müll. Arg.	T	N	Ind.
	Ricinus communis L.	S	N	Ind.
	Trewia nudiflora L.	T	N	Ind.
Fabaceae	*Abrus precatorius* L.	C	N	Ind.
	Bauhinia sp.	T	--	---
	Crotalaria juncea L.	H	N	Ind.
	Dalbergia sissoo Roxb. ex DC.	T	N	Ind.
	Indigofera sp.	S	E	Trop. America
	Lathyrus aphaca L.	H	--	---
	Melilotus indicus (L.) All.	H	N	Ind.
	Pithecellobium dulce (Roxb.) Benth.	T	E	Mexico
	Prosopis juliflora (Sw.) DC.	T	E	S. America
	Sesbania bispinosa (Jacq.) W. Wight	H	E	Trop. America
	Tephrosia purpurea (L.) Pers.	H	N	Ind.
	Vicia hirsuta (L.) Gray	C	N	Ind.
Fumariaceae	*Fumaria indica* Pugsley	H	N	Ind.
Geraniaceae	*Geranium collinum* Stephan ex Willd.	H	N	Ind.
	Geranium nepalense Sweet	H	N	Ind.
Hydrocharitaceae	*Hydrilla verticillata* (L. f.) Royle	Aq	N	Ind.
	Vallisneria natans (Lour.) H. Hara	Aq	N	Ind.
Lamiaceae	*Anisomeles indica* (L.) Kuntze	H	N	Ind.
	Colebrookea oppositifolia Sm.	S	N	Ind.
	Leonurus sibiricus L.	H	N	Ind.
	Leucas aspera (Willd.) Link	H	N	Ind.
	Micromeria biflora (Buch.-Ham. ex D. Don) Benth.	H	N	Ind.
	Ocimum sp.	H	--	---
	Ocimum americanum L.	H	E	Trop. America
	Thymus linearis Benth.	H	N	Ind.
	Vitex negundo L.	T	N	Ind.
Liliaceae	*Notholirion thomsonianum* (Royle) Stapf	H	N	Ind.
Linaceae	*Reinwardtia indica* Dumort.	H	N	Ind.
Linderniaceae	*Lindernia antipoda* (L.) Alston	Aq	N	Ind.
Lythraceae	*Lagerstroemia* sp.	T	N	Ind.
	Woodfordia fruticosa (L.) Kurz	S	N	Ind.
Malvaceae	*Abelmoschus moschatus* Medik.	H	N	Ind.
	Abutilon indicum (L.) Sweet	S	N	Ind.
	Malva verticillata L.	H	N	Ind.
	Sida acuta Burm.f.	S	E	Trop. America
	Sida sp.	H	--	---
	Sida cordifolia L.	H	--	---
	Sida ovata Forssk.	H	--	---
	Sida rhombifolia L.	H	--	---
	Urena lobata L.	H	E	Trop. Africa

Family	Species name	Habit	Status	Nativity
Marsileaceae	*Marsilia quadrifolia* L.	Aq	E	Europe
Martyniaceae	*Martynia annua* L.	H	E	Trop. America
Meliaceae	*Azadirachta indica* A. Juss.	T	N	Ind.
	Melia azedarach L.	T	N	Ind.
Menyanthaceae	*Nymphoides cristata* (Roxb.) Kuntze	Aq	N	Ind.
Mimosaceae	*Acacia* sp.	S	--	—-
	Acacia auriculiformis A. Cunn. ex Benth.	T	E	—-
	Acacia catechu (L. f.) Willd.	T	N	Ind.
	Acacia nilotica (L.) Willd. ex Delile	T	N	Ind.
	Albizia lebbeck (L.) Benth.	T	N	Ind.
	Albizia procera (Roxb.) Benth.	T	N	Ind.
	Leucaena leucocephala (Lam.) de Wit	T	E	Trop. America
	Mimosa himalayana Gamble	S	N	Ind.
	Mimosa pudica L.	H	E	Brazil
Moraceae	*Ficus benghalensis* L.	T	N	Ind.
	Ficus exasperata Vahl	T	N	Ind.
	Ficus religiosa L.	T	N	Ind.
	Morus alba L.	T	N	Ind.
Moringaceae	*Moringa oleifera* Lam.	T	N	Ind.
Musaceae	*Musa paradisiaca* L.	T	N	Ind.
Myrsinaceae	*Anagallis arvensis* subsp. foemina (Mill.) Schinz & Thell.	H	E	Europe
Myrtaceae	*Eucalyptus globulus* Labill.	T	E	Australia
	Eucalyptus tereticornis Sm.	T	E	Australia
	Psidium guajava L.	T	N	Ind.
	Syzygium cumini (L.) Skeels	T	N	Ind.
Nelumbonaceae	*Nelumbo nucifera* Gaertn.	Aq	N	Ind.
Nyctaginaceae	*Boerhavia diffusa* L.	H	N	Ind.
Nymphaeaceae	*Nymphaea nouchali* Burm. f.	Aq	N	Ind.
	Nymphaea pubescens Willd.	Aq	N	Ind.
	Nymphaea rubra Roxb. ex Salisb.	Aq	N	Ind.
Oxalidaceae	*Oxalis corniculata* L.	H	E	Europe
Papaveraceae	*Argemone mexicana* L.	H	E	Trop. C. & S. America
Pedaliaceae	*Sesamum indicum* L.	H	N	Ind.
Phyllanthaceae	*Phyllanthus emblica* L.	T	N	Ind.
Pinaceae	*Cedrus deodara* (Roxb. ex D. Don) G. Don	T	N	Ind.
	Pinus wallichiana A.B. Jacks.	T	N	Ind.
Plantaginaceae	*Plantago major* L.	H	N	Ind.
	Scoparia dulcis L	H	E	Trop. America
	Veronica anagallis-aqatica L.	Aq	N	Ind.
Poaceae	*Bambusa* sp.	H	--	—-
	Chrysopogon zizanioides (L.) Roberty	G	N	Ind.
	Coix lacryma-jobi L.	G	N	Ind.
	Cynodon dactylon (L.) Pers.	G	N	Ind.
	Eleusine indica (L.) Gaertn.	G	N	Ind.
	Neyraudia arundinacea (L.) Henrard	G	N	Ind.
	Oplismenus burmannii (Retz.) P. Beauv.	G	E	Tropical Africa
	Phragmites karka (Retz.) Trin. ex Steud.	R	E	--
	Polypogon monspeliensis (L.) Desf.	G	N	Ind.
	Saccharum sp. 1	G	--	—-
	Saccharum sp. 2	G	--	—-
	Saccharum munja Roxb.	G	N	Ind.
	Saccharum ravennae (L.) L.	G	N	Ind.
	Saccharum spontaneum L.	G	E	Trop. West Asia
	Setaria sp.	G	--	—-
	Thysanolaena maxima (Roxb.) Kuntze	G	N	Ind.

Family	Species name	Habit	Status	Nativity
Polygonaceae	*Polygonum barbatum* L.	Aq	N	Ind.
	Polygonum hydropiper L.	Aq	N	Ind.
	Polygonum lapathifolium L.	Aq	N	Ind.
	Polygonum plebeium R. Br.	Aq	N	Ind.
	Polygonum sp.1	Aq	--	–
	Polygonum sp.2	Aq	--	–
	Polygonum sp.3	Aq	--	–
	Polygonum sp.4	Aq	--	–
	Polygonum sp.5	Aq	--	–
	Rumex sp.	H	--	–--
	Rumex hastatus D. Don	S	N	Ind.
	Rumex nepalensis Spreng.	H	N	Ind.
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	Aq	E	Trop. America
	Monochoria hastata (L.) Solms	Aq	N	Ind.
Potamogetonaceae	*Potamogeton crispus* L.	Aq	E	Trop. America
	Potamogeton octandrus Poir.	Aq	N	Ind.
	Potamogeton nodosus Poir.	Aq	E	Trop. America
	Stuckenia pectinata (L.) Börner	Aq	E	Trop. America
Ranunculaceae	*Ranunculus sceleratus* L.	H	N	Ind.
	Thalictrum foliolosum DC.	H	N	Ind.
Rhamnaceae	*Ziziphus nummularia* (Burm. f.) Wight & Arn.	S	N	Ind.
	Ziziphus mauritiana Lam.	T	N	Ind.
Rosaceae	*Prunus bokhariensis* Royle ex C.K.Schneid.	T	N	Ind.
	Rosa canina L.	T	N	Ind.
Rubiaceae	*Anthocephalus cadamba* (Roxb.) Miq.	T	N	Ind.
	Dentella repens (L.) J.R. Forst. & G. Forst.	H	E	–
	Galium aparine L.	C	N	Ind.
	Haldina cordifolia (Roxb.) Ridsdale	T	N	Ind.
	Oldenlandia corymbosa L.	H	N	Ind.
Rutaceae	*Aegle marmelos* (L.) Corrêa	T	N	Ind.
	Citrus maxima (Burm.) Merr.	T	N	Ind.
	Murraya koenigii (L.) Spreng.	T	N	Ind.
Sagitariaceae	*Sagittaria sagittifolia* L.	H	N	Ind.
Santalaceae	*Osyris quadripartita* Salzm. ex Decne.	S	N	Ind.
	Santalum album L.	T	N	Ind.
Sapindaceae	*Cardiospermum halicacabum* Linn.	C	N	Ind.
	Litchi chinensis Sonn.	T	E	S. China
Sapotaceae	*Madhuca longifolia* var. longifolia	T	N	Ind.
Scrophulariaceae	*Bacopa monnieri* (L.) Wettst.	Aq	N	Ind.
	Nanorrhinum ramosissimum (Wall.) Betsche	H	N	Ind.
	Scrophularia sp.	H	--	–--
	Scrophularia sp. 1	H	--	–--
	Scrophularia sp. 2	H	--	–--
	Verbascum chinense (L.) Santapau	H	N	Ind.
	Verbascum thapsus L.	H	N	Ind.
Solanaceae	*Datura* sp.	S	--	Ind.
	Datura stramonium L.	H	N	Ind.
	Datura wrightii Regel	H	E	–--
	Lycopersicon esculentum Mill.	H	N	Ind.
	Nicotiana plumbaginifolia Willd.	H	E	Trop. America
	Nicotiana sp.	H	--	–--
	Physalis minima L.	H	E	Trop. America
	Solanum nigrum L.	H	E	Trop. America
	Solanum sisymbriifolium Lam.	H	E	–--
	Solanum surattense Burm. f	H	N	Ind.
	Solanum viarum Dunal	H	E	Trop. America

Family	Species name	Habit	Status	Nativity
Sterculiaceae	*Sterculia foetida* L.	T	E	—-
Tamaricaceae	*Tamarix indica* Willd.	H	N	Ind.
Tiliaceae	*Corchorus olitorius* L.	H	N	Ind.
Typhaceae	*Typha angustata* Bory. & Choub.	R	E	Trop. America
Ulmaceae	*Holoptelea integrifolia* Planch.lia	T	N	Ind.
Urticaceae	*Debregeasia hypoleuca* (Steud.) Wedd.	S	N	Ind.
	Urtica ardens Link	H	N	Ind.
Verbenaceae	*Clerodendrum japonicum* (Thunb.) Sweet	S	--	--
	Clerodendrum phlomidis var. *rubrum* Roxb. ex Voigt	S	N	Ind.
	Lantana camara L.	S	E	Trop. America
	Lippia alba (Mill.) N.E. Br. ex Britton & P. Wilson	H	E	Trop. America
	Phyla nodiflora (L.) Greene	H	N	Ind.
	Tectona grandis L. f.	T	N	Ind.
Violaceae	*Viola canescens* Wall.	H	N	Ind.
Zygophyllaceae	*Tribulus terrestris* L	C	E	Trop. America
	UID 1	Aq	--	—-

PLATE I



Habitat: Riparian forest

a. *Cedrus deodara*
b. *Falconeria insignis*
c. *Jatropha curcas*
d. *Trewia nudiflora*
e. *Dalbergia sissoo*
f. *Acacia catechu*
g. *Acacia auriculiformis*
h. *Sterculia foetida*
i. *Aegle marmelos*
j. *Vitex negundo*
k. *Moringa oleifera*

PLATE II

a

b

c

d

e

f

g

h

Habitat - Riparian bank

a. Riparian bank - Lower stretch
b. *Woodfordia fruiticosa*
c. *Arbus precatorius*
d. *Colebrookea oppositifolia*
e. *Datura strammonium*
f *Argemone mexicana*
g. *Callicarpa macrophylla*
h. *Holoptelea intergrifolia*

PLATE III

a. Habitat - Marshy wetland
b. *Nelumbo nucifera*
c. *Monochoria hastata*
d. *Vallisenaria natans*
e. *Nymphaea pubescens*
f. *Potamogeton crispus*
g. *Eichhornia crassipes*
h. *Potamogeton nodosus*
i. *Hydrilla verticillata*
j. *Pistia stratiotes*

PLATE IV

a

b

c

d

e

f

g

h

a. Habitat - Tall grassland
b. *Eriocaulon* sp.
c. *Schoenoplectus mucronatus*
d. *Phragmites karka*
e. *Celosia argentea*
f. *Typha angustata*
g. *Chrysopogon zizanoides*
h. *Arundo donax*

PLATE V

a

b

e

h

c

d

f

g

i

j

a. Habitat - Climber
inset - *Coccinia grandis*
b. *Operculina turpethum*
c. *Ipomoea eriocarpa*
d. *Ipomoea purpurea*
e. *Ipomoea aquatica*
f. *Cardiospermum halicacabum*
g. *Merremia aegyptica*
h. *Caesalpinia bonduc*
i. *Lagenaria siceraria*
j. *Trichosanthes cucumerina*

PLATE VI

a

b

c

d

e

f

g

Anthropogenic disturbances

a. *Religious activities*
b. *Concrete ghats*
c. *Grazing by animals*
d. *Agricultural fields*
e. *Man-made embankments*
f. *Sand mining*
g. *Fishing boats*

STATUS OF DRAGONFLY AND DAMSELFLY DIVERSITY ALONG THE GANGA RIVER

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ABSTRACT

Freshwater ecosystems constitute highly vulnerable habitats of the world as they harbour about 6% of all described species, and face widespread threats such as habitat degradation, exotic species introduction, water pollution and flow regulation. More then 6000 species of odonates (damselflies and dragonflies) are described from the freshwater habitats which are frequently used as bioindicators for aquatic environmental health and conservation management. Therefore, present study was designed to understand diversity and distribution pattern of odonates and their relationship with water quality parameters in the Ganga River. For this study, the entire stretch of the Ganga River was partitioned into 6 habitat zones, based on geological, topological and ecological distinctness. Within these habitat zones, a total 32

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sampling sites, each characterized by 5 km long stretch, were selected for the study. A total of 37 species of odonates belonging to 26 genera and 6 families were found, where 24 species were dragonflies (Anisoptera) and 13 were damselflies (Zygoptera). Maximum numbers of species were observed from the dragonfly family Libellulidae (21 species under 15 genera) followed by damselfly family Coenagrionidae (10 species under 5 genera). The habitat zone 2 (Haridwar to Narora, which includes the 'Upper Ganga River' Ramsar site area) was found to be foremost in terms of species richness (27 species). The species richness and Shannon diversity index showed significant ($p<0.05$) linear relationship with pH, total dissolved solids (TDS), specific conductivity and salinity. The results of the study suggest a rich diversity of odonates and their competence as the bioindicator of different physiochemical parameters of water which in turn provide baseline information for planning aquatic species restoration in the Ganga River.

Keywords: Odonata, Species Richness, Diversity Index, Water Quality, the Ganga River

4.1 INTRODUCTION

Freshwaters are highly diverse habitats and include ponds, lakes, springs, streams, rivers, wetlands, reservoirs, and ditches (Dijkstra et al., 2014). Though fresh water makes up only 0.01% of the World's water but this small fraction supports nearly 6% of all described species (Dudgeon et al., 2006). But freshwater systems are directly threatened by anthropogenic activities and stand to be further affected by global climate changes (Vörösmarty et al., 2010).

High habitat heterogeneity and biodiversity are the characters of large rivers and their floodplains (Chovanec et al., 2004). One of the most effective means of evaluating the effects of anthropogenic disturbances in riverine ecosystems is the use of bioindicators. Damselflies and dragonflies (Insecta: Odonata) are among the most efficient bioindicators (Kutcher and Bried, 2014; Miguel et al., 2017) and are being used as an indicators for different habitat properties such as water quality (Kutcher and Bried, 2014), pollution by heavy metals (Lesch and Bouwman, 2018; Nasirian and Irvine, 2017; Villanueva, 2010; Girgin et al., 2010), changes in the habitat structure (Yang et al., 2017), habitat alteration via urbanization (Prescott and Eason,

2018.), grazing effects on wetlands (Lee Foote and Hornung, 2005.), wetland restoration (D'amico et al., 2004), ecological condition of streams (de Oliveira Junior et al, 2015), environmental quality (Júnior et al., 2015) and climate change (Dingemanse and Kalkman, 2008).

Globally 6256 species in 686 genera of odonates are known (Subramanian and Babu, 2017) and majority of them are restricted to the tropical regions, especially to forest ecosystems, where the diversity of the group is maximum (Kalkman et al., 2008). Odonates of India are represented by 488 species and 27 subspecies in 154 genera and 18 families (Subramanian and Babu, 2017). The suborder Zygoptera (Damselflies) comprises of 211 species under 59 genera and 9 families; Anisozygoptera one species under one genera and one family; Anisoptera (Dragonflies) 276 species under 94 genera and 8 families (Subramanian and Babu, 2017).

Primarily the loss of natural habitat causes extinction threats to 10% of dragonfly species of the world (Tippler et al., 2018). The ruination of forests in tropical areas is the greatest threat to the global odonate diversity, which results in the extinction of several species (Kalkman et al., 2008). Among Indian species 2 are Endangered (EN), 8 are Vulnerable (VU) and 15 are Near Threatened (NT) (Subramanian and Babu, 2017).

In the context of faunal diversity studies of the Ganga River, the invertebrates, in general, draw very little attention due to the presence of other glorified vertebrates such as birds and mammals. There were some studies which have documented the invertebrate faunal diversity of the Ganga River, such as diversity of benthic macro-invertebrates (Khan et al., 1999; Khanna et al., 2001; Khanna and Bhutiani, 2005; Nath and Banerjee, 2009; Gaur et al., 2010; Nesemann et al., 2011), Annelida (Nesemann et al., 2004; Nesemann and Sharma, 2011, Indian Institutes of Technology, 2012) and Mollusca (Rao, 2001; Sinha and Sharma, 2001; Sinha et al., 2003, Nesemann et al., 2003; Nesemann et al., 2005, Indian Institutes of Technology, 2012). Rao (2001) reported 8 species of Coleoptera, 4 species of Diptera, 5 species of Ephemeroptera, 14 species of Hemiptera, 3 species of Plecoptera and 6 species of Trichoptera from the Ganga River between Rishikesh and Kanpur. Indian Institutes of Technology (2012) reported the presence of 12 species of Coleoptera, 5 species of Diptera, 3 species of Ephemeroptera, 15 species of Hemiptera and 4 species of Trichoptera in the Ganga River between Varanasi and Farakka.

Habitat at Mokama, Bihar

Bilgrami (1991) reported presence of 5 species of Odonata [*Paragomphus lineatus* Selys, 1850 (as *Mesogomphus lineatus* Selys); *Potamarcha congener* Rambur, 1842 (as *Potamarcha obscura* Rambur); *Cordulegaster* Leach, 1815; *Ischnura rubilio* Selys, 1876 (as *Ischnura delicata* Hagen) and *Ischnura senegalensis* Rambur, 1842] from the Ganga River between Munger and Farakka. Rao (2001) reported presence of 5 species of Odonata [*Cordulegaster* Leach, 1815; *Paragomphus* Cowley, 1934 (as *Mesogemphus* sp.); *Ischnura* Charpentier, 1840; *Potamarcha congener* Rambur, 1842 (as *Potomarcha obsura*) and *Lestes* Leach, 1815] in the Ganga River between Rishikesh and Kanpur. Indian Institutes of Technology (2012) reported presence of 7 species of Odonata [*Asiagomphus* Asahina, 1984; *Cordulegaster* Leach, 1815; *Ischnura rubilio* Selys, 1876 (as *Ischnura delicate*); *Ischnura senegalensis* Rambur, 1842; *Macrogomphus* Selys, 1857; *Paragomphus lineatus* Selys, 1850 and *Potamarcha congener* Rambur, 1842 (as *Potomarcha obscura*)] in the Ganga River between Varanasi and Farakka.

4.2 OBJECTIVES

The study was conducted with the following objectives -

1. To make an inventory of Odonates of the Ganga River.
2. To find out the habitat zones of the Ganga River with high and low Odonata diversity.
3. To find out the relationship between Odonata species richness and water quality parameters of the Ganga River .

Data collection

The data for the abundance of odonates and physiochemical parameters of water were collected from October, 2017 to March, 2018. Each site was visited once during this period. Odonata data collection methodology proposed by Buchsbaum et al. (2016) was followed. In this method, at each site, a 5 km long stretch was chosen and in each 5 km stretch, 6 sampling points having a distance of 1 km were selected for point count. The observer stood at an observation point for 10 min and recorded all the odonates that passed within ~ 5 m of the sampling point. Only one bank (either left or right, depending on the convenience and accessibility) of the main channel of the Ganga River was chosen for data collection. Only adult odonates were counted during data collection. Physiochemical parameters of water [temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), specific conductivity (SPC), nitrate (NO_3^-), ammonium (NH_4^+) and salinity] were measured by ProDSS and Professional Plus (digital sampling system) by Yellow Springs Instruments, Yellow Springs, OH 45387, USA.

Data analysis

The site-wise and zone-wise species richness, Shannon diversity index, and Fisher's alpha diversity were calculated for diversity comparisons. The alpha diversity was also estimated by opting Chao1 and Jackknife2 estimator. Pearson's correlation coefficient (r) and linear regression models were used to test the relationship between the site-wise diversity and physicochemical parameters of water. All analysis was conducted on R statistical programming (version 3.4.1; R Core Team, 2018) software platform using package '*vegan*' (Oksanen et al., 2018).

Estimation of diversity

For estimating diversity, the Fisher's alpha diversity (Fisher et al., 1943), rarefied species number (Hurlbert, 1971), the Chao1 estimator (Chao, 1984; Colwell and Coddington, 1994) and Jacknife2 estimator (Smith and van Belle, 1984) was calculated for 6 habitat zones because it was found that Fisher's alpha is efficient to discriminate between the sites, and the frequencies of species of medium abundance mainly influence it (Kempton and Taylor, 1974; Brehm et al., 2003). If species assemblages are sampled with different intensity or success, then rarefied species number is useful (Hurlbert, 1971; Gotelli and Colwell 2001). Based on the number of rare species i.e., singletons and doubletons in a sample, the absolute number of species in an assemblage can be estimated by Chao1 estimator and it is suggested for inventory completeness values where completeness is the ratio between observed species richness and estimated species richness (Sorensen et al., 2002; Scharff et al., 2003; Buddle et al., 2005). In comparison with other estimators, the Jackknife2 estimator is found to work better in extrapolation of species richness, with greater legibility, low bias and low dependence on sample size (Palmer, 1990; 1991; Baltanás, 1992; Brose et al., 2003; Petersen et al., 2003; Chiarucci et al., 2003).

The mean species richness and mean Shannon diversity index were calculated for 6 habitat zones.

Estimation of relationship with water quality parameters

Pearson's correlation coefficient (r) was calculated between physiochemical parameters of water [temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), specific conductivity (SPC), nitrate (NO_3^-), ammonium (NH_4^+) and salinity] and species richness as well as Shannon diversity Index for 20 sampling sites (site 5 to site 25, except site 13, habitat zone 2 to habitat zone 5) located in middle and upper-lower stretch of Ganga River because of similarity of river characteristics in these sites.

Simple linear regression model using species richness and Shannon diversity as dependent variable and physiochemical parameters of water [temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), specific conductivity (SPC), nitrate (NO_3^-), ammonium (NH_4^+) and salinity] as explanatory variables was calculated for 20 sampling sites (site 5 to site 25, except site 13, habitat zone 2 to habitat zone 5) located in middle and upper-lower stretch of the Ganga River because of similarity of river characteristics in these sites.

Field activity at Shamshabad village, Uttar Pradesh

Estimation of diversity

1. A total of 37 species of odonates under 26 genera and 6 families were found, among them, the dragonflies (Anisoptera) were represented by 24 species, 18 genera and 3 families and the damselflies (Zygoptera) were represented by 13 species, 8 genera and 3 families (Table 4.1, Figure 4.1, Figure 4.2).
2. Total 13 species (under 11 genera) from habitat zone 1, 27 species (under 20 genera) from habitat zone 2, 18 species (under 14 genera) from habitat zone 3, 17 species (under 12 genera) from habitat zone 4, 23 species (under 17 genera) from habitat zone 5 and 22 species (under 16 genera) from habitat zone 6 were recorded (Table 4.2, Figure 4.3).
3. Fisher's alpha diversity was maximum in habitat zone 2 (6.65), followed by habitat zone 6 (4.93) and habitat zone 5 (4.80). Chao1 species richness estimator was maximum in habitat zone 2 (27) followed by habitat zone 6 (23.5) and habitat zone 5(23). Jackknife 2 species richness estimator was maximum in habitat zone 2 (27) and habitat zone 6 (27) followed by habitat zone 5 (25) (Table 4.2, Figure 4.4).
4. The mean species richness in habitat zone 1 was 4.25 (SD ± 3.1, sampling sites = 4), habitat zone 2 was 19.67 (SD ± 5.13, sampling sites = 3), habitat zone 3 was 9.00 (SD ± 1.83, sampling sites = 4), habitat zone 4 was 8.80 (SD ± 1.79, sampling sites = 5), habitat zone 5 was 10.63 (SD ± 3.85, sampling sites = 8) and habitat zone 6 9.29 (SD ± 5.19, sampling sites = 7) (Table 4.2, Figure 4.5).
5. The mean Shannon diversity index in habitat zone 1 was 1.18 (SD ± 0.81), in habitat zone 2 was 2.76 (SD ± 0.30), in habitat zone 3 was 1.86 (SD ± 0.27), in habitat zone 4 was 1.92 (SD ± 0.20), in habitat zone 5 was 2.11 (SD ± 0.38) and in habitat zone 6 was 1.85 (SD ± 0.59) (Table 4.2, Figure 4.6).

Estimation of relationship with water quality parameters

1. It was found that both species richness and Shannon diversity index had significant ($p<0.05$) Pearson's correlation with pH, TDS, specific conductivity and salinity of water (Table 4.3).
2. It was found that the species richness had significant ($p<0.05$) linear relationship with pH [$p = 0.003$; explained 39% variability ($R^2 = 0.39$) of the species richness], TDS [$p = 0.02$; explained 28% variability ($R^2 = 0.28$) of the species richness], specific conductivity [$p = 0.02$; explained 27% variability ($R^2 = 0.27$) of the species richness] and salinity [$p = 0.01$; explained 29% variability ($R^2 = 0.29$) of the species richness] for 20 sampling sites (site 5 to site 25, except site 13, habitat zone 2 to habitat zone 5) (Table 4.4, Figure 4.7).
3. It was found that the Shannon diversity index had significant ($p<0.05$) linear relationship with pH [$p = 0.01$; explained 30% variability ($R^2 = 0.39$) of the species richness], TDS [$p = 0.04$; explained 21% variability ($R^2 = 0.21$) of the species richness], specific conductivity [$p = 0.05$; explained 20% variability ($R^2 = 0.20$) of the species richness] and salinity [$p = 0.03$; explained 23% variability ($R^2 = 0.23$) of the species richness] for 20 sampling sites (site 5 to site 25, except site 13, habitat zone 2 to habitat zone 5) (Table 4.4, Figure 4.8).

Species with potential threats and conservation requirements (As per IUCN):

Though all the 37 species of odonates found in the Ganga River come under IUCN Least Concern category, yet IUCN advises to take attention for 16 species which need conservation awareness. These species are -

1. *Platygomphus dolabratus* Selys, 1854: Deforestation caused by agricultural and forestry activities, and developmental activities (such as hydropower development), are threats to this species. More information on this species about distribution, habitat requirements and tolerance to disturbance is required.
2. *Brachydiplax farinosa* Krüger, 1902: The loss of habitat (especially loss of lowland swamp forests) is a threat to this species. Protection of suitable lowland habitat and more information about habitat requirements of this species is required.
3. *Brachydiplax sobrina* Rambur, 1842: Habitat loss due to urbanization is a threat to this species. More information on distribution of this species is required. Beside, monitoring is

Habitat at Bahagalpur, West Bengal

required to understand how this species subsists with growing urbanization.

4. *Diplacodes trivialis* Rambur, 1842: The loss of wetlands because of agriculture and developmental activities is a threat to this species.
5. *Indothemis carnatica* Fabricius, 1798: Habitat loss due to developmental activities is the threat to this species. More information on distribution and population sizes and protection of this species is required.
6. *Neurothemis tullia* Drury, 1773: At present, there are no significant threats to this species, but monitoring of population is needed.
7. *Orthetrum pruinosu*m Burmeister, 1839: At local level, individual populations are likely to be threatened by developmental activities and further information on distribution is needed.
8. *Orthetrum sabina* Drury, 1770: At present, this species is not under any threat, but a study about the genetic variability or homogeneity is required.
9. *Rhodothemis rufa* Rambur, 1842: At present, this species is not under any threat, but some habitat areas may come under threat from urbanization, so monitoring of populations to check for any decline is required.
10. *Tramea basilaris* Palisot de Beauvois, 1805: This species does not need any protective actions at the global scale, but at the local level, drainage and habitat destruction by agricultural activities and water pollution are threats to this species.
11. *Trithemis festiva* Rambur, 1842: At present, there are no significant threats to this species, but monitoring of populations to check for any decline is required.
12. *Aristocypha quadrimaculata* Selys, 1853: Though this species is not under any threat but, larval habitats might be affected by agricultural runoff, sedimentation and hydroelectric dams. More information on distribution and disturbance tolerance is required.
13. *Agriocnemis lacteola* Selys, 1877: Habitat loss is the threat to this species. More information on distribution and population sizes is required.
14. *Ischnura nursei* Morton, 1907: There are no threats to this species, but, more information on population, ecology and potential threats is required.
15. *Pseudagrion decorum* Rambur, 1842: There are no threats to this species, but more information on range and population, and potential threats is required.
16. *Calicnemia eximia* Selys, 1863: Deforestation caused by agricultural and forestry activities and developmental activities (such as hydropower development) are threats to this species. More information on population size, trends and threats is required.

4.5 DISCUSSION

Biological diversity of inland and freshwater make a worthy natural resource, and in the interest of all human beings, its conservation management is critical (Dudgeon et al., 2006) and the Ganga River is not an exception. Riverine systems comprise of varieties of patches and habitats which are linked by diverse processes to support highly complex biological communities and invertebrate animals, which show a high biological diversity in these systems and are very important components of these systems as several landscape ecological processes are influenced by their patterns of distribution, movements and effects on ecological flows (Malmqvist, 2002).

For nature management and conservation, the dragonflies are known to be very convenient. Presently increased efforts are being made to gather more information on dragonflies available for both scientific community and policymakers (Kalkman et al., 2008). So it is indispensable to document the status of the diversity of odonates from the entire Ganga River. But, past studies to document odonates from the Ganga were fragmented as those were done between Munger and Farakka (by Bilgrami, 1991), between Rishikesh and Kanpur (by Rao, 2001) and between Varanasi and Farakka (by Indian Institutes of Technology, 2012). Moreover, these studies are not enough to understand the diversity profile of odonates of the entire Ganga River.

The present study reported presence of 37 species of odonates under 26 genera in the Ganga River which is significantly higher than the past studies.

Both species richness and Shannon diversity index were found to be high in the habitat zone 2 where the Upper Ganga River Ramsar site (Brijghat to Narora Stretch) and Hastinapur wildlife sanctuary are located, which indicates better aquatic habitat present in those areas. The species richness and Shannon diversity index were found to be low in the habitat zone 3 and habitat zone 5 where cities like Kannauj, Kanpur, Fatehpur, Allahabad, Mirzapur and Varanasi are present. This low species richness and Shannon diversity index indicate degradation of aquatic habitat in those zones.

So far, no studies have been done to relate Odonata species richness and physiochemical parameters of water in the Ganga River. In the present study, it was found that both the species richness and Shannon diversity index of odonates have significant correlation with pH, TDS, specific conductivity and salinity, which also fits significant linear model. It signifies that odonates have the potential to be used as indicator taxa for different physiochemical parameters of water of the Ganga River .

Perhaps the protection of the biological diversity of freshwater ecosystems is the ultimate conservation challenge because it is influenced by several factors such as upstream drainage networks, surrounding lands, riparian zones and for the migratory aquatic animals the downstream reaches (Dudgeon et al., 2006). The present study suggests a rich diversity of odonates in different habitat zones of the Ganga River which in turn provide baseline conditions for planning aquatic species restoration.

Sampling site at Kachla, Uttar Pradesh

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Order: Odonata Fabricius, 1793

Suborder: Anisoptera Selys, 1854

Superfamily: Aeshnoidea Leach, 1815

Family: Aeshnidae Leach, 1815

Anax guttatus Burmeister, 1839 - Blue-Tailed Green Darner

Superfamily: Gomphoidea Rambur, 1842

Family: Gomphidae Rambur, 1842

Platygomphus dolabratus Selys, 1854

Ictinogomphus rapax Rambur, 1842 - Indian Common Clubtail

Superfamily: Libelluloidea Leach, 1815

Family: Libellulidae Leach, 1815

Acisoma panorpoides Rambur, 1842 - Trumpet-Tail

Brachydiplax farinosa Krüger, 1902 - Black-Tailed Dasher

Brachydiplax sobrina Rambur, 1842 - Little Blue Marsh Hawk

Brachythemis 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

Neurothemis fulvia Drury, 1773 - Fulvous Forest Skimmer

Neurothemis tullia (Drury, 1773) - Pied Paddy Skimmer

Orthetrum luzonicum Brauer, 1868 - Tri-coloured Marsh Hawk

Orthetrum pruinosum Burmeister, 1839 - Crimson-tailed Marsh Hawk

Orthetrum sabina Drury, 1770 - Green Marsh Hawk

Orthetrum triangulare Selys, 1878 - Blue-Tailed Forest Hawk

Pantala flavescens Fabricius, 1798 - Wandering Glider

Rhodothemis rufa Rambur, 1842 - Rufous Marsh Glider

Rhyothemis variegata Linnaeus, 1763 - Common Picturewing

Tholymis tillarga Fabricius, 1798 - Coral-Tailed Cloudwing

Tramea basilaris Palisot de Beauvois, 1805 - Red Marsh Trotter

Trithemis aurora Burmeister, 1839 - Crimson Marsh Glider

Trithemis festiva Rambur, 1842 - Black Stream Glider

Urothemis signata Rambur, 1842 - Greater Crimson Glider

Suborder: Zygoptera Selys, 1854

Superfamily: Calopterygoidea Selys, 1850

Family: Chlorocyphidae Cowley, 1937

Aristocypha quadrimaculata Selys, 1853

Superfamily: Coenagrionoidea Kirby, 1890

Family: Coenagrionidae Kirby, 1890

Agriocnemis femina Brauer, 1868 - Pruinosed Dartlet

Agriocnemis lacteola Selys, 1877 - Milky Dartlet

Agriocnemis pygmaea Rambur, 1842 - Pygmy Dartlet

Amphiallagma parvum Selys, 1876 - Azure Dartlet

Ceriagrion coromandelianum Fabricius, 1798 - Coromandel Marsh Dart

Ischnura forcipata Morton, 1907 - Forcipate Dartlet

Ischnura nursei Morton, 1907 - Pixie Dartlet

Table 4.1: List of odonates found in the sampling sites of the Ganga river (Systematic position by Dijkstra et al., 2013)

Ischnura rubilio Selys, 1876 - Western Golden Dartlet
Pseudagrion decorum Rambur, 1842 - Three-lined Dart
Pseudagrion rubriceps Selys, 1876 - Saffron-faced Blue Dart
Family: Platycnemididae Yacobson and Bianchi, 1905
Calicnemia eximia Selys, 1863
Copera sp.

	HZ - 1	HZ - 2	HZ - 3	HZ - 4	HZ - 5	HZ - 6
Observed number of species	13	27	18	17	23	22
Fisher's alpha	3.73	6.65	4.83	4.11	4.80	4.93
Rarefied species number	1.90	1.942	1.90	1.86	1.92	1.90
Chao1 estimator	14	27	18.33	17	23	23.5
Jackknife 2 estimator	17	27	20	16	25	27
Mean species richness	4.25±3.1	19.67±5.13	9.0±1.83	8.80±1.79	10.63±3.85	9.29±5.19
Mean Shannon diversity index	1.18±0.81	2.76±0.30	1.86±0.27	1.92±0.20	2.11±0.38	1.85±0.59

Table 4.2: Comparative account of diversity of odonates in six habitat zones

Parameters	**Species richness**		**Shannon diversity index**	
	r	**p**	**r**	**p**
Temperature (°C)	-0.126	0.596	-0.186	0.433
pH	**-0.621**	**0.03**	**-0.548**	**0.012**
DO (mg/L)	0.027	0.909	-0.055	0.819
TDS (mg/L)	**-0.530**	**0.016**	**-0.455**	**0.044**
Specific conductivity (µS/cm)	**-0.521**	**0.018**	**-0.444**	**0.050**
Nitrate (mg/L)	-0.227	0.335	-0.144	0.544
Ammonium (mg/L)	0.065	0.785	0.091	0.701
Salinity (ppt)	**-0.543**	**0.013**	**-0.479**	**0.032**

Table 4.3: Pearson correlation coefficient (r) and its significance (p) between physiochemical parameters of water and species richness and Shannon diversity index for 20 study sites (site 5 to site 25, except site 13) [significant ($p<0.05$) correlations are in boldface]

Parameters	**Species Richness**			**Shannon diversity index**		
	R^2	**F (df = 1,18)**	**p**	**R^2**	**F (df = 1,29)**	**p**
Temperature (°C)	0.02	0.29	0.60	0.03	0.64	0.43
pH	0.39	11.31	0.003	0.30	7.74	0.01
DO (mg/L)	0.0007	0.01	0.91	0.003	0.05	0.82
TDS (mg/L)	0.28	7.02	0.02	0.21	4.71	0.04
Specific Conductivity (µS/cm)	0.27	6.72	0.02	0.20	4.43	0.05
Nitrate (mg/L)	0.05	0.98	0.34	0.02	0.38	0.54
Ammonium (mg/L)	0.004	0.07	0.78	0.008	0.15	0.70
Salinity (ppt)	0.29	7.52	0.01	0.23	5.37	0.03

Table 4.4: Linear regression model using physiochemical parameters of water as explanatory variables and species richness and Shannon diversity index as dependent variable for 20 sampling sites of middle stretch (site 5 to site 25, except site 13) [significant ($p<0.05$) linear models are in boldface]

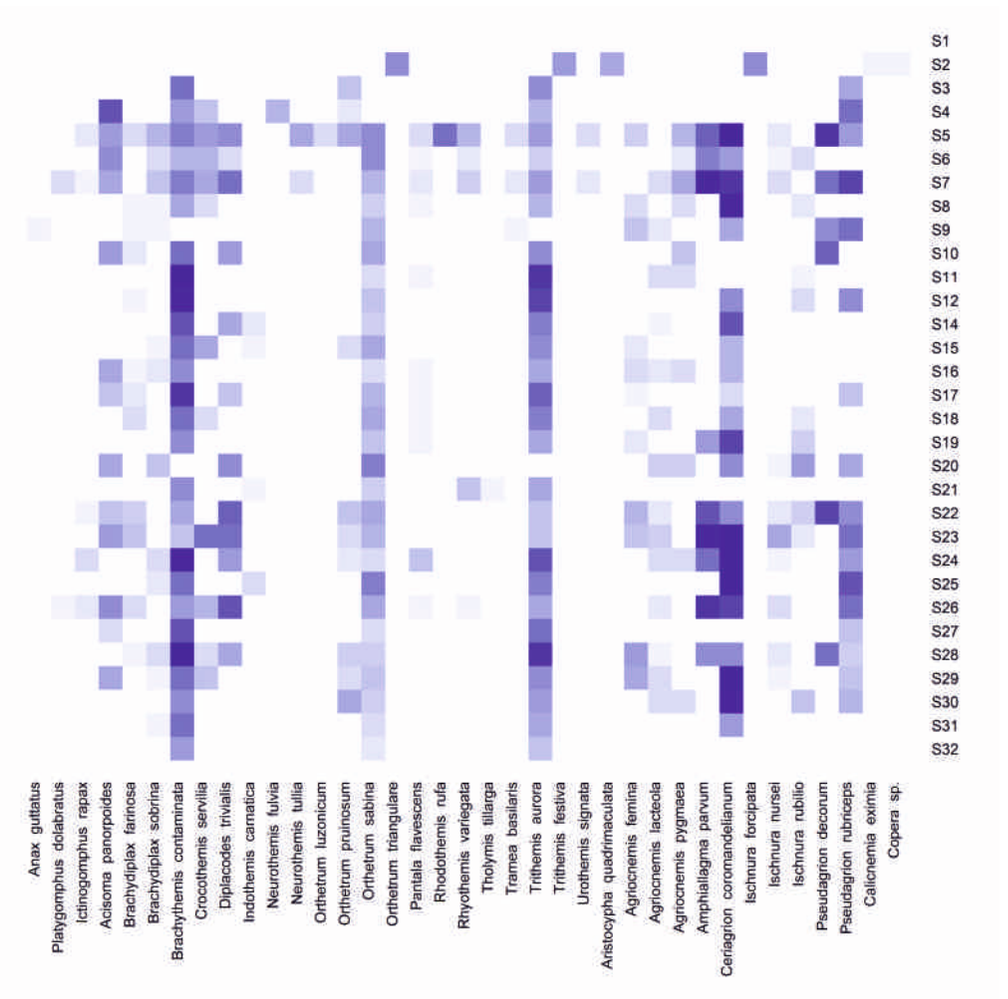

Figure 4.1: Distribution of 37 species of odonates in 31 sampling sites (Darker blue areas indicate high abundance, white areas indicate complete absence)

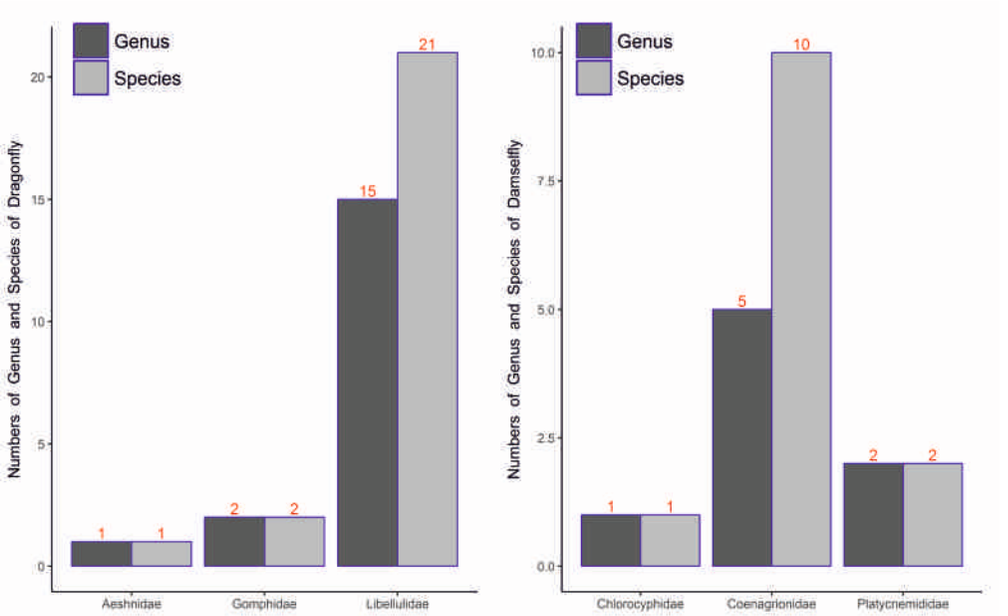

Figure 4.2: Comparative account of numbers of genus and species of different families of dragonflies and damselflies

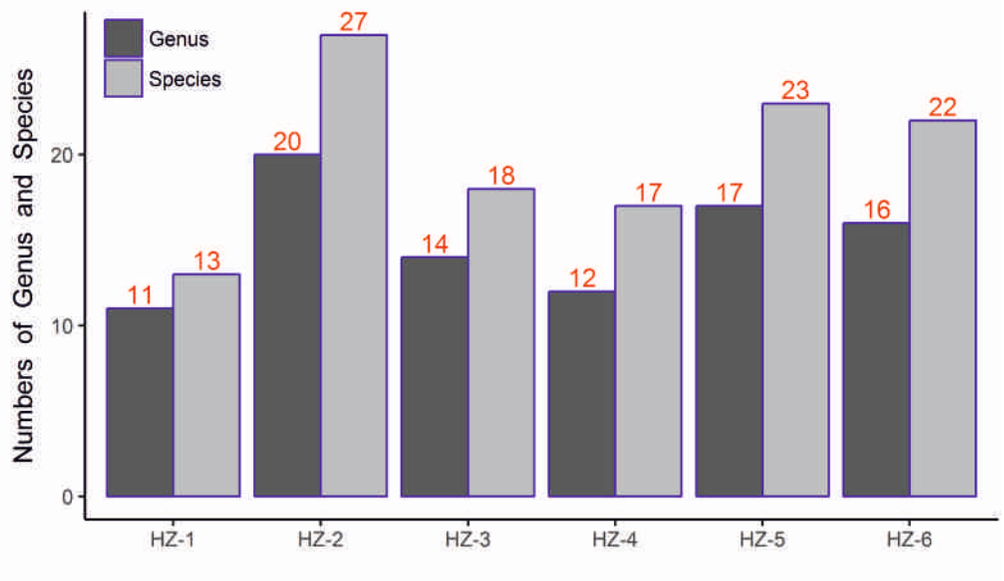

Figure 4.3: Comparative account of numbers of genus and species of odonates in six habitat zones

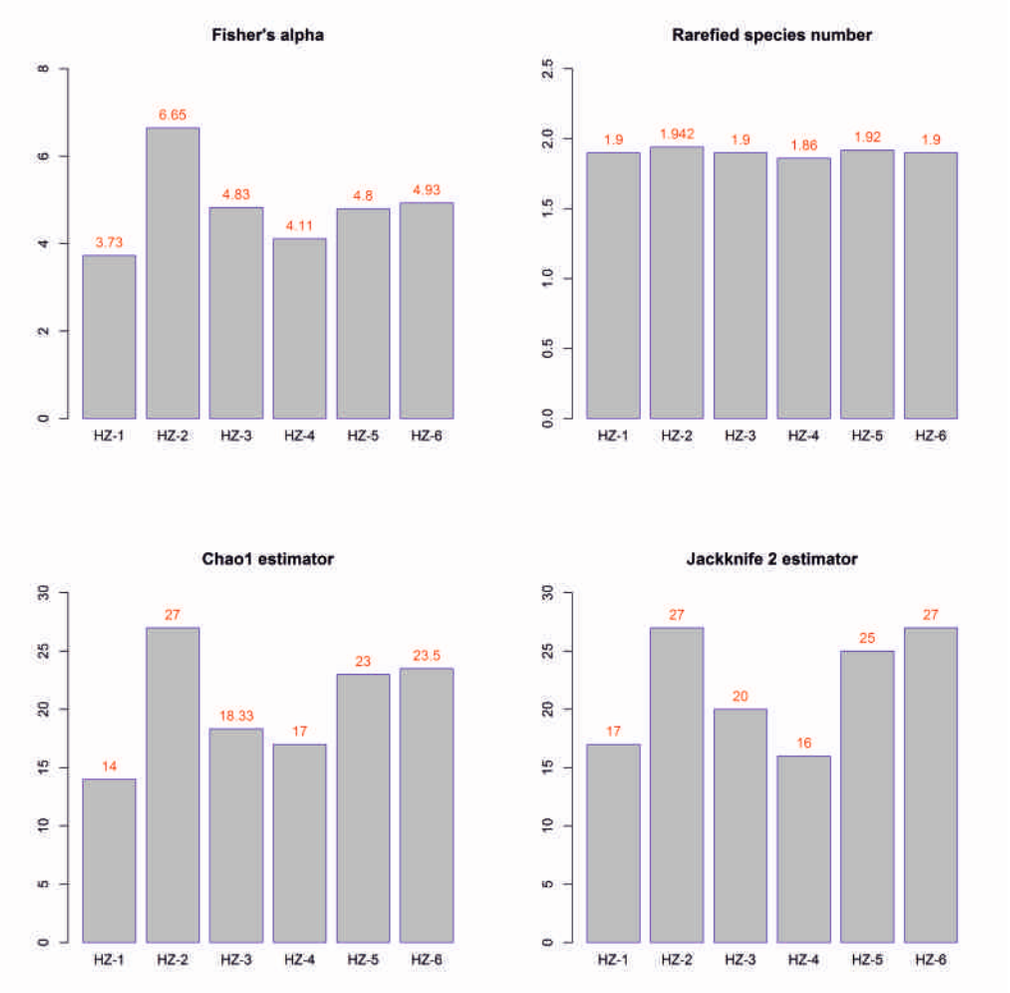

Figure 4.4: Comparative account of alpha diversity parameters of odonates in six habitat zones

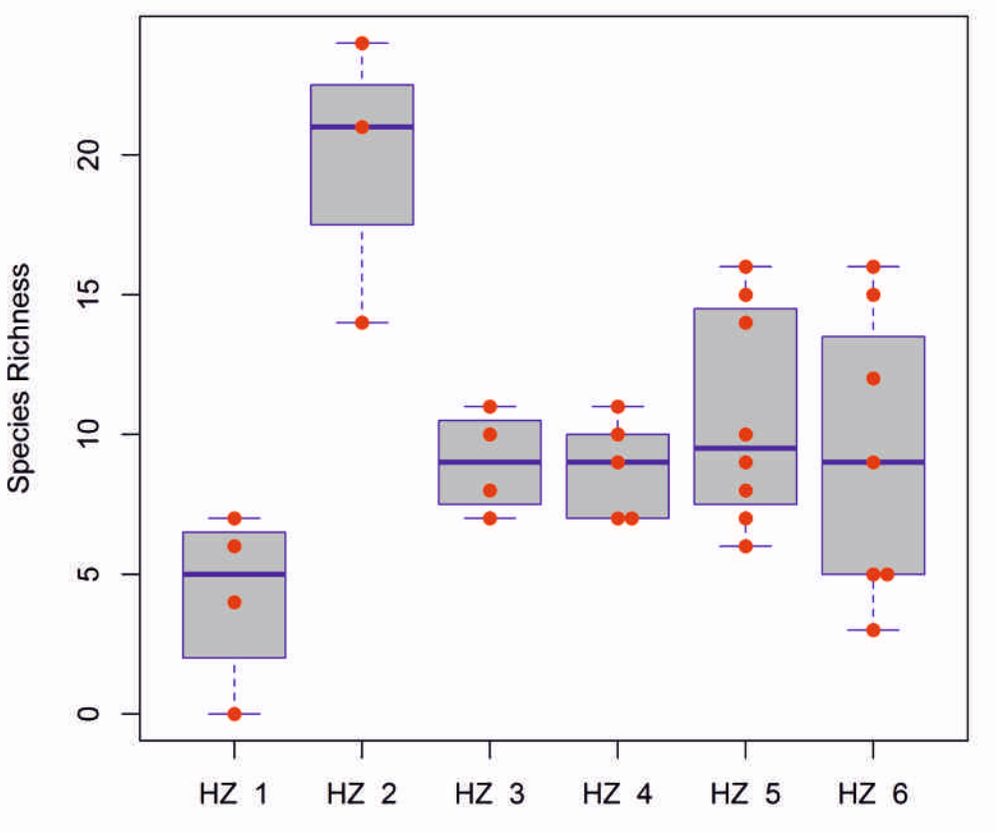

Figure 4.5: Box-plot of species richness of odonates in six habitat zones

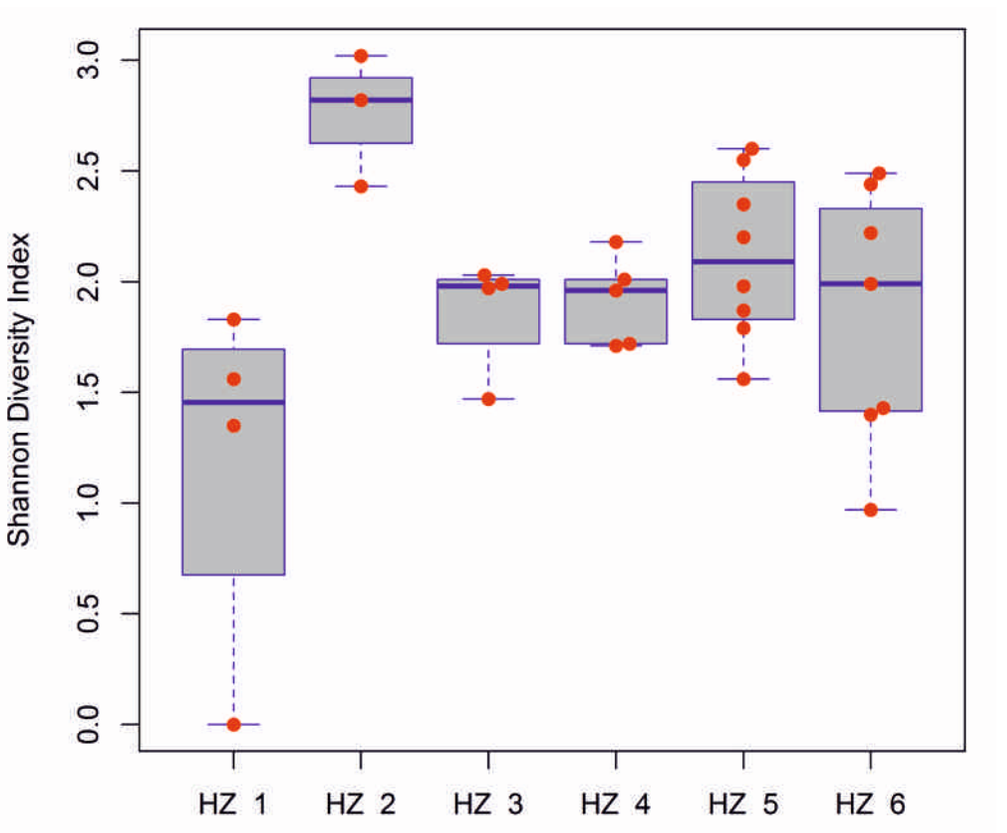

Figure 4.6: Box-plot of Shannon diversity index of odonates in six habitat zones

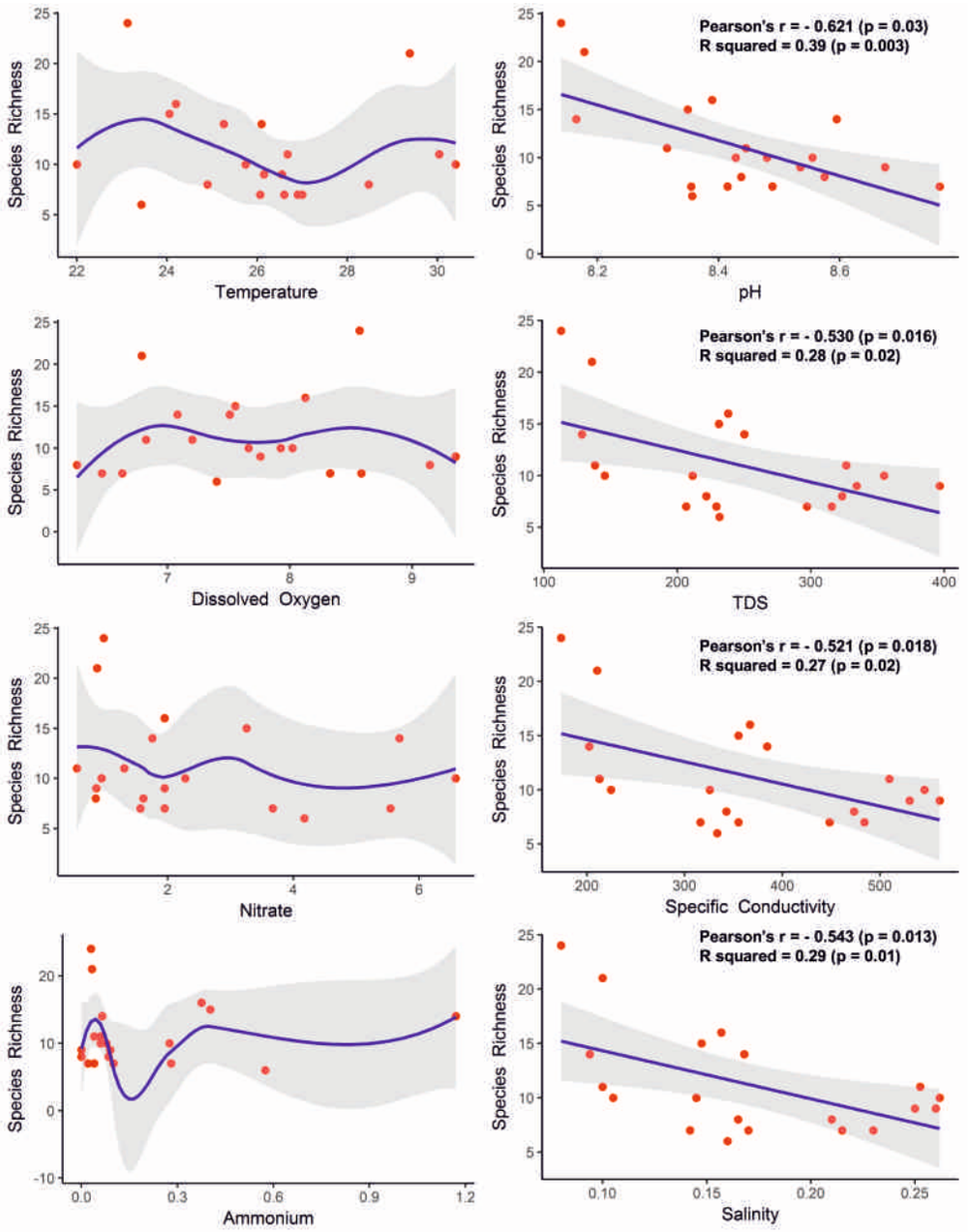

Figure 4.7: Scatter plot between species richness of odonates and physiochemical parameters of water for site 5 to site 25 (except site 13). The species richness shows significant ($p<0.05$) linear relationship with only 4 parameters - pH, TDS, specific conductivity and salinity

Habitat at Sahibganj, Jharkhand

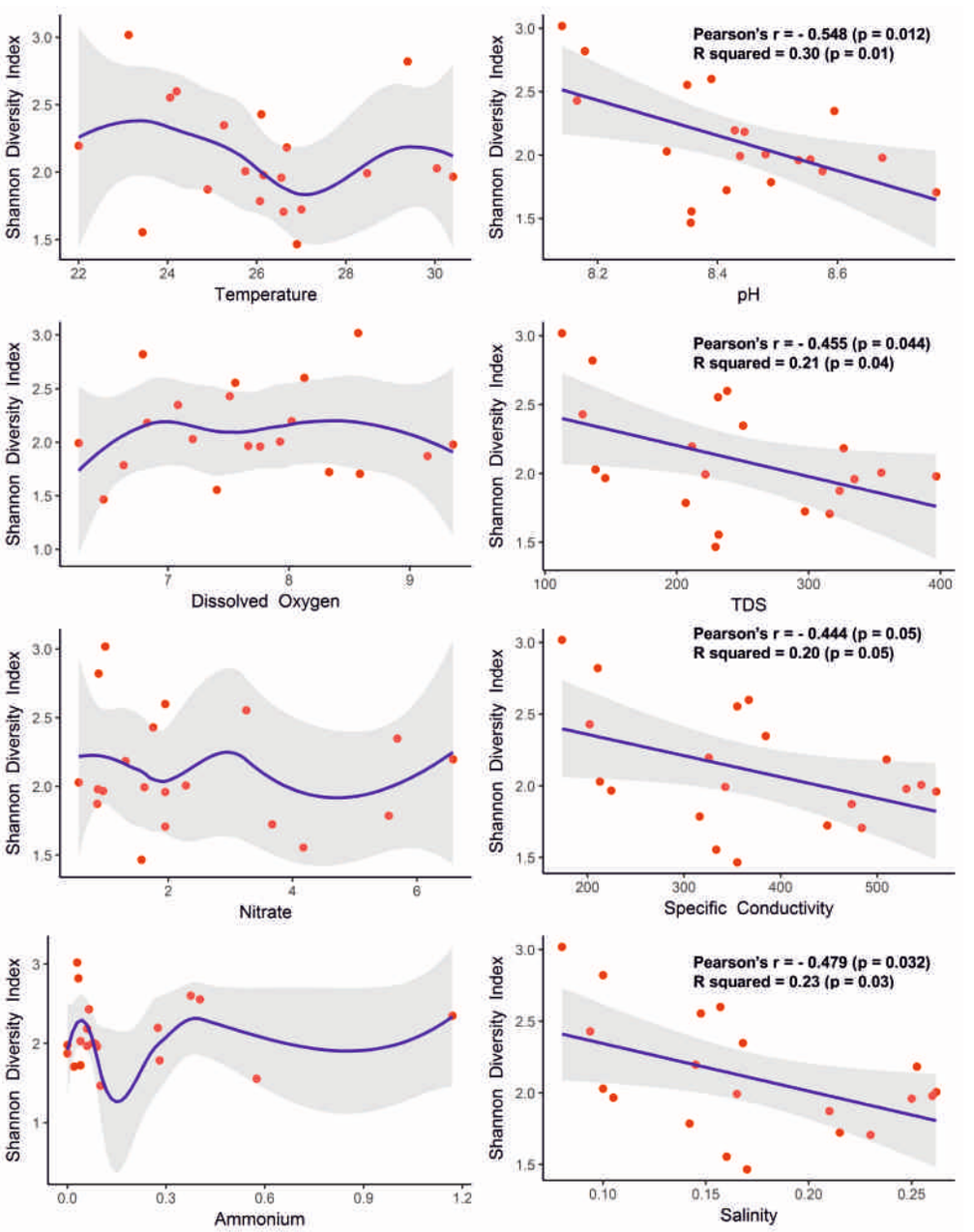

Figure 4.8: Scatter plot between Shannon diversity index of odonates and physiochemical parameters of water for site 5 to site 25 (except site 13). The species richness shows significant ($p<0.05$) linear relationship with only 4 parameters - pH, TDS, specific conductivity and salinity

Aristocypha quadrimaculata Selys, 1853

Agriocnemis lacteola Selys, 1877

Ischnura nursei Morton, 1907

Ischnura rubilio Selys, 1876

Brachythemis contaminata Fabricius, 1793

Neurothemis fulvia Drury, 1773

Orthetrum triangulare Selys, 1878

Rhyothemis variegata Linnaeus, 1763

Ceriagrion coromandelianum, Fabricius, 1798

Excuvae of odonate naiad (nymph), at Sahibganj, Jharkhand

Habitat at Bhimgoda barrage, Uttarakhand

STATUS OF FISH DIVERSITY IN THE GANGA RIVER

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ABSTRACT

Maintaining a healthy river system is a big challenge in current globally changing scenario. The Ganga River is not just known for its biodiversity, but also for its deteriorating habitat conditions. The baseline diversity data is required for effective and sustainable conservation planning of fishes in this region. We investigated fish occurrence and diversity patterns across the mainstem of the river. For this, 32 sampling sites were selected in 6 different habitat zones. Fish and environmental data were collected in the post-monsoon and post-winter season using gill nets of varying mesh sizes. A total of 2138 individuals of fishes were sampled and 125 species belonging to 88 genera, 34 families and 11 orders were recorded across all the sites. Out of 125 species, 117 species were native and 8 species were exotics. The highest diversity was observed for the habitat zone 2 (Haridwar to Narora). Water temperature was found to be a strong predictor of species diversity along the river. Our study

5

provides the baseline information for current status of fish diversity along the Ganga River and offers a template for future conservation efforts.

Keywords: Fish, Ganga River, Biodiversity, Species Richness, Exotic Fish.

5.1 INTRODUCTION

The National Ganga River is the cradle of Indian civilization and has ecological, cultural and spiritual significance. The extensive Ganga basin spreads over an area of 860,000 sq km across 11 states, that is home to about 500 million people, a staggering 40% of the Indian population.

The Ganga River is not only an important source of surface water, but also supports a wide array of flora and fauna, both terrestrial and aquatic, including several species of fish such as Critically Endangered Gangetic shark (*Glyphis gangeticus*), Gangetic stingray (*Himantura fluviatilis*), Endangered golden mahseer (*Tor putitora*), mangur (*Clarias magur*), vulnerable snow trout (*Schizothorax richardsonii*) and an economically important anadromous hilsa shad (*Tenualosa ilisha*).

The distinguished hydrology and geo-climatic conditions in the upper, middle and lower stretches of the Ganga River support distinctive fish fauna. In the early records, Talwar and Jhingran (1991) reported 375 fish species from the Ganga River while Sinha et al. (1998) reported 140 fish species. Payne et al. (2004) reported 161 fish species from the river. In a more recent study conducted by Vass et al. (2010), 47 fish species have been reported. The upper stretch of the river represents 23, middle 29, lower 37, estuarine 34 and marine 10 fish species. Sarkar et al. (2011) reported that Ganga River nurtures 143 species of fish belonging to 32 families where upper stretch is represented by 56 species, while the middle and lower stretches harbour 92 and 95 species, respectively. The above information pertains to the entire river basin and not to any particular site.

The fish diversity of the Ganga basin including the mainstem river is under immense stress due to multiple factors, for example, habitat modifications, increasing pollution resulting from rapid population expansion, exponential growth of industrialization and sudden rise in energy demand causing upsurge of more dams and barrages, which in turn results in loss of connectivity, changes in water regime and decreased water quality. There are also evidences of overexploitation of fishes and introduction of exotic invasive species resulting reduction in fish yield (Vass et al., 2010).

The available information on the Ganga River addressed physio-chemical characteristics of the river at various places (CPCB, 2009; Bhutiani et al., 2016), fish diversity (Rao, 2001; Payne et al., 2004; Vass et al., 2010; Das et al., 2010; Sarkar et al., 2012; Nautiyal et al., 2014) and to some extent the effect of altered hydrology and water-quality on biota (Vass et al., 2010) in an incoherent manner. These approaches lacked a holistic approach in considering the Ganga River as a riverscape.

Besides, they did not fulfil the necessary inclusiveness of methods to assess 'ecosystem health' of the Ganga River. The aim of this study was, therefore, to generate baseline information on the current status of fish diversity and its ecological condition in the fixed sampling locations from the upper reaches of the Ganga to the lower reaches at Ganga Sagar.

5.2 METHODOLOGY

Study Area

Based on topography, geography and ecological features, Ganga River has been characterised into six zones i.e., Habitat zone 1 (Gaumukh to Rishikesh), ii) Habitat zone 2 (Haridwar to Narora), iii) Habitat zone 3 (Kachla to Kanpur), iv) Habitat zone 4 (Fatehpur to Varanasi), v) Habitat zone 5 (Ghazipur to Farakka) and vi) Habitat zone 6 (Farakka to Gangasagar) for fish diversity assessment. Altogether, 32 sampling sites were selected throughout the entire course of river.

Sampling sites were selected after every 75km representing all six zones. The detail of the sampling sites is described in Chapter 2 and map is presented in Fig. 5.1. However, site no. 13 was discarded from the study area due to some logistics constraints, thus 31 sites (1-12 and 14-32) were retained.

Sampling

Fish samples and physico-chemical attributes were collected in 5km stretch of selected sites in post monsoon season (October and November 2017)

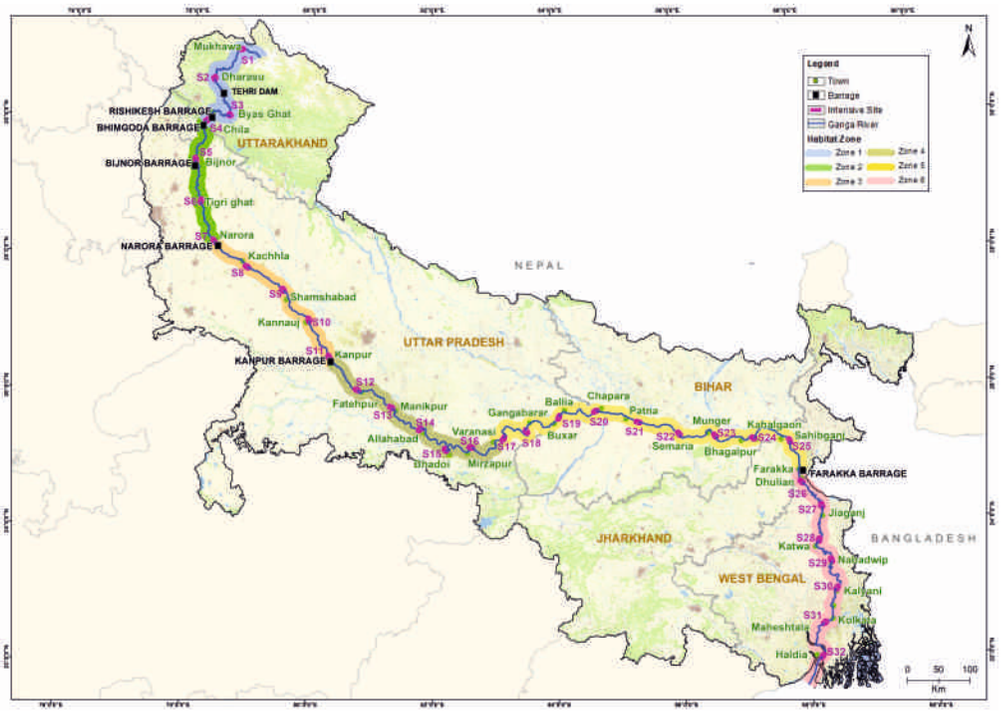

Figure 5.1: Map for the Ganga River depicting sampling sites and six habitat zones.

Gill-net sampling method

and same sites were resampled during post winter (March to May, 2018) season. At each site, six different mono-filamentous gill nets with varying mesh sizes (30m long × 3m wide; mesh size 2cm, 2.5cm, 4cm, 5cm, 7.5cm and 12.5cm) were used for average of 4 hours. Photographs of experimental fishing at various sites are depicted in Figure 5.1. Fish trapped in the gill nets were photographed and identified using keys given in taxonomic literature (Talwar, 1991; Talwar and Jhingran, 1991; Das et al., 2010; Jayaram, 2010). After counting the sampled individuals, length and weight of fishes were recorded. Valid nomenclatural names for species were adopted as per the Catalogue of Fishes of the California Academy of Sciences (Eschemeyer et al., 2016).

Collection of physiochemical parameters

Environmental variables were measured at the same site and fishes were sampled (Figure 5.2). Eight environmental variables: temperature (^{0}C), pH, DO (mg/l), total dissolved solids (TDS) (mg/l), specific conductivity (μS/cm), NO_3^- (mg/l), NH_4^+ (mg/l), and salinity (ppt) were measured by YSI made PRODSS multiparameter.

Statistical analysis

We have used species richness and Shannon diversity index (Magurran, 2004) for the diversity comparisons across the sampled sites, six zones and three stretches. Catch per unit efforts (CPUE) were calculated as the number of captured fishes per hour in all applied gill nets. Linear regression models were used to test the relationship between the site-wise diversity and physico-chemical water parameters. All the analysis and statistical tests were conducted in R statistical programming (version 3.4.1; R Core Team, 2018) software using package 'vegan' (Oksanen et al., 2018).

5.3 RESULTS

Diversity

A total of 2138 individuals of 125 species belonging to 88 genera, 34 families and 11 orders were recorded across all the 31 sites of Ganga River (Table 5.2). Out of 125 species, 117 species were native and remaining 8 species were exotics. In upper stretch (zone 1), 18 species belonging to 11 genera and 4 families were recorded from four sites (S-1 to S-4). In middle stretch (zone 2-5), 103 species belonging to 70 genera and 27 families were recorded from 21 sites. In lower stretch (zone 6), 51 species belonging to 46 genera and 21 families were recorded from 7 sites (Fig.5.2 a,b,c). Photographs of important fish species from upper, middle and lower stretch are illustrated in Plate 3. Overall, family Cyprinidae (36.80%) was the most dominant, followed by Sisoridae (9.60%) and Bagridae (6.40%); see Fig. 5.3a. Stretch wise comparison also shows that, family Cyprinidae was the most dominant with 72.22%, 36.89% and 25.49% in upper, middle and lower stretch, respectively (Fig. 5.3 b,c,d).

Relative Abundance

Overall, relative abundance showed dominance of small sized indigenous species such as *Salmostoma bacaila* (4.91%), *Cabdio morar* (4.54%), *Macrognathus pancalus* (4.35%) and *Puntius sophore* (4.26%). In upper stretch (zone 1), *Tor putitora* (31.33%) showed maximum relative abundance followed by *Bangana dero* (21.69%) and *Tor tor* (7.23%). In middle stretch (zone 2-5), relative abundance showed trend similar to overall with *Salmostoma bacaila* (5.26%) being the most dominant followed by *Cabdio morar* (4.84%) and *Macrognathus pancalus* (4.74%). In lower stretch (zone 1), *Rhinomugil corsula* and *Setipinna phasa* were the most dominant (8.77%) followed by *Tenualosa ilisha* (7.02%) and *Sicamugil cascasia* (6.14%). However, overall relative abundance of species of conservation importance was reversed with low relative abundance of species such as *Sperata aor* (1.36%), *Sperata seenghala* (1.31%), *Tor putitora* (1.22%), *Wallago attu* (0.89%), *Cirrhinus cirrhosus* (0.70%), *Gibelion catla* (0.47%), *Tenualosa ilisha* (0.37%), *Bagarius bagarius* (0.37%), *Labeo rohita* (0.33%), *Chitala chitala* (0.28%), *Schizothorax richardsonii* (0.09%) and *Anguilla bengalensis* (0.05%).

Occurrence

Fish composition of upper, middle and lower

Traditional Fishing practice in the Ganga River

stretches showed a high level of divergence in terms of site occupancy. The pattern of fish occurrence is presented in Table 5.2. Overall, 11 species viz., *Cirrhinus reba*, *Puntius sophore, Puntius conchonius, Salmostoma bacaila, Cabdio morar, Mystus cavasius, Xenentodon cancila, Channa punctatus, Mastacembelus armatus, Macrognathus aral* and *Macrognathus pancalus* showed wide distribution range and were recorded from 21 sites whereas 24 species including *Tor putitora, Tor tor, Labeo dyochelius, Silonia silondia, Scatophagus argus* and *Liza persicus* showed narrow distribution range.

Diversity Indices

The values for species richness and Shannon diversity index of upper, middle and lower stretches are given in Table 5.3. Site-wise species richness, diversity was found to be maximum at site S5 (Bijnor; 86, 4.24) followed by S-7 (Narora; 77, 4.16) and site S-26 (Bahagalpur; 43, 3.16). Zone-wise maximum species richness (diversity index) was 89 (4.15±0.09) in zone 2 (Bijnor to Narora) followed by 51 (3.20±0.20) in zone 4 (Fatehpur to Varanasi), 51 (1.78±1.00) in zone 6 (Farakka to Haldia) and 43 (3.07±0.16) in zone 5 (Gazhipur to Sahebganj). However, minimum species richness (diversity index) was 0.79 (1.00) found in zone 1 (Harsil to Haridwar). Stretch-wise maximum species richness (diversity index) was 103 (3.30±0.40) recorded in middle stretch (Bijnor to Sahebganj) followed by 51 (1.78±1.00) and 18 (0.79±1.00) in lower and upper stretch, respectively.

Exotics

A total of 8 exotic species were recorded across all the studied zones of Ganga River. Overall, the highest relative abundance was recorded for *Cyprinus carpio carpio* (1.73%) followed by *Oreochromis niloticus* (0.75%) and *Pterygoplichthys disjunctivus* (0.09%). *Cyprinus carpio carpio* was the most widely distributed species recorded from 10 sites.

Catch per unit efforts

CPUE was observed maximum at site S5 (Bijnor, 50.88 ±64.87 fishes/hr) and minimum at S1 and S2 (Dharasu and Vyasghat, 0.125± 0.176 fishes/hr) (Table 5.1). CPUE values were found to be maximum in habitat zone 2 (33.38±18.36 fishes/hr) and minimum in habitat zone 6 (2.04±3.17 fishes/hr) (Table 5.1).

Relationship of fish diversity with physico-chemical water parameters

Results for regression analysis, showing relationship of physico-chemical characteristics with species richness and Shannon diversity index are presented in Table 5.4. None of the selected water variables were found significant with species richness. Temperature was the only variable found significant ($R2=$, $p<0.05$) with Shannon diversity index. Relationships of species richness and Shannon diversity index with physico-chemical water parameters in middle stretch are shown in Table 5.5. pH, total dissolved solids (TDS), specific conductivity and salinity had significant relationship ($p<0.05$) with species richness and Shannon diversity index.

5.4 DISCUSSION

This study represents the diversity and distribution of fish species along the mainstem of the Ganga River and their relationships with water conditions. The changes in the distribution patterns of fishes were observed when compared to the existing literature (Payne et al., 2004; Sarkar et al., 2012). In general, reduction in freshwater fish diversity might be a result of commissioning of hydro-power projects on river stretches (Vass et al., 2009; Payne et al., 2004). However, high species richness and diversity index were observed in areas between Bijnor to Narora as compared to earlier studies conducted at larger scales (Sarkar et al., 2012). Results of family wise species distribution and species relative abundance are similar to the previous studies in river Ganga and other Asian rivers (De Silva and Abery, 2007; Raghavan et al., 2008; Sarkar et al., 2008; Sarkar et al., 2012). High level of dissimilarity is observed in fish occurrences of upper stretch in comparison to middle and lower stretches of Ganges as showed in an earlier report (Sarkar et al., 2012). This might be due to difference in hydrology and temperature.

Fish assemblages are influenced by environmental variables at multiple spatial scales (Schlosser, 1982, 1987; Marsh-Matthews and Matthews, 2000). In this study, results of linear regression analysis of environmental variables with species richness and diversity index show that temperature, pH, TDS, specific conductivity and salinity are the most important environmental variables for the fish assemblage in Ganga River. These factors were also identified as the key drivers of fish assemblage patterns in other tropical Indian rivers (Shukla and Bhat, 2017; Johnson et al., 2012; Dubey et al., 2012; Sarkar and Bain, 2007).

Conclusion

Maximum species richness (89) was recorded from habitat zone 2 (Haridwar to Narora) which was comparatively higher than earlier records from this area. *Leiodon cutcutia* was recorded from upstream of Bijnor barrage, a new distribution range of this species in Ganga River. It was also observed that the distribution of golden mahseer (*Tor putitora*) is restricted only in the habitat zone 1(between Harshil to Haridwar). Similarly presence of Hilsa (*Tenualosa ilisha*) was recorded below Farraka barrage.

The current status of fishes recorded in 32 sites forms a baseline data for monitoring future distribution status of fish fauna in the Ganga River.

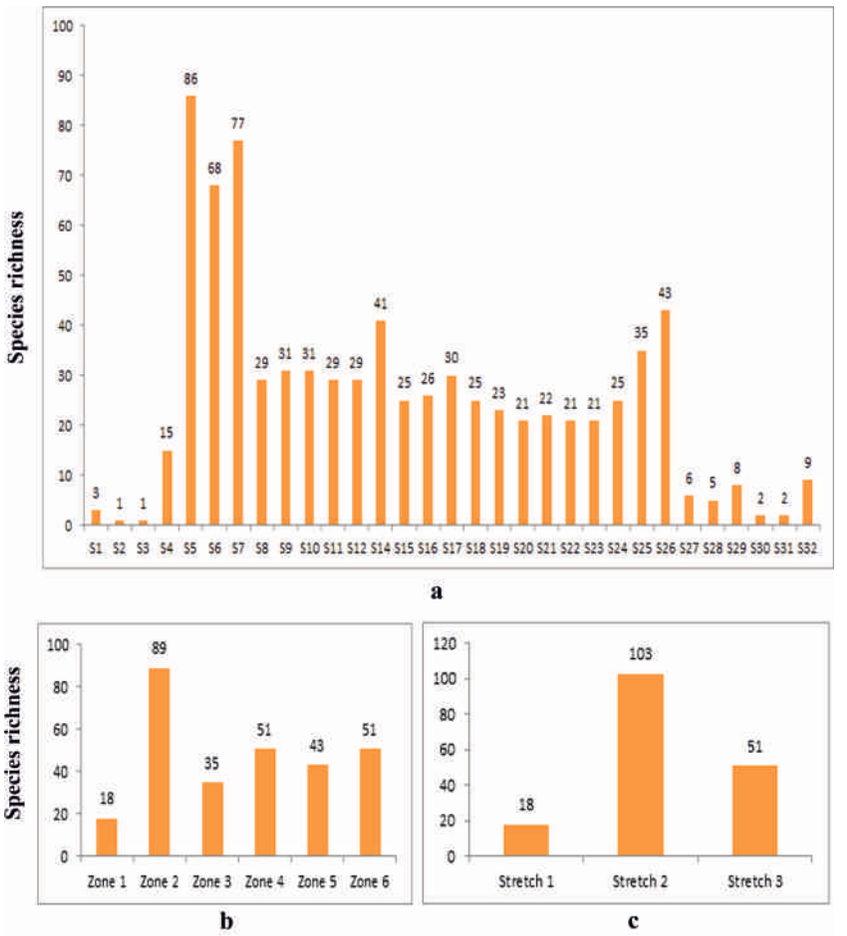

Figure 5.2: Species richness along the Ganga River, a) site-wise, b) zone-wise, c) stretch wise

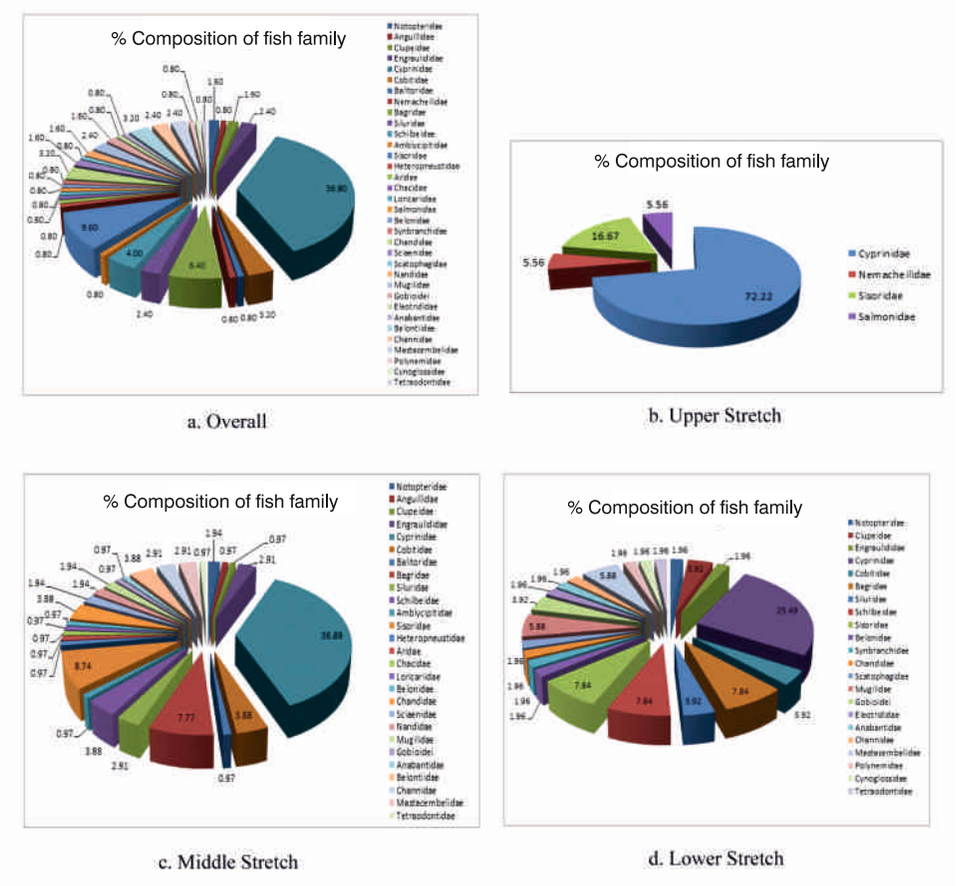

Figure 5.3: Representation of fish families in Ganga River. a) overall, b) upper stretch, c) middle stretch and d) lower stretch

5.5 CONCLUSION

This study provides a baseline information for diversity and distribution of fishes along the entire stretch of the Ganga River. This study is the first survey of its kind, as it covers entire main stem of the Ganga River in India and also accounts for not only the status, but also the relationship of fish diversity with water quality parameters. The results from the study prepare the platform for future ecological studies and diversity comparisons across the different stretches of Ganga. Future conservation efforts would rely on the large scale monitoring efforts conducted systematically and scientifically, incorporating all the essential components of degrading ecological conditions. Therefore, appropriate planning for fish biodiversity conservation and management are important to attain sustainable utilization of fishery resources of Ganga River, so that people dependent on fishery resources are able to maintain and sustain their livelihoods.

The National Mission for Clean Ganga (NMCG) and Wildlife Institute of India (WII)'s project "Biodiversity Conservation and Ganga Rejuvenation" aims at aquatic species restoration plan through science-based research and knowledge sharing to the various stakeholders with the aim to provide information on fish diversity, their conservation status, ecology and human threats.

This document is expected to be useful in understanding the threat levels, conservation prioritization and also formulating species-specific conservation plans for Ganga River.

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A top view of Nayar confluence

Table 5.1 Results for the catch per unit efforts in different sites and habitat zones

Sites/habitat zone	Mean CPUE (fish/hr)	SD
S 1 (Mukhawa)	0.38	0.53
S 2 (Dharasu)	0.13	0.18
S 3 (Byas Ghat)	0.13	0.18
S 4 (Chilla)	9.75	13.44
HZ 1 (Gangotri - Haridwar)	**2.59**	**4.77**
S 5 (Gangoli Khadar)	50.88	64.88
S 6 (Tigri)	14.25	19.80
S 7 (Narora)	35	46.32
HZ 2 (Haridwar - Narora)	**33.38**	**18.37**
S 8 (Sahwajpur)	6	7.79
S 9 (Azizabad)	7.63	6.19
S 10 (Mehendipur)	13.5	17.68
S 11 (Kanpur)	15.13	18.92
HZ 3 (Narora - Kanpur)	**10.56**	**4.43**
S 12 (Bhitura)	5	7.07
S 13 (Manikpur)	-	-
S 14 (Allahabad)	18.25	22.27
S 15 (Tela)	7.63	9.37
S 16 (Kolhar)	11.5	12.02
S 17 (Mustafabad Ramchandrapur)	15.38	7.60
HZ 4 (Kanpur - Varanasi)	**9.62**	**6.77**
S 18 (Zamania gangbarar)	5.38	5.83
S 19 (Pipra)	4.88	5.83
S 20 (Ravelganj)	6.75	9.55
S 21 (Raghupur)	5.13	7.25
S 22 (Maranchi)	4.88	6.89
S 23 (Tilakpur)	2.63	3.71
S 24 (Kahalgaon)	3.38	4.77
S 25 (Maharajpur)	9.5	13.44
HZ 5 (Varanasi - Farakka)	**5.31**	**2.10**
S 26 (Chandpur)	9.13	12.55
S 27 (Jiaganj - Azimganj)	1.75	2.12
S 28 (Naliapur)	0.63	0.53
S 29 (Rudrapura Nabadwip)	1	1.06
S 30 (Raninagar Kalyani)	0.25	0
S 31 (Maheshtala)	0.25	0
S 32 (Haldia - Dimond Harbour)	1.25	1.06
HZ 6 (Farakka - Ganga Sagar)	**2.04**	**3.17**

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Table 5.2: List of fishes recorded in fixed sampling stations along the Ganga River

		Habitat zone 1				Habitat zone 2			Habitat zone 3				
	Species	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
1.	*Paracanthocobitis botia*	-	-	-	-	+	+	+	-	-	-	-	-
2.	*Ailia coila*	-	-	-	-	+	+	+	+	+	+	+	+
3.	*Amblyceps mangois*	-	-	-	-	+	+	+	-	-	-	-	-
4.	*Amblypharyngodon mola*	-	-	-	-	+	+	+	+	+	+	+	+
5.	*Anabas testudineus*	-	-	-	-	+	-	+	-	-	-	-	-
6.	*Anguilla bengalensis*	-	-	-	-	-	-	-	-	-	-	-	-
7.	*Apocryptes bato*	-	-	-	-	-	-	-	-	-	-	-	-
8.	*Arius gagora*	-	-	-	-	-	-	-	-	-	-	-	-
9.	*Aspidoparia jaya*	-	-	-	-	+	+	+	+	+	+	+	+
10.	*Badis badis*	-	-	-	-	+	-	+	-	-	-	-	-
11.	*Bagarius bagarius*	-	-	-	-	+	+	+	+	-	-	-	-
12.	*Bagarius yarrellii*	-	-	-	-	+	+	+	-	-	-	-	-
13.	*Bangana dero*	-	-	-	+	+	+	+	-	-	-	-	-
14.	*Barilius bendelisis*	-	-	-	+	+	-	+	-	-	-	-	-
15.	*Barilius spp. (UI 2)*	-	-	-	-	+	-	+	+	+	-	-	-
16.	*Barilius vagra*	-	-	-	+	+	-	-	-	-	-	-	-
17.	*Batasio batasio*	-	-	-	-	+	+	+	-	-	-	-	-
18.	*Botia lohachata*	-	-	-	-	+	+	+	-	-	-	-	-
19.	*Botia rostrata*	-	-	-	-	-	-	-	-	-	-	-	-
20.	*Cyprinus carpio*	-	-	-	-	+	-	-	-	-	+	+	+
21.	*Cyprinus carpio specularis*	-	-	-	-	-	-	-	-	-	-	-	-
22.	*Cyprinus idella*	-	-	-	-	-	-	-	-	-	-	-	-
23.	*Cabdio morar*	-	-	-	-	+	+	+	+	+	+	+	+
24.	*catfish (UI3)*	-	-	-	-	+	-	-	-	-	-	-	-
25.	*catfish (UI4)*	-	-	-	-	+	-	-	-	-	-	-	-
26.	*Chaca chaca*	-	-	-	-	+	-	-	-	-	-	-	-
27.	*Chagunius chagunio*	-	-	-	-	+	+	+	-	-	-	-	-
28.	*Chanda nama*	-	-	-	-	+	+	+	-	-	-	-	-
29.	*Channa marulius*	-	-	-	-	+	+	+	-	-	-	-	-
30.	*Channa punctatus*	-	-	-	-	+	+	+	+	+	+	+	+
31.	*Channa striata*	-	-	-	-	+	+	+	-	-	-	-	-
32.	*Chela laubuca*	-	-	-	-	+	+	+	-	-	-	-	-
33.	*Chitala chitala*	-	-	-	-	+	+	+	-	-	-	-	-
34.	*Cirrhinus cirrhosus*	-	-	-	-	+	+	+	+	+	+	+	+
35.	*Cirrhinus reba*	-	-	-	-	+	+	+	+	+	+	+	+
36.	*Clupisoma garua*	-	-	-	-	+	+	+	+	+	+	+	+
37.	*Tariqilabeo latius*	-	-	-	-	+	+	+	-	-	-	-	-
38.	*Cynoglossus cynoglossus*	-	-	-	-	-	-	-	-	-	-	-	-
39.	*Devario devario*	-	-	-	-	-	-	-	-	-	-	-	-
40.	*Eleotris fusca*	-	-	-	-	-	-	-	-	-	-	-	-
41.	*Erethistes pussilus*	-	-	-	-	+	-	-	-	-	-	-	-
42.	*Eutropiichthys murius*	-	-	-	-	+	+	+	-	-	-	-	-
43.	*Eutropiichthys vacha*	-	-	-	-	+	+	+	+	+	+	+	+

Habitat zone 4				Habitat zone 5								Habitat zone 6						
S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	+	-	-	+	+	+	-	-	-	-	-	-
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		Habitat zone 1				Habitat zone 2			Habitat zone 3				
	Species	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
44.	*Gagata cenia*	-	-	-	-	+	+	+	-	-	-	-	-
45.	*Gagata sexualis*	-	-	-	-	+	+	+	-	-	-	-	-
46.	*Garra gotyla*	-	-	-	+	-	-	-	-	-	-	-	-
47.	*Gibelion catla*	-	-	-	-	+	+	+	+	+	+	+	+
48.	*Glossogobius giuris*	-	-	-	-	+	+	+	-	-	-	-	-
49.	*Glyptothorax cavia*	-	-	-	+	+	-	-	-	-	-	-	-
50.	*Glyptothorax gracilis*	-	-	-	+	-	-	-	-	-	-	-	-
51.	*Gogangra viridescens*	-	-	-	-	+	-	-	-	-	-	-	-
52.	*Gonialosa manmina*	-	-	-	-	-	-	-	-	-	-	-	-
53.	*Gudusia chapra*	-	-	-	-	+	+	+	-	+	+	-	-
54.	*Hypophthalmichthys molitrix*	-	-	-	-	-	-	-	-	-	-	-	-
55.	*Hypophthalmichthys nobilis*	-	-	-	-	-	-	-	-	-	-	-	-
56.	*Heteropneustes fossilis*	-	-	-	-	+	+	+	-	-	-	-	-
57.	*Johnius coitor*	-	-	-	-	-	-	-	-	-	-	-	-
58.	*Johnius gangeticus*	-	-	-	-	-	-	-	-	-	-	-	-
59.	*Labeo bata*	-	-	-	-	+	+	+	+	+	+	+	+
60.	*Labeo boga*	-	-	-	-	+	-	+	-	-	-	-	-
61.	*Labeo calbasu*	-	-	-	-	+	+	+	+	+	+	+	+
62.	*Labeo dyochelius*	-	-	-	+	-	-	-	-	-	-	-	-
63.	*Labeo fimbriatus*	-	-	-	+	-	-	-	-	-	-	-	-
64.	*Labeo gonius*	-	-	-	-	+	+	+	-	-	-	-	-
65.	*Labeo pangusia*	-	-	-	+	-	-	+	-	-	-	-	-
66.	*Labeo rohita*	-	-	-	-	+	+	+	-	-	-	-	-
67.	*Lepidocephalichthys guntea*	-	-	-	-	+	+	+	-	-	-	-	-
68.	*Leiodon cutcutia*	-	-	-	-	+	-	+	-	-	-	-	-
69.	*Leptomelanosoma indicum*	-	-	-	-	-	-	-	-	-	-	-	-
70.	*Liza persicus*	-	-	-	-	-	-	-	-	-	-	-	-
71.	*Macrognathus aral*	-	-	-	-	+	+	+	+	+	+	+	+
72.	*Macrognathus pancalus*	-	-	-	-	+	+	+	+	+	+	+	+
73.	*Mastacembelus armatus*	-	-	-	-	+	+	+	+	+	+	+	+
74.	*Monpterus cuchia*	-	-	-	-	-	-	-	-	-	-	-	-
75.	*Mystus cavasius*	-	-	-	-	+	+	+	+	+	+	+	+
76.	*Mystus tengara*	-	-	-	-	+	+	+	-	-	+	-	-
77.	*Mystus vittatus*	-	-	-	-	+	+	+	-	-	-	-	-
78.	*Nandus nandus*	-	-	-	-	+	+	+	-	-	-	-	-
79.	*Notopterus notopterus*	-	-	-	-	+	+	+	-	-	-	-	-
80.	*Oreochromis niloticus*	-	-	-	-	-	-	-	-	-	+	+	+
81.	*Ompok bimaculatus*	-	-	-	-	+	+	+	-	-	-	-	-
82.	*Ompok pabda*	-	-	-	-	+	+	+	-	-	-	-	-
83.	*Salmo trutta fario*	+	-	-	-	-	-	-	-	-	-	-	-
84.	*Opsarius barna*	-	-	-	+	+	-	-	-	-	-	-	-
85.	*Osteobrama cotio*	-	-	-	-	+	+	+	+	+	+	+	+
86.	*Pachypterus atherinoides*	-	-	-	-	+	+	+	-	-	-	-	-
87.	*Pangio pangia*	-	-	-	-	+	+	+	-	-	-	-	-
88.	*Parambassis baculis*	-	-	-	-	+	+	+	-	-	-	-	-

Habitat zone 4				Habitat zone 5								Habitat zone 6						
S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32
-	-	-	-	+	+	-	-	-	-	-	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	+	-	+	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	+	+	+	+	+	-	-	-	-	+	+	-	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

		Habitat zone 1				Habitat zone 2			Habitat zone 3				
	Species	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
89.	*Parambassis lala*	-	-	-	-	+	+	+	-	+	-	-	-
90.	*Parambassis ranga*	-	-	-	-	+	+	+	-	-	-	-	-
91.	*Pethia conchonius*	-	-	-	-	+	+	+	+	+	+	+	+
92.	*Pethia spp (UI1)*	-	-	-	-	+	-	-	-	-	-	-	-
93.	*Pethia ticto*	-	-	-	-	+	+	+	+	+	+	+	+
94.	*Polyacanthus sota*	-	-	-	-	+	-	+	-	-	-	-	-
95.	*Psudoechensis sulcata*	-	-	-	+	-	-	-	-	-	-	-	-
96.	*Pterygoplichthys disjunctivus*	-	-	-	-	+	-	-	-	-	-	-	-
97.	*Puntius chola*	-	-	-	-	+	+	+	+	+	+	+	+
98.	*Puntius sophore*	-	-	-	-	+	+	+	+	+	+	+	+
99.	*Raimas bola*	-	-	-	-	-	+	-	-	-	-	-	-
100.	*Rasbora deniconius*	-	-	-	-	+	+	+	-	-	-	-	-
101.	*Rhinomugil corsula*	-	-	-	-	-	-	-	-	-	-	-	-
102.	*Rita rita*	-	-	-	-	+	+	+	-	-	-	-	-
103.	*Salmostoma bacaila*	-	-	-	-	+	+	+	+	+	+	+	+
104.	*Scatophagus argus*	-	-	-	-	-	-	-	-	-	-	-	-
105.	*Schistura rupecola*	-	-	-	+	-	-	-	-	-	-	-	-
106.	*Schizothorax paligostomus*	+	-	-	-	-	-	-	-	-	-	-	-
107.	*Schizothorax richardsonii*	+	+	-	-	-	-	-	-	-	-	-	-
108.	*Securicula gora*	-	-	-	-	+	+	+	-	-	-	-	-
109.	*Setipinna brevifilis*	-	-	-	-	-	-	-	-	-	-	-	-
110.	*Setipinna phasa*	-	-	-	-	-	-	+	-	-	-	-	-
111.	*Sicamugil cascasia*	-	-	-	-	+	+	+	-	+	-	-	-
112.	*Silonia silondia*	-	-	-	-	-	-	-	-	-	-	-	-
113.	*Sisor rhabdophorus*	-	-	-	-	-	-	-	-	-	-	-	-
114.	*Sperata aor*	-	-	-	-	+	+	+	+	+	+	+	+
115.	*Sperata seenghala*	-	-	-	-	+	+	+	+	+	+	+	+
116.	*Systomus sarana sarana*	-	-	-	-	+	+	+	+	+	+	+	+
117.	*Tenualosa ilisha*	-	-	-	-	-	-	-	-	-	-	-	-
118.	*Naziritor chelynoides*	-	-	+	+	-	-	-	-	-	-	-	-
119.	*Tor putitora*	-	-	-	+	-	-	-	-	-	-	-	-
120.	*Tor tor*	-	-	-	+	-	-	-	-	-	-	-	-
121.	*Trichogaster chuna*	-	-	-	-	+	-	+	-	-	-	-	-
122.	*Trichogaster fasciata*	-	-	-	-	+	+	+	-	-	-	-	-
123.	*Trichogaster lalius*	-	-	-	-	+	+	+	-	-	-	-	-
124.	*Wallago attu*	-	-	-	-	+	+	+	+	+	+	+	+
125.	*Xenentodon cancila*	-	-	-	-	+	+	+	+	+	+	+	+

Habitat zone 4				Habitat zone 5								Habitat zone 6						
S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
+	-	-	+	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-
-	+	-	-	-	-	+	+	+	+	+	-	+	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-
+	+	+	+	+	+	-	-	-	-	-	+	+	-	-	-	-	-	-
+	+	+	+	+	+	-	-	-	-	-	+	+	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-

Table 5.3: Fish diversity (species richness and Shannon diversity) along the fixed study sites

	Sampling Area		Species Richness	Shannon index (H')±SD
Upper Stretch				
	Habitat zone 1		**18**	**0.79±1.00**
		S-1	3	1.10
		S-2	1	0.00
		S-3	1	0.00
		S-4	15	2.07
Middle Stretch			103	3.30±0.40
	Habitat zone 2		**89**	**4.15±0.09**
		S-5	86	4.24
		S-6	68	4.06
		S-7	77	4.16
	Habitat zone 3		**35**	**3.23±0.06**
		S-8	29	3.21
		S-9	31	3.29
		S-10	31	3.26
		S-11	29	3.16
	Habitat zone 4		**51**	**3.20±0.20**
		S-12	29	3.25
		S-13	-	-
		S-14	41	3.49
		S-15	25	2.93
		S-16	26	3.16
		S-17	30	3.16
	Habitat zone 5		**43**	**3.07±0.16**
		S-18	25	3.13
		S-19	23	3.03
		S-20	21	2.90
		S-21	22	2.99
		S-22	21	2.93
		S-23	21	3.04
		S-24	25	3.17
		S-25	35	3.38
Lower Stretch				
	Habitat zone 6		**51**	**1.78±1.00**
		S-26	43	3.61
		S-27	6	1.63
		S-28	5	1.61
		S-29	8	2.08
		S-30	2	0.69
		S-31	2	0.69
		S-32	9	2.16
Total		**S-1 to S-32**	**125**	**2.63±1.15**

Table 5.4: Results of regression analysis between species diversity and physico-chemical characteristics of 32 study sites

Environmental Variable	Species Richness				Shannon index (H')			
	F	df	R^2	p	F	df	R^2	p
Temp	3.22	1,29	0.07	0.08	10.64	1,29	0.24	0.00*
pH	0.53	1,29	-0.06	0.47	1.97	1,29	0.03	0.17
DO	0.08	1,29	-0.03	0.78	1.18	1,29	0.01	0.29
TDS	0.65	1,29	-0.01	0.43	0.65	1,29	-0.01	0.43
Specific Conductivity	0.67	1,29	-0.01	0.42	0.13	1,29	-0.03	0.73
NO_3	0.68	1,29	-0.01	0.42	0.19	1,29	-0.03	0.67
NH_4	1.13	1,29	0.00	0.30	0.35	1,29	-0.02	0.56
Salinity	0.63	1,29	-0.01	0.43	0.12	1,29	-0.03	0.73

Table 5.5: Results of regression analysis between species diversity (Species richness and Shannon index) physico-chemical characteristics of study sites following in middle stretch of Ganga

Environmental Variable	Species Richness				Shannon index (H')			
	F	df	R^2	p	F	df	R^2	p
Temp	0.26	1,18	-0.04	0.64	0.73	1,18	-0.01	0.40
pH	10.6	1,18	0.34	0.00*	8.26	1,18	0.28	0.01*
DO	0.01	1,18	-0.05	0.91	0.09	1,18	-0.05	0.77
TDS	9.27	1,18	0.30	0.01*	9.31	1,18	0.30	0.01*
Specific Conductivity	9.23	1,18	0.30	0.01*	9.77	1,18	0.32	0.01*
NO_3	2.16	1,18	0.06	0.16	2.05	1,18	0.05	0.17
NH_4	1.88	1,18	0.04	0.19	1.63	1,18	0.03	0.22
Salinity	7.39	1,18	0.25	0.01*	7.50	1,18	0.25	0.01*

A shoal of golden mahseer

PLATE I

Common fishes of upper reaches of Ganga River

a. Schizothorax richardsonii
b. Barilius vagra

PLATE II

Iconic fishes of foot hills of Himalayas

a. Tor putitora
b. Garra gotyla

PLATE III

Small loaches and barbs of Ganga River

a. Schistura rupecola
b. Pethia ticto
c. Lepidocephalyicthys guntea

AN OVERVIEW OF ANURAN AND SQUAMATE REPTILE DIVERSITY ALONG THE GANGA RIVER

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ABSTRACT

We present report of an herpetofaunal inventory from twenty five sites along the Ganga River. Thirty species belonging to 25 genera and 16 families are recorded. Dicroglossidae and Gekkonidae are the most dominant families with 13.33% of the species. Species accumulation curves in most of the study sites reached asymptote. Average encounter rate of amphibians and reptiles was found 26.72 and 3.4 individuals per sampling respectively. *Euphlyctis cyanophlyctis* was the most abundant (0.35) with the encounter rate of 9.79/hour. Important species records from the families Homalopsidae, Microhylidae, Colubridae and Natricidae are discussed.

Keywords: Herpetofauna, Natural History, Survey, Northern India, the Ganga River.

6

6.1 INTRODUCTION

Globally, amphibian and reptilian fauna are represented by 7,899 species (amphibiaweb.org) and 10,793 species (Uetz et al. 2018) respectively. In India, 424 species of amphibians (amphibiaweb.org) and more than 500 species of reptiles are known.

Study on herpetofauna of the Ganga River basin can be traced back to Walton (1911) and Boulenger (1920). Since then some work had been carried out by Bhatnagar (1969, 1972), Waltner (1974), Chopra (1979), Tilak and Husain (1977), Sanyal et al. (1979), Singh and Gupta (1979a, b), Bedi (1985), Tilak and Ray (1985), Lamba (1987), Osmaston and Sale (1989), Sarkar (1991), Husain (1995), Ray and Tilak (1995), Ray (1992, 1995, 1999), Husain and Ray (1995, 1997), Husain (2003, 2004), Khati (2004), Khanna and Tiwari (2006), Sarkar and Kumar (2006), Bahuguna (2008), Mehta (2008), Hegde et al. (2009a, b), Ohler et al. (2009). Most recent work on it include Hegde and Roy (2011a, b), Das et al. (2012), Hegde (2013), Bahuguna (2018). Though studies are mostly restricted to the protected areas of the Ganga River basin and Western Himalaya, a systematic study on herpetofauna along Ganga River is still lacking. Previously 12 species of amphibians from Ganga river were reported by Chanda (1991), and Sharma (1991) reported three species of lizards and five species of snakes. Bashir et al. (2012) reported six species of snakes and two species of lizards from upper Ganges (Bijnor-Narora).

In the present study, an attempt has been made to survey the herpetofaunal diversity along the Ganga.

6.2 METHODOLOGY

The study was conducted at 25 sites (Table 1) during the period May 2017 and September 2018. We employed Visual Encounter Survey (VES) to document species richness. In each site, the first author carried out time constrained VES at dusk. Sampling effort i.e., number of observer was kept constant during the sampling. All potential habitats (i.e., wetlands, crop fields and other temporary water bodies) within 500m buffer area along Ganga were surveyed. During the study, number of individuals of species encountered, microhabitat, and behavioral activities were recorded. Photographs of representatives of each species were taken in their natural habitat. Specimens that were collected were fixed in formalin and preserved in 70% ethanol. Species were identified using field guides viz. Smith (1935, 1943), Schleich & Kastle (2002), Dutta (1997), Chanda (2002), Whitaker and Captain (2004) and Das and Das (2017). Nomenclature and taxonomic arrangement follows Frost (2018) for amphibians and Uetz et al. (2018) for reptiles. The threat status of the recorded species using IUCN Red List criteria (http://www.iucnredlist.org) is reported. Statistical analysis was done in 'R' Version 3.4.1 using the package vegan. For statistical analysis, we considered the species which were encountered in the VES. Species recorded opportunistically were only included in species composition of the study sites.

6.3 RESULTS

During the study period, we recorded a total 30 species of herpetofauna from 16 families (Table: 6.1). All recorded amphibians are anurans representing 10 species belonging to 8 genera and 5 families. Dicroglossidae was the dominant family with 13.33% species. Bufonidae and Rhacophoridae were represented by 6.67% species followed by Ranidae and Microhylidae (3.33%). Reptiles were represented by 20 species belonging to 17 genera and 8 families. Among the recorded families of the reptiles, Gekkonidae was the richest family with 13.33% species followed by Natricidae and Elapidae (10%). Rest of the families were represented by 3.33% species.

Species richness and diversity were found to be high in Bijnor (Table 6.2). On average, 26.72 individuals of anurans and 3.4 individuals species of reptiles were observed in each sample of one hour. Among the recorded anurans, *Euphlyctis cyanophlyctis* is the most abundant species with encounter rate 9.79/hour (Table 6.3).

Species accounts

Amphibians

Bufonidae

Bufonidae is represented by two species belonging to a single genus *Duttaphrynus* Frost, Grant, Faivovich, Bain Haas, Haddad, de Sa, Channing,

Wilkinson, Donnellan, Raxworthy, Campbell, Blotto, Moler, Drewes, Nussbaum, Lynch, Green, and Wheeler, 2006.

The two species, *D. melanostictus* (Gunther, 1864) (Figure: 6.4 & 6.5) and *D. stomaticus* (Lütken, 1864) (Figure: 6.6) are large bodied toads with keratinized warts and a pair of parotid gland present behind the eye. *D. melanostictus* is different from *D. stomaticus* by the presence of cranial ridges on head.

Both species were commonly encountered in the study sites. Calling aggregations of the two species were found along the stagnant water at the bank of the river, crop fields, temporary watersheds, swampy areas. We observed breeding male and female individuals between March to September. Juveniles were recorded on the river banks. Individuals of *D. stomaticus* were recorded from dry places away from water. Juveniles were also recorded almost throughout the study period along the river bank.

Sewage discharge to the river is one of major contributions leading habitat degradation of amphibians.

Dicroglossidae

Medium to large sized frogs, represented by 4 species belonging to 4 genera, namely *Euphlyctis* Fitzinger, 1843, *Hoplobatrachus* Peters, 1863, *Fejervarya* Bolkay, 1915 and *Sphaerotheca* Gunther, 1859 were observed. Each genus was represented by single species.

Except *Sphaerotheca breviceps* (Figure: 6.15) all other three species i.e., *Euphlyctis cyanophlyctis* (Figure: 6.8 & 6.9), *Hoplobatrachus tigerinus* (Figure: 6.11), *Fejervarya* sp. (Figure: 6.10) of this family were found commonly along the study sites. We observed adults of the latter three species in shallow and stagnant water bodies along the river, crop fields and roadside temporary water pools.

Juveniles of *H. tigerinus* were recorded near swampy areas in Narora, in the month of August 2017. Juveniles of *Fejervarya* sp. were found almost throughout the study period along the river banks. We also observed an adult of *Fejervarya* sp. feeding on *Microhyla* sp. in Narora. This is the first report of Dicroglossid frog feeding on *Microhyla* sp.

Calling individuals of *S. breviceps* were found in roadside water puddles in Byas Ghat. We encountered another individual on roadside in Tigri (zone 2). We also recorded calling aggregation in stagnant water bodies on the sandy bank of Alaknanda River in Srinagar, Uttarakhand.

Ranidae

We recorded only one species, *Hylarana tytleri* Theobald, 1868 (Figure: 6.7), a small sized frog with elongated body. We encountered individuals in temporary water pools with Eichhornia sp. near agricultural field in Nabadwip, West Bengal (zone 6) in the month of May 2018.

Microhylidae

This family was represented by only one species, *Microhyla nilphamariensis* Howlader, Nair, Gopalan and Merila, 2015 (Figure: 6.12 and 6.13). A Small sized frog. Body oval shaped with irregular shaped dark brown markings.

Individuals were encountered along temporary water bodies with vegetation and agricultural fields. Juveniles were recorded in Tigri and Narora (zone 2) in the month of July and August, 2017. We observed adults feeding on small ants in Tigri, Uttar Pradesh.

Rhacophoridae

Small to medium sized tree frog. We recorded two species belonging to a single genus of this family,

namely *Polypedates taeniatus* (Boulenger, 1906) (Figure: 6.14) and *Polypedates maculatus* (Gray, 1830).

Calling aggregation of *P. taeniatus* was observed near wetland and swampy areas with *Saccharum spontaneum* and *Typha angustifolia*. The species was recorded only from the stretch between Bijnor and Narora (zone 2). Male also calls from the ground. Juveniles were found in Narora in the month of August, 2017.

Opportunistically, we recorded one individual of *Polypedates maculatus* from the bushes 100 m away from Ganga River, in Fattehpur, Uttar Pradesh.

Snakes

Boidae

Represented by only one species i.e., *Eryx johnii* (Russell, 1801) (Figure: 6.30). A short and stout bodied snake, head indistinct from the neck, tail short and blunt.

We recorded one individual from the main channel of the Ganga River in Kachla at day time. Another one individual was recorded from the urban area of Narora on the road side.

Pythonidae

Only one species from this family, *Python molurus* (Linnaeus, 1758) (Figure: 6.31) was recorded. A stout bodied snake with slightly distinct head. Sensory pits present on rostrum, fist two supra labials and in few infra labials.

We recorded one juvenile from Bhadohi (zone 4) in the month of November, 2017.

Colubridae

Represented by two genera namely *Ptyas* (one species), *Lycodon* (one species).

The genus *Ptyas* Fitzinger, 1843 is represented by *Ptyas mucosa* (Linnaeus, 1758). We observed the species along the river banks and agricultural fields.

Another genus of this family, *Lycodon* Boie, 1826 is represented by one species, *Lycodon aulicus* (Linnaeus, 1758) (Figure: 6.26). This species is a medium sized snake with distinct head. One individual was encountered in Kalyani in the month of May, 2018. Another individual was encountered on a concrete wall at bank of Alaknanda River in Srinagar, Uttarakhand. We encountered one individual in human habitation in Kannauj. All the individuals were recorded at night.

Homalopsidae

We recorded single species belonging to the genus *Enhydris* Sonnini and Latreille, 1802.

E. sieboldii (Schlegel, 1837) (Figure: 6.22 & 6.23) was commonly encountered on the river bank near Bijnor barrage. It is more active at night. We recorded six individuals in Bijnor in July, 2017. A juvenile was recorded from Tigri, Uttar Pradesh (zone 2).

Natricidae

Represented by two genera, i.e., *Xenochrophis* (two species) and *Amphiesma* (one species).

The genus *Xenochrophis* Gunther, 1864 is represented by two species, *Xenochrophis piscator*

Amolops jaunsari

(Schneider, 1799) (Figure: 6.24 & 6.25) and *Xenochrophis cerasogaster* (Cantor, 1839), stout or slender bodied snakes with keeled scales.

X. piscator was the most common species among all the recorded species of snakes. We found the species along all the stretches of the Ganga River. Individuals were found on river bank, swampy areas, crop fields and wetlands. Juveniles were recorded between May and August.

In the month of September, 2017 we found two individuals of *X. cerasogaster* in Bijnor. Individuals were observed in the wetlands associated with Ganga River. Among other natricine snakes, we have recorded *Amphiesma* Dumeril and Bibron, 1854. Only one species of this genus, *Amphiesma stolatum* (Linnaeus, 1758) (Figure: 6.33) was recorded in Bijnor.

Lamprophiidae

This family is represented by a single species, *Psammophis candanarus* (Merrem, 1820) (Figure: 6.32). This rare snake was recorded in Bijnor in the month of September, 2018. The individual was encountered at night while roosting on *Typha* grass at a height of 1m.

Elapidae

This family includes all the venomous snakes. Species of this family are slender bodied with slightly distinct head. From this family, we recorded three species belonging to two genera, i.e., *Naja* (two species) and *Bungarus* (one species).

Species recorded under the genus *Naja* Laurenti, 1768 were *N. naja* (Linnaeus, 1758) (Figure: 6.28) and *N. kaouthia* (Lesson, 1831) (Figure: 6.29).

We recorded only one individual of *N. naja* from a village in Fattehpur (zone 4). Another species of the genus, *N. kaouthia* was recorded from Haldia, West Bengal in May, 2018. It was recorded from agricultural field.

The genus *Bungarus* Daudin, 1803 is represented by a single species, *Bungarus caeruleus* (Schneider, 1801) (Figure: 6.27), recorded from Haldia, West Bengal (zone 6). It was encountered at night on the roadside along agricultural field in the month of May, 2018.

Lizards

Scincidae

Represented by a single species, *Eutropis dissimilis* (Hallowell, 1857) (Figure: 6.16).

It was recorded in the stretch between Narora to Kannauj (zone 3). We observed the species in the vegetation along river bank and agricultural fields. Active both day and night time.

Agamidae

This family was represented by two genus, *Calotes* Cuiver, 1817 (one species) and *Sitana* Cuiver, 1829 (one species).

Frequently encountered species of this family is *Calotes versicolor* (Daudin, 1802) (Figure: 6.20). It has a stout body that is laterally compressed. The head is large and tail long. Body scales pointed, directing backward and upward. Commonly found in almost every habitat; bushy thickets to human habitation, agricultural fields.

Only a single species of this genus *Sitana* Cuiver, 1829 was encountered (Figure: 6.21). It has a slender body with a long tail, snout acute and dorsal keeled scales. We recorded only one individual (male) from Ballia (zone 5). It was recorded from bushes along the river bank.

Gekkonidae

From this family we recorded four species belonging to two genera *Hemidactylus* Oken, 1817 (3 species) and *Cyrtodactylus* Gray, 1827 (one species).

Recorded species of the genus *Hemidactylus* Oken, 1817 are medium sized, flat bodied geckos with vertical eye pupil. The genus was represented by 3 species such as *Hemidactylus* cf. *brookii* (Gray, 1854) (Figure: 6.18), *Hemidactylus flaviviridis* Ruppell, 1835 and *Hemidactylus* cf. *frenatus* (Duméril & Bibron, 1836) (Figure: 6.19).

Individuals were recorded from bushes and rocky embankments along the river. *H. flaviviridis* was frequently encountered in Byas Ghat. 0nly one individual of *H.* cf. *frenatus* was observed on *Ziziphus* sp. on the river bank in Kalyani, West Bengal.

Another genus of the family *Cyrtodactylus* Gray, 1827 is represented by a single species, *Cyrtodactylus fasciolatus* (Blyth, 1861) (Figure: 6.17). This species was frequently encountered in Byas Ghat. It was also recorded from Srinagar, Uttarakhand. It prefers rocky habitats along the river and nocturnal in habit.

Varanidae

The family was represented by single species belonging to the genus *Varanus* Merrem, 1820.

Varanus bengalensis (Daudin, 1802) is a large bodied lizard. Only one individual was recorded from the river bank in Narora.

Table 6.1: Site wise presence absence of amphibian and reptile species along with their WL(P)A 1972 and IUCN status. ("+" present, "-" absent, Sc.- Schedule, LC- Least Concern, NE- Not Evaluated, DD- Data Deficient)

		Species Name											
Group	**Family**	**Scientific Name**	**Common English Name**	**Byas Ghat**	**Bijnor**	**Tigri Ghat**	**Narora**	**Kachla**	**Shamsabad**	**Kannauj**	**Kanpur**	**Fattehpur**	**Allahabad**	**Bhadoi**
Amphibians	Bufonidae	*Duttaphrynus melanostictus*	Common Asian Toad	+	+	+	+	+	+	+	+	+	+	+
		Duttaphrynus stomaticus	Marbled Toad	+	+	+	+	+	+	+	+	+	+	-
	Dicroglossidae	*Euphlyctis cyanophlyctis*	Skittering Frog	+	+	+	+	+	+	+	+	+	+	+
		Hoplobatrachus tigerinus	Indian Bull Frog	-	+	+	+	+	+	+	+	-	-	-
		Fejervarya sp.	Cricket Frog	-	+	+	+	+	+	+	+	-	+	-
		Sphaerotheca breviceps	Indian Burrowing Frog	+	-	-	-	-	-	-	-	-	-	-
	Ranidae	*Hylarana tytleri*	Leaf Frog	-	-	-	-	-	-	-	-	-	-	-
	Microhylidae	*Microhyla nilphamariensis*	-	-	+	+	+	-	-	-	-	-	-	-
	Rhacophoridae	*Polypedates taeniatus*	Terai Tree Frog	-	+	+	+	-	-	-	-	-	-	-
		Polypedates maculatus	Common Indian Tree Frog	-	-	-	-	-	-	-	-	+	-	-
Snakes	Boidae	*Eryx johnii*	Red Sand Boa	-	-	-	-	+	-	-	-	-	-	-
	Pythonidae	*Python molurus*	Indian Rock Python	-	-	-	-	-	-	-	-	-	-	+
	Homalopsidae	*Enhydris sieboldii*	Siebold's Smooth-scaled Water Snake	-	+	+	-	-	-	-	-	-	-	-
	Natricidae	*Xenochrophis piscator*	Checkered Keelback	+	+	+	+	+	+	+	+	+	+	-
		Xenochrophis cerasogaster	Painted Keelback	-	+	-	-	-	-	-	-	-	-	-
		Amphiesma stolatum	Buff-striped Keelback	-	+	-	-	-	-	-	-	-	-	-
	Colubridae	*Ptyas mucosa*	Indian Rat Snake	-	-	-	-	-	-	-	-	-	-	+
		Lycodon aulicus	Common Wolf Snake	-	-	-	-	-	-	-	-	-	-	-
	Lamprophiidae	*Psammophis condanarus*		-	+	-	-	-	-	-	-	-	-	-

Study Sites																	
	Mirzapur	Varanasi	Gangabarar	Ballia	Chhapra	Semaria	Munger	Sahibganj	Farakka	Jiaganj	Katwa	Nabadwip	Kalyani	Haldia	WL(P)A 1972	IUCN Status
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	LC
	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	LC
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	Sc. IV	LC
	-	+	-	-	+	+	-	-	+	+	+	-	+	+	Sc. IV	LC
	-	+	+	+	+	+	+	-	+	+	+	+	+	+	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	LC
	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	LC
	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	LC
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	LC
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sc. IV	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sc. I	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sc. IV	DD
	+	+	+	-	-	-	-	+	+	-	+	+	-	-	Sc. II	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sc. IV	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sc. IV	NE
	-	-	-	-	-	-	-	-	+	-	-	-	-	-	Sc. II	NE
	-	-	-	-	-	-	-	-	-	-	-	-	+	-	Sc. IV	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sc. IV	LC

Species Name												
Group	Family	Scientific Name	Common English Name	Byas Ghat	Bijnor	Tigri Ghat	Narora	Kachla	Shamsabad	Kannauj	Kanpur
	Elapidae	*Naja naja*	Spectacled Cobra	-	-	-	-	-	-	-	-
		Naja kaouthia	Monocled Cobra	-	-	-	-	-	-	-	-
		Bungarus caeruleus	Common Krait	-	-	-	-	-	-	-	-
Lizards	Scincidae	*Eutropis dissimilis*	Striped Grass Skink	-	+	+	+	+	+	+	-
	Agamidae	*Calotes versicolor*	Garden Lizard	-	+	+	+	+	+	+	+
		Sitana sp.	Fan Throated Lizard	-	-	-	-	-	-	-	-
	Gekkonidae	*Hemidactylus* cf. *brookii*	Brook's Gecko	-	+	+	+	-	-	-	-
		Hemidactylus flaviviridis	Indian House Gecko	+	+	-	-	-	-	-	-
		Hemidactylus cf. *frenatus*	Asian House Gecko	-	-	-	-	-	-	-	-
		Cyrtodactylus fasciolatus	Banded Bent-toed Gecko	+	-	-	-	-	-	-	-
	Varanidae	*Varanus bengalensis*	Indian Monitor Lizard	-	-	-	+	-	-	-	-

	Study Sites																		
	Fattehpur	Allahabad	Bhadoi	Mirzapur	Varanasi	Gangabarar	Ballia	Chhapra	Semaria	Munger	Sahibganj	Farakka	Jiaganj	Katwa	Nabadwip	Kalyani	Haldia	WL(P)A 1972	IUCN Status
	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sc. II	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	Sc. II	LC
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	Sc. IV	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NE
	+	-	-	-	+	-	-	-	-	-	-	+	+	-	-	+	-	-	NE
	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	+	-	-	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	LC
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NE
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sc. I	LC

Agricultural fields and temporary water bodies are breeding habitat of Microhylid and Dicroglossid Frogs

Table 6.2: Site wise herpetofaunal species recorded in the visual encounter survey across the study sites.

	Name of the Sites									
	Byas Ghat	**Bijnor**	**Tigri Ghat**	**Narora**	**Kachla**	**Shamsabad**	**Kannauj**	**Kanpur**	**Allahabad**	**Bhadoi**
Total no. of individuals of all species	47	38	52	69	29	34	40	38	4	8
Species Richness	6	12	11	9	5	5	5	6	2	4
Species Diversity	1.37	2.34	2.17	1.89	1.45	1.42	1.07	0.75	0.56	1.21

Table 6.3: Total number of individuals, relative abundance and encounter rate of the recorded herpetofaunal species in the Visual Encounter Survey.

	Name of the Species									
	D. melanostictus	***D. stomaticus***	***E. cyanophlyctis***	***H. tigerinus***	***Fejervarya* sp.**	***S. breviceps***	***H. tytleri***	***M. nilphamariensis***	***P. taeniatus***	***P. molurus***
Total no. of Individuals	142	38	234	60	134	3	5	37	15	1
Relative Abundance	0.21	0.06	0.35	0.09	0.2	0.01	0.01	0.06	0.02	0.01
Encounter Rate	5.92	1.58	9.75	2.5	5.58	0.13	0.21	1.54	0.63	0.04

6.4 DISCUSSION

The present survey yielded 30 species of herpetofauna from the study area including 10 species of anurans, 12 species of serpents and 8 species of lacertids. The three species of anurans, *D. melanosticus, Fejervarya* sp. and *E. cyanophlyctis* were frequently encountered and found to be distributed almost in all the study sites (Table 6.2 and 6.3). We recorded few species viz. *P. taeniatus, H. tytleri, E. seiboldii, C. fasciolatus,* which were found to be locally common. *P. taeniatus* and *E. seiboldii* were only recorded from the zone 2 of the middle stretch. *H. tytleri* was recorded from zone 6 of the river. Similarly, *C. fasciolatus* is restricted to the high elevational zone of the upper stretch. The study also recorded rare species of snakes such as *X. cerasogaster* and *P. condanarus.* We reported *M. nilphamariensis* from the region for the first time. Earlier population of *M. nilphamariensis* of this region was considered as *M. ornata.* Recently, Garg et al. (2018) assigned the population of the region to *M. nilphamariensis*. In the present study, species richness was found to be high in the zone 2 (Bijnor-Narora) of the middle stretch of Ganga River (Table 6.2). The high species richness in the region is probably due to the movement of the animals from the nearby protected forest such as Hastinapur wildlife Sanctuary and presence of potential wetlands in the area. Species richness in the zones 4-5 was found to be comparatively low, and no reptile species was recorded during the study period (Table 6.2). This is because of the area is mostly occupied by settlements and also reptile species of the area are more secretive in nature. In our study, three species (*D. melanosticus, Fejervarya* sp. and *E. cyanophlyctis*) were in the most abundant range with 128-255 individuals recorded (Figure: 6.2). Similarly four species (*P. molurus, L. aulicus, N. kaouthia, B. caeruleus*) were represented by single individuals. Four species, i.e., *H. tytleri, E. dissimilis, C. versicolor, E. sieboldii* were found to be moderately abundant within the frequency range of 4-7 individuals, as shown by the peak of the curve (Figure: 6.2). Besides, we recorded a few species

Mirzapur	Varanasi	Gangabarar	Ballia	Chhapra	Semaria	Munger	Sahibganj	Farakka	Jiaganj	Katwa	Nabadwip	Kalyani	Haldia
8	19	8	17	43	20	66	40	35	20	28	24	11	55
2	1	1	1	5	4	3	3	7	5	5	5	6	7
0.38	≈0	≈ 0	≈ 0	1.36	1.25	0.56	0.61	1.24	1.26	1.31	1.26	1.49	1.6

E. sieboldii	*X. piscator*	*L. aulicus*	*N. kaouthia*	*B. caeruleus*	*E. dissimilis*	*C. versicolor*	*H. cf. brookii*	*H. flaviviridis*	*C. fasciolatus*
7	23	1	1	1	4	5	16	18	8
0.08	0.27	0.01	0.01	0.01	0.05	0.06	0.19	0.21	0.09
0.29	0.96	0.04	0.04	0.04	0.17	0.21	0.67	0.75	0.33

(*Fejervarya* sp., *Sitana* sp. *Hemidactylus* cf. *frenatus*, *Hemidactylus* cf. *brookii*) which are either conferred to closely related species whose identity is unknown. Most of the species complexes are widespread, though the members of these species complexes can have limited ranges within this broad range (Bain et al., 2003). Members of the species complexes recorded in our study are *C. versicolor* (Zug et al. 2006), *L. aulicus, X. piscator* (Vogel & David, 2006). The species recorded during the study period are composed of Indo-Malayan genera (*Amphiesma, Enhydris, Naja, Python, Varanus* and *Xenochrophis*), followed by of Indian genera (*Bungarus, Hemidactylus)* and transitional elements such as *Lycodon* (sensu Das, 1996). The number of species recorded in this study was low in comparison to other studies in India. Most of them are common and widely distributed in India, South Asia and Southeast Asia. However, a few species viz. *Duttaphrynus himalayanus, Nanorana, minica, Nanorana vicina, Amolops jaunsari, Amolops formusus, Meghophrys* cf. *parva, Lygosoma albopunctata, Laudakia tuberculata, Dendrelaphis tristis*, were recorded from the Alaknanda Basin. The number of herpetofaunal species of region will increase with further extensive sampling. This assumption is supported by the rarefaction curve (Figure: 6.3) from the present study. However, the present result was based on single year and time constrained survey. Considering the paucity of knowledge on diversity, distribution of the herpetofauna in the region, the present study assumes significance to provided baseline for future study on many aspects such as ecotoxicology taking herpetofauna as model organisms.

The Ganges basin is known for some name bearing taxa, type localities of which within the biogeographical limit of the river basin (*Chiromantis dudhwaensis, Polypedates taeniatus, Enhydris sieboldii* and *Xenochrophis cerasogaster*). The region needs a systematic study on herpetofauna as is evident from the recent discoveries of amphibian species by Ohler et al. (2009) and Bahuguna (2018). Systematic study and intensive sampling throughout the region in combination with integrated taxonomy would be beneficial to understand the taxonomic identity of the species and their geographical distribution and conservation requirements.

Among the recorded species, *P. molurus* and *V. bengalensis* have been accorded the highest legal protection status, under Schedule I of WL(P)A, 1972. Four species, *N. naja, N. kaouthia, X. piscator, P. mucosa* are under Schedule II of the Act. Rest of the snake species and two anurans (*H. tigerinus* and *E. cyanophlyctis*) are listed under Schedule IV of the Act (Table 6.1). Moreover, two species of snakes (*P. condanarus* and *N. kaouthia*), two species lizards (*H.* cf. *frenatus* and *V. bengalensis*) and all recorded anuran species (except *M. nilphamariensis*) are categorized as Least Concern (LC) under the IUCN Red List.

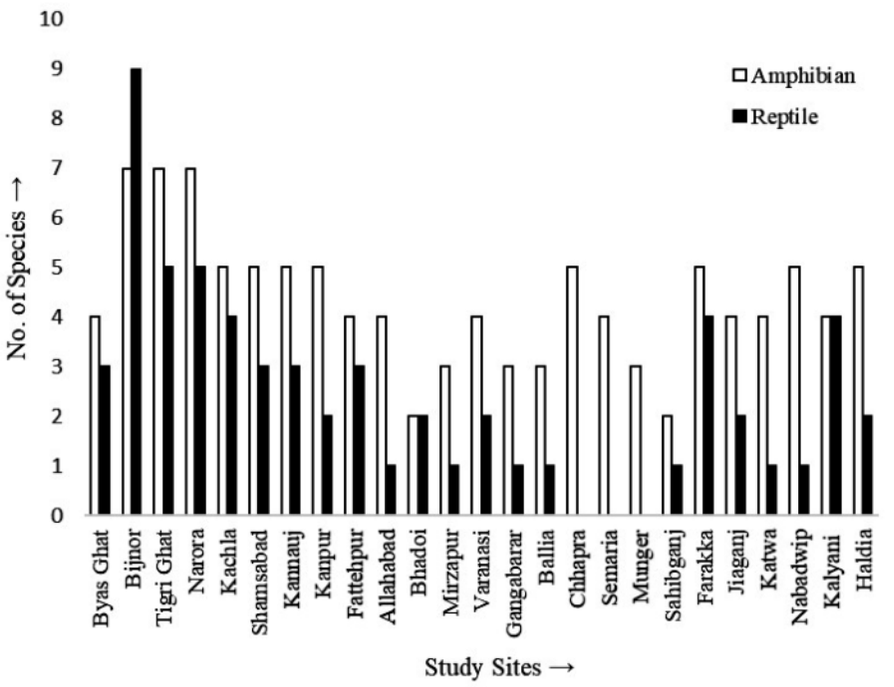

Figure 6.1: Schematic representation of site wise species richness of herpetofauna along Ganga River

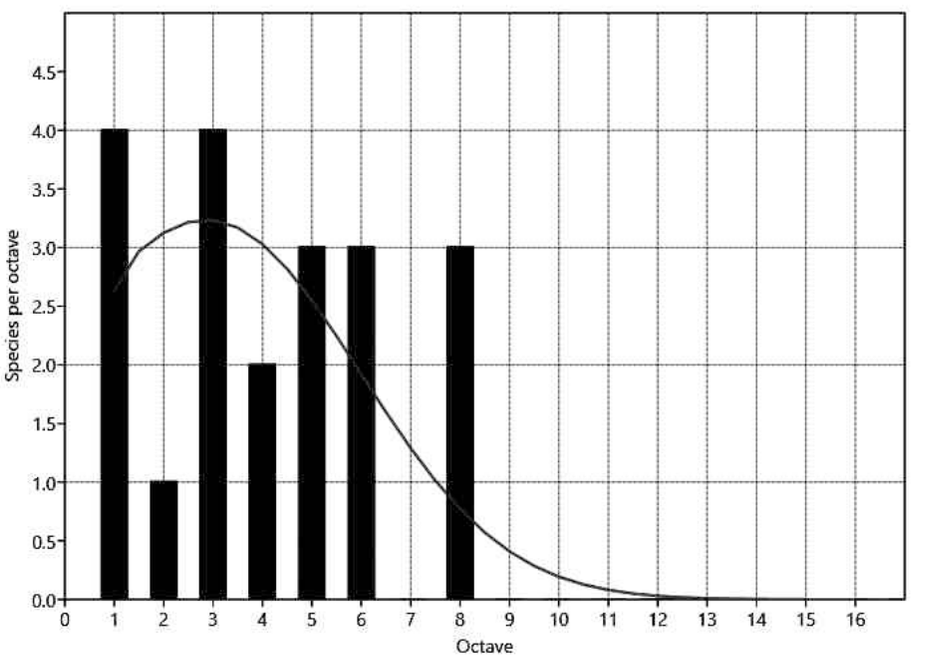

Figure 6.2: Log normal plot of herpetofaunal species sampled from the study sites. Four species are moderately abundant as indicated by the peak of the curve occurring in the octave 3 (4-7 individuals)

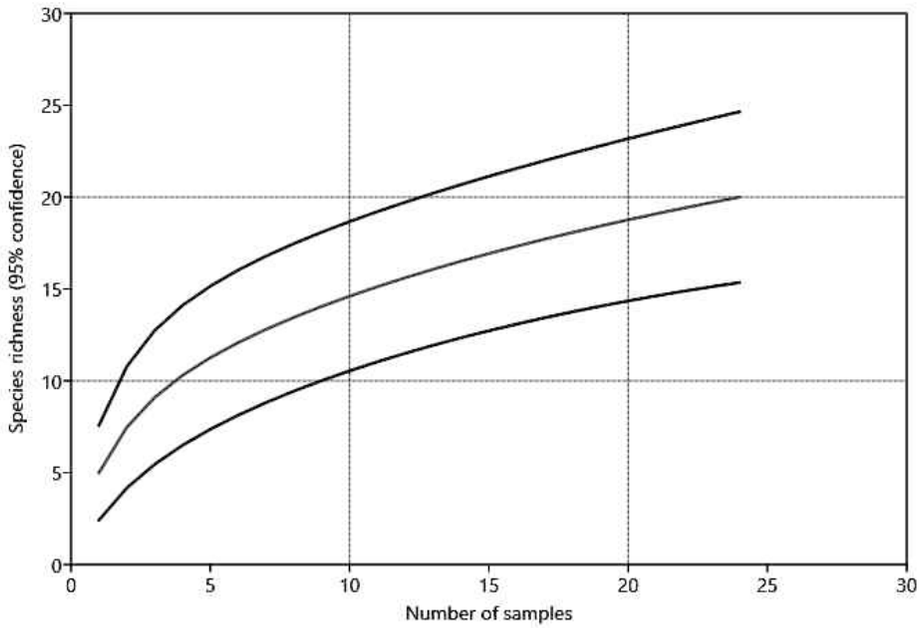

Figure 6.3: Rarefaction curve of herpetofaunal communities with 95% confidence limit

Typha Grass along Ganga River is typical habitat for terai tree frog (*Polypedates taeniatus*)

Figure 6.4: An amplectant pair of *Duttaphrynus melanostictus*

Figure 6.5: *Duttaphrynus melanostictus* (a calling male)

Figure 6.6: An amplectant pair of *Duttaphrynus stomaticus*

Figure 6.7: *Hylarana tytleri*

Figure 6.8: An An amplectant pair of *Euphlyctis cyanophlyctis*

Figure 6.9: *Euphlyctis cyanophlyctis* (a calling male)

Figure 6.10: *Fejervarya* sp.

Figure 6.11: *Hoplobatrachus tigerinus*

Figure 6.12: *Microhyla nilphariensis*

Figure 6.13: Froglets of *Microhyla nilphamariensis*

Figure 6.14: *Polypedates taeniatus*

Figure 6.15: *Sphaerotheca breviceps*

Figure 6.16: *Eutropis dissimilis*

Figure 6.17: *Cyrtodactylus fasciolatus*

Figure 6.18: *Hemidactylus* cf. *brookii*

Figure 6.19: *Hemidactylus* cf. *frenatus*

Figure 6.20: *Calotes versicolor*

Figure 6.21: *Sitana* sp.

Figure 6.22: *Enhydris sieboldii*

Figure 6.23: A juvenile of *Enhydris sieboldii*

Figure 6.24: *Xenochrophis piscator*

Figure 6.25: *Xenochrophis piscator* feeding on *D. melanostictus*

Figure 6.26: *Lycodon aulicus*

Figure 6.27: *Bungarus caeruleus*

Figure 6.28: *Naja naja*

Figure 6.29: *Naja kaouthia*

Figure 6.30: *Eryx johnii*

Figure 6.31: *Python molurus*

Figure 6.32: *Psammophis condanarus*

Figure 6.33: *Amphiesma stolatum*

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Amolops formosus, A fast flowing stream frog

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Shallow Water Pools along river bank provides breeding habitat for anurans like *Duttaphrynus melanostictus* and *Euphlyctis cyanophlyctis*

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INSIGHTS INTO FRESHWATER TURTLE DIVERSITY OF THE GANGA RIVER AND THE PERCEIVED THREATS

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ABSTRACT

The Ganga River supports 13 species of freshwater turtles, including eight that are threatened. Despite being a 'Global Turtle Hotspot', this region lacks baseline information on the status and distribution of turtles. The study is aimed at documenting the distribution, local diversity patterns, of turtles and assess threats at 29 representative sites from Haridwar in Uttarakhand to Ganga Sagar in West Bengal, each spanning 5 km. Visual Encounter Surveys (VES), Gill Net (GN) sampling and interviews with local fisherman were carried out during post-monsoon (October – November 2017) and summer (May-June 2018) seasons. The rapid survey resulted in recording a total of 11 species (n= 161) of turtles across Ganga. *Pangshura smithii* was recorded as the most abundant. The Endangered *Batagur dhongoka* and *Chitra indica* were encountered at

7

three sites indicating select regions to be important turtle conservation priority areas. Shannon diversity indices were highest in sites at Brijghat to Narora in the middle stretch of river Ganga. 80% of respondents who were expert fishermen with considerable ecological knowledge of turtles, identified a minimum of five species from photographs. Accidental capture in nets was identified as the biggest threat, followed by intentional hook line captures for consumption, and then turtle nest predation primarily by feral dogs. Additionally, a site-specific estimation of turtle populations was carried out at Narora, Uttar Pradesh, through a mark-recapture study during post-winter and summer season of 2018, within a 25 km stretch on either side of the Narora Barrage. At the Narora site, 11 species (n=549) were encountered from 198 trap efforts. Two distinct sub-species of *Pangshura smithii* (n=331) were captured, *P. s. pallidipes* and *P. s. smithii*. More systematic efforts are required to learn about turtle assemblage patterns at local scales, their habitat affinities and responses to anthropogenic activities along the Ganga River.

Keywords: Aquatic Ecology; Freshwater Turtle Assemblage; Species Richness; Mark-recapture; Threat Assessment

7.1 INTRODUCTION

The Ganga River supports upto 13 species of freshwater turtles, and this level of taxonomic diversity and high species richness patterns can be related to high rates of speciation (Mittelbach et al., 2007). While more than 50% of freshwater turtle species are threatened with extinction (Rhodin et al., 2011), the Ganga River is known to support eight species which are in threat categories, such as Painted Roofed Turtle *Batagur kachuga* (CR), Indian Narrow-headed softshell *Chitra indica* (EN) and Indian softshell *Nilssonia gangetica* (VU). Despite the uniqueness of diversity, no qualitative or quantitative base line information exists on the species wise occurrence or abundance in different habitats, in the State of Uttar Pradesh (Singh et al., 2009) as well as other States. There have been few scientific surveys in Northern Indian rivers (Basu, 1993 in Gomti River, Behera and Rao, 1999 in Upper Ganges River).

Table 7.1: Freshwater turtles of Ganga River, their IUCN status and Wildlife Protection Act (WPA), 1972 Schedules

S.N.	Scientific name	Common name	IUCN status	WPA Schedule
1	*Batagur baska*	Northern River Terrapin	Critically Endangered	Schedule I
2	*Batagur kachuga*	Painted Roofed Turtle	Critically endangered	Schedule I
3	*Batagur dhongoka*	Three-striped Roofed Turtle	Endangered	Not listed
4	*Geoclemys hamiltonii*	Spotted Pond Turtle	Vulnerable	Schedule I
5	*Pangshura tecta*	Indian Roofed Turtle	Least concern	Schedule I
6	*Pangshura smithii*	Brown Roofed Turtle	Near Threatened	Not listed
7	*Pangshura tentoria*	Indian Tent Turtle	Least concern	Not listed
8	*Hardella thurjii*	Crowned River Turtle	Vulnerable	Not listed
9	*Melanochelys trijuga*	Indian Black Turtle	Near Threatened	Not listed
10	*Chitra indica*	Indian Narrow-headed softshell	Endangered	Not listed
11	*Nilssonia gangetica*	Indian/Ganges softshell	Vulnerable	Schedule I
12	*Nilssonia hurum*	Indian Peacock softshell	Vulnerable	Schedule I
13	*Lissemys punctata*	Indian Flapshell Turtle	Least concern	Schedule I

As freshwater turtles depend critically on natural river flows, sand and silt deposition, and emergent floodplain and river island habitats for feeding, basking, and breeding (Lenhart et al., 2013), increasing anthropogenic pressures on the riverscape can lead to extirpation of turtles. In particular, flow regulation and fragmentation of riverine habitats by dams and barrages pose a major threat to river turtles, such as river systems under the control of man-made barrages and altered flow regimes. Increased agriculture, illegal fishing and sand mining is posing a great threat to muggers, gharials, turtles, and breeding birds of Ganga (Hussain, 2009). Human modifications to the natural flow regimes of rivers have had serious consequences on global freshwater biodiversity (Dudgeon et al., 2006). A successful river restoration project should be based on the ecological character of a healthy river monitoring its biology. Baseline data collection of the habitat parameters of the river influencing the status and distribution of turtles is very essential for conservation planning and subsequently assessing the effectiveness of management actions. Intensive monitoring of the distribution and diversity of species of turtles in crucial stretches of the Ganga will help create baselines for species conservation strategies of threatened turtle species.

Study area

The Ganga River basin and its floodplain is a 'Global Turtle Hotspot' and an important 'Global Turtle Priority Area' (Buhlmann et al., 2009). The Ganges river floodplains are of key importance to the conservation of riverine wildlife and can be identified as a critical habitat for turtles in need of protection, as the region is under constant pressure of many threats (e.g. pollution, sand mining, turtle hunting/poaching, riverbed agriculture, and barrage-regulated flows). In this study the entire river stretch was stratified into 32 intensive sampling sites (Figure 7.1) from Gangotri in Uttarakahnd to Ganga Sagar in West Bengal, to serve as representative monitoring sites for the river Ganga.

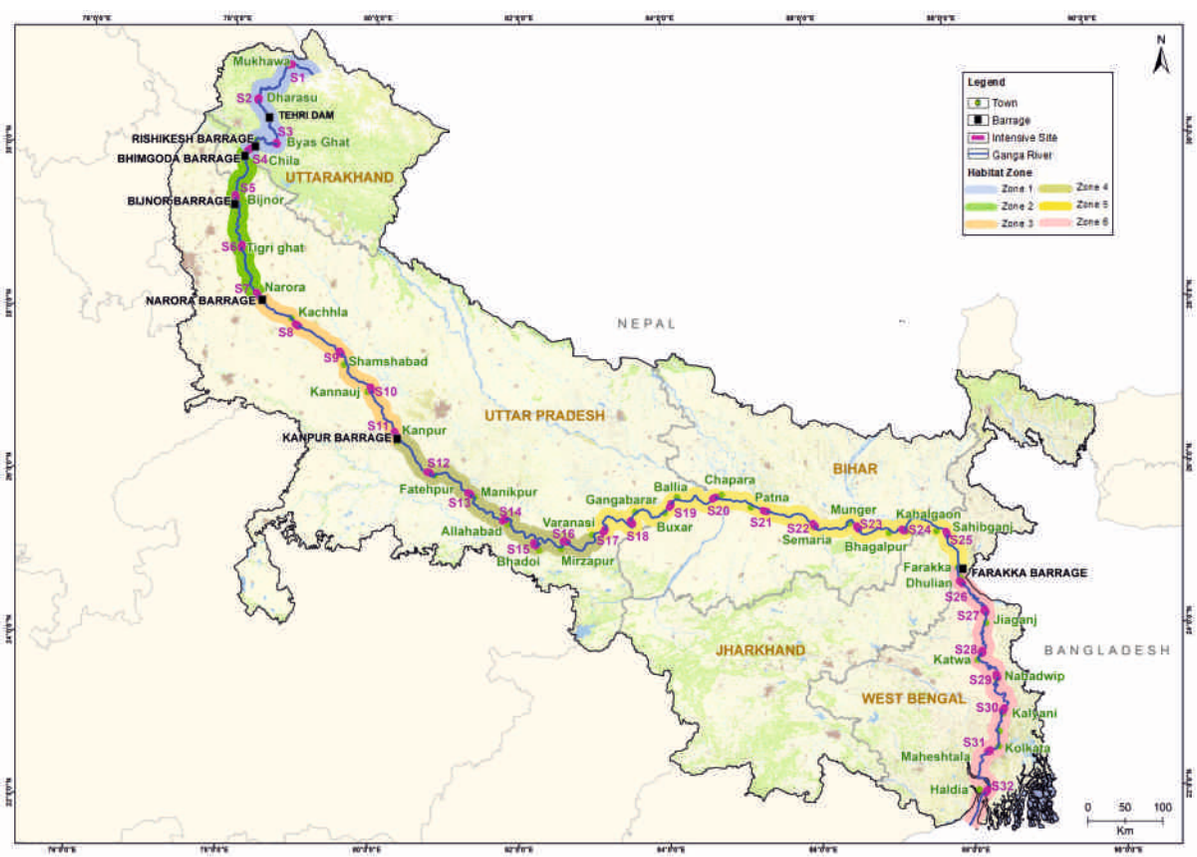
The survey was conducted in two seasons- Post monsoon (October to December 2017) and Summer (February to June 2018) in the 32 sites across three stretches

- Upper stretch- Gangotri to Haridwar (4 sites)
- Middle- Bijnor to Sahibganj (21 sites)
- Lower- Farakka to Ganga Sagar (7 sites)

The sites are also stratified into six zones across the three stretches of the Ganga River.

- HZ 1- Gangotri to Haridwar (4 sites)
- HZ 2- Haridwar to Narora (3 sites)
- HZ 3- Narora to Kanpur (4 sites)
- HZ 4- Kanpur to Varanasi (6 sites)
- HZ 5- Varanasi to Farakka (8 sites)
- HZ 6- Farakka to Ganga Sagar (7 sites)

Figure 7.1: Map of 32 intensive sampling sites along the Ganga River



7.2 MATERIALS AND METHODS

The survey for freshwater turtles was carried out in 29 of the 32 intensive sites from Bijnor till Ganga Sagar only in the four states of Uttar Pradesh, Bihar, Jharkhand and West Bengal. The survey was conducted by a team of researchers using a motor boat in the 5 km river stretches for conducting the following:

- Visual encounter survey and net sampling
- Aquatic habitat assessments

Documenting presence of freshwater turtles through visual surveys and net sampling

Turtles can alternatively be caught using a wide variety of trapping methods, each suitable for a specific habitat or species. Gill mesh nets, hoop traps, basking traps are commonly used for many turtle ecological studies across the world. To increase the likelihood of species detection, multiple trapping methods are deployed in a variety of depths (Glorioso et al., 2010) and to reduce bias towards certain species or size classes. When working with assemblages of species that differ in behaviour, a suite of capture techniques may be required (Liner, 2006).

- Visual encounter surveys were conducted in all 29 intensive sampling sites of the middle and lower stretches of the Ganga River during the day. Basking turtles on land or surfacing in water were observed using a Nikon binoculars (8X40), by motor boat travelling at a distance of 6-10 m from the river bank.
- Four and eight inch mesh nylon gill nets of dimensions 50 m length and 3 m height were deployed in the day time to detect presence of elusive species for time periods of 3-4 hours, and checked for turtles at a two hour interval. The gill nets were deployed at only 20 of the 29 intensive sampling points due to logistical reasons. Sampling locations within each stretch were chosen on the basis of accessibility, suitability to deploy nets and probability of encountering turtles, based on habitat quality and least anthropogenic disturbances.

Morphometric data such as Curved and Straight Carapace Lengths and Width; Plastron Length and Width, and weight was measured for each turtle, when captured. Age class and sex was also recorded. Geo locations and photographs of each turtle were also maintained. All turtles caught were marked for individual identification by notching the marginal scutes with a small 'V' using a bone saw to represent a numeric code. Soft shell turtles were marked with metal tags with an alpha-numerical code on the hind limbs (For example a Ganges softshell turtle *Nilssonia gangetica* would have a code of NG001).

Aquatic habitat survey

The 29 intensive sampling sites were assessed for suitability for turtle nesting to see/check whether the water flow and level and river bank habitat was adequate to support turtles. The river banks which could serve as basking and nesting habitat for turtles were assessed for characteristics such as riverbank slope, sand bank extent, % cover of riparian vegetation. This was recorded through visual surveys by walking along the river bank edge. Land-cover types of the floodplains (agriculture, scrub, bare sand, etc.) was also recorded and a habitat matrix was prepared. Eight water quality parameters were also assessed during the surveys in the intensive sites namely water temperature, Dissolved Oxygen (DO) levels, water pH, TDS, specific conductivity, NO3, NH4 and salinity levels.

Figure 7.2: Deploying Gill nets from wooden boat

Figure 7.3: Morphometric measurement of turtles

Diversity and species richness

A total of 11 turtle species were encountered across the four states, of which nine species were encountered through net sampling and seven species were encountered during Visual Encounter Surveys (VES) (Table 7.2). Three species *Hardella thurjii, Chitra indica* and *Nilssonia hurum* were also encountered in the study sites opportunistically either due to fishing net mortalities or through interactions with fishermen.

Table 7.2: Freshwater turtle species encountered across 29 intensive sites in four states

S.N.	Species	Visual Encounter (n=6)	Net Sampling (n=9)	Opportunistic (n=4)
1	*Batagur baska*			
2	*Batagur kachuga*			
3	*Batagur dhongoka*		●	
4	*Pangshura smithii*	●	●	
5	*Pangshura tentoria*	●	●	
6	*Pangshura tecta*		●	
7	*Geoclemys hamiltonii*	●		
8	*Hardella thurjii*	●	●	●
9	*Melanochelys trijuga*	●	●	
10	*Chitra indica*		●	●
11	*Nilssonia gangetica*	●	●	●
12	*Nilssonia hurum*			●
13	*Lissemys punctata*	●	●	

The Gangetic-Brahmaputra floodplains is known to have high species richness and is regarded as a 'Turtle Priority Area'; with 21 species of freshwater turtles occurring in the region. The state of Uttar Pradesh shows the highest species richness (Figure 7.4) with a total of 11 species encountered. The river stretch from Haridwar to Narora (Zone 2) which is reported to be a biodiversity rich area, as it has the presence of a Ramsar site, was found to have the presence of 11 species of freshwater turtles including endangered species like *Chitra indica* and *Batagur dhongoka*. Site 6 Tigri Ghat and Site 7 Narora were found to have the highest diversity followed by Sites 10 Kannauj. Overall zones 2 to 4 covering the upper middle Ganga stretch in the state of Uttar Pradesh is seen to be the most diverse stretches for freshwater turtles.

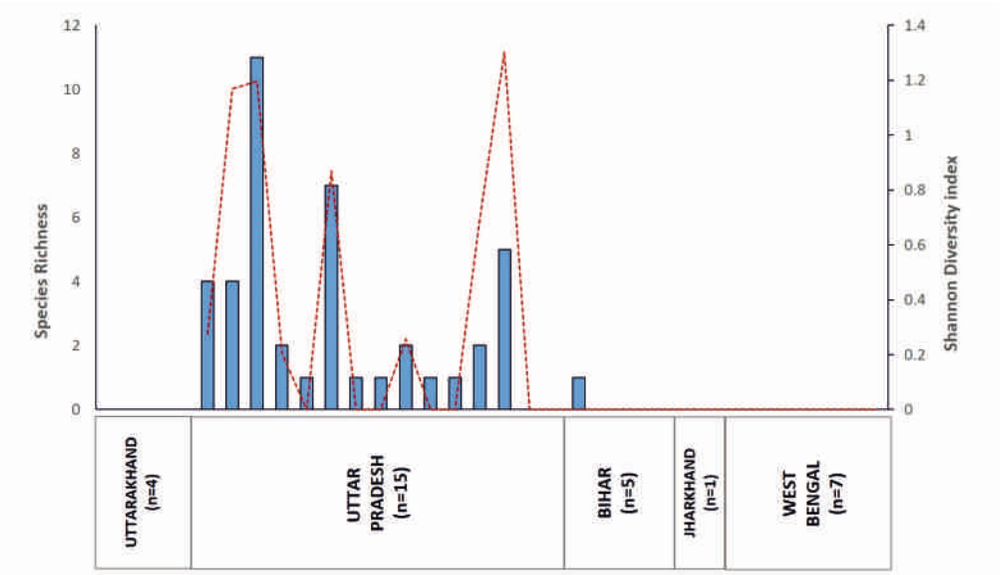


Figure 7.4: Species Richness and Shannon Diversity Index of Freshwater turtle species encountered across the 29 intensive sites along the Ganga River in post monsoon and summer sampling seasons

Water quality relationships

A multiple regression analysis of species richness as well as Shannon diversity index for all sites with eight water quality parameters for the sites, did not result in any significant relation between the effects of water physico-chemical parameters on the diversity or species richness of freshwater turtles across sites in the Ganga River .

Encounter rates and catch per unit effort of freshwater turtle captures

A total of 474 turtles were encountered during the study across 29 sites in four states through visual encounter surveys, net sampling (Table 7.3). *Pangshura smithii* was reported to be the most abundant species from all the intensive study sites, and was visually encountered across many sites. Rare and endangered species such as *Batagur dhongoka, Chitra indica* and *Hardell thurjii* were encountered in few numbers only in sites above the Narora barrage which could indicate suitable habitats for such species only in the upper stretches of Ganga River with low human modification to the riverine habitat.

Table 7.3: Total abundance of freshwater turtle species encountered across the 29 intensive sites in four states during the Ganga survey in post monsoon and summer sampling seasons.

S.N.	SPECIES	POST MONSOON		SUMMER		TOTAL ABUNDANCE
		Visual Encounter Rate (km)	CPUE (hr)	Visual Encounter Rate (km)	CPUE (hr)	
1	*P. smithii*	2.26	0.12	6.92	2.25	357
2	*P. tentoria*	0.09	0	0.33	1.06	60
3	*P. tecta*	0.00	0.01	0.17	0.02	5
4	*B. dhongoka*	0.00	0.03	0	0.17	19
5	*H. thurjii*	0.03	0	0	0.02	3
6	*G. hamitonii*	0.00	0	0.08	0	1
7	*M. trijuga*	0.00	0	0.25	0.02	4
8	*C. indica*	0.00	0.01	0	0	4
9	*N. gangetica*	0.09	0	0.42	0.08	15
10	*N. hurum*	0.00	0	0	0.02	2
11	*L. punctata*	0.03	0	0.08	0.02	4
	TOTAL					**474**

Perception of threats to freshwater turtles by local fishermen

As the threats vary across the entire landscape, semi structured questionnaires were utilised to understand local fishermen's traditional knowledge of turtles, and the threats they felt impacted turtle populations the most. 80 % of the fishermen identified a minimum of 5 species of turtles from photograph, shown to them. 53% said that they encountered more turtles in the summer in their nets, which would make it a better sampling period. Almost 60 % felt that fishing nets were a threat to turtles, even unintentionally, while they fished for their livelihood or knowingly for the meat trade.

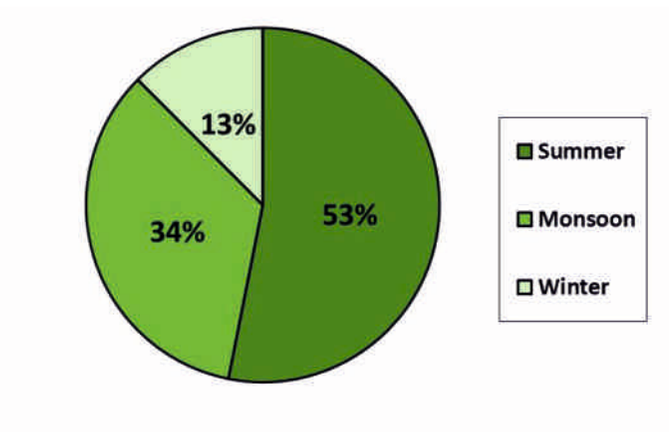


Figure 7.5: Percentage of respondents reporting peak activity season when turtles are encountered most in their nets

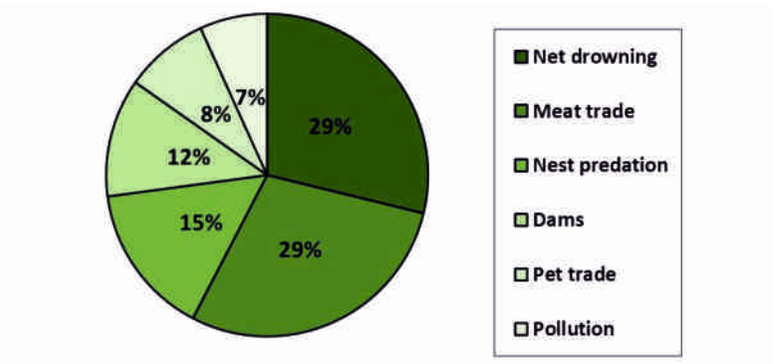


Figure 7.6: Percentage of respondents reporting the threats to freshwater turtles

7.4 POPULATION STUDY OF FRESHWATER TURTLES AT NARORA, UTTAR PRADESH

Background

Turtle populations in Uttar Pradesh are reported to have declined considerably along with habitat loss (Singh et al., 2009). Studies conducted on freshwater turtles in India are few, with the emphasis on the taxonomy and distribution range, while there are a few studies on demography and life history of turtles. The structure of a population has an important ecological value as it ultimately affects the community structure. Populations can be naturally dynamic and change due to human intervention which is a matter of concern (Smith and Smith, 2001). Studies on population and ecology of many commonly observed species like *Pangshura smithii, Pangshura tentoria* are lacking in India, and studies on other specialist and rare species such as *Chitra indica*, and *Batagur dhongoka* are recommended to understand their interactions with riverine habitats and the impact of human modifications on these landscapes.

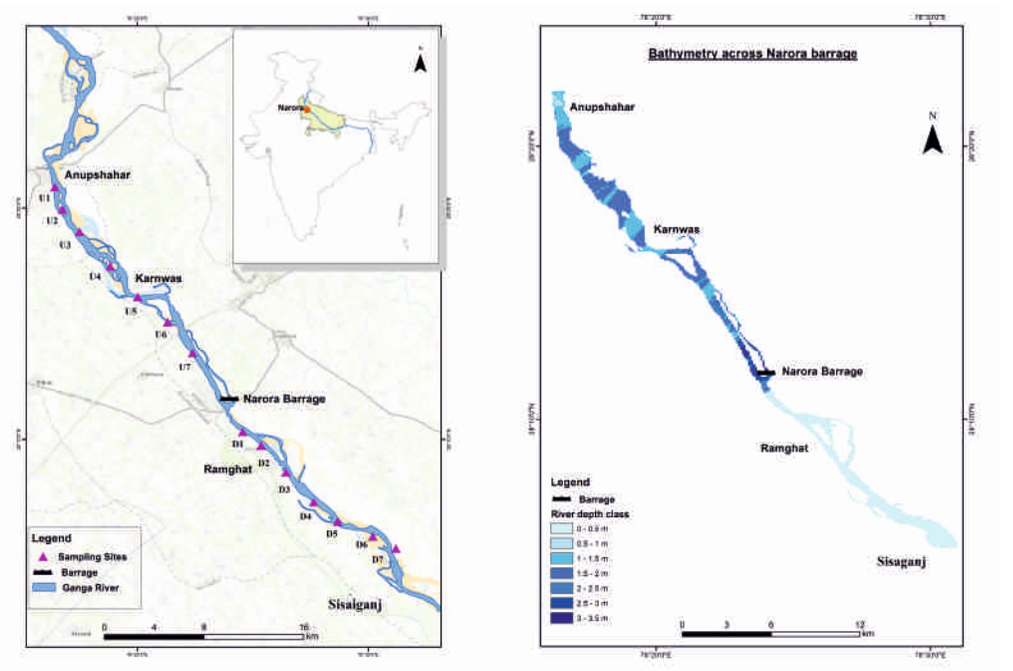


Figure 7.7: Map of the seven sampling sites upstream and downstream each of the Narora barrage, and bathymetric profile of the entire 50 km river stretch from Anupshahr to Sisaganj. (Map Courtesy: Ms. Aishwarya R. and Mr Vipin Rao)

Study Area

The intensive study area, Narora, is a part of upper portion of the Middle Ganga stretch. From the Narora barrage, a river channel is diverted to support agricultural activities through the lower Ganga canal. The study area is a part of upper Ganga Ramsar site with rich biodiversity of fishes, Gangetic dolphin, birds, reptiles and is an important turtle conservation site (Garg and Joshi, 2015; Bashir et al., 2012). Intensive site sampling was conducted in a 45 km river stretch upstream and downstream of the Narora barrage in Uttar Pradesh to gather baseline information on the population status and abundance of freshwater turtles. The sampling was conducted from February to July 2018 in two seasons- Post-winter and summer seasons.

Materials and Methods

Seven sampling sites from upstream and downstream of the Narora barrage were selected for trapping turtles. Nylon gill fishing nets of four and eight inches were placed near the river banks or river islands after carefully examining the area for turtle tracks, habitat, and minimun anthropogenic activity, and were deployed for four hours at each sampling site and checked after every two hours. Turtles caught were measured, marked and released at the same site. Trapping of turtles was done for two days at each sampling site. Each turtle was given a unique ID that represents an alpha-numeric code by notching marginal scutes with a small "v" using bone-saw. Soft- shell turtles were marked with the help of metal tags which contain a three digits unique ID.

Figure 7.8: . Scute notching of a hard shell turtle

Figure 7.9: . Application of metal tag to left hind limb of a soft shell turtle

Results

Total efforts of 198 trap sessions (4 hours each) yielded 549 encounters of turtle individuals, representing 11 species across all sites in Narora (Table 7.4). An individual of *Geoclemys hamiltonii* and 17 dead turtle individuals, including adult size classes of *Batagur dhongoka* and *Hardella thurjii* were encountered during visual survey of the sites. A hatchling of *Chitra indica* was opportunistically captured in a site upstream of the Narora barrage indicating Ramsar as the suitable habitat for breeding sites for this endangered species.

Table 7.4: Table 4 Total abundance of freshwater turtle species encountered across the 29 intensive sites in four states during the Ganga survey in post monsoon and summer sampling seasons

S.No.	Species	Upstream			Downstream		
		Net Sampling	Visual Encounter	Opportunistic	Net Sampling	Visual Encounter	Opportunistic
1	*P. smithii**	112	24	0	178	17	0
2	*P. tentoria*	85	7	0	71	5	0
3	*P. tecta*	1	0	0	1	1	0
4	*B. dhongoka*	8	0	6	4	0	7
5	*H. thurjii*	1	0	0	0	0	3
6	*M. trijuga*	3	1	0	1	0	0
7	*G. hamiltonii*	0	1	0	0	0	0
8	*N. gangetica*	6	0	1	2	0	0
9	*N. hurum*	1	0	0	0	0	0
10	*L. punctata*	1	0	0	0	0	0
11	*C. indica*	0	1	0	0	0	0
	TOTAL	**218**	**34**	**7**	**257**	**23**	**10**

**Pangshura smithii* species has two distinct subspecies *Pangshura smithii pallidipes* and *Pangshura smithii smithii* which were both encountered during the study

Abundance of freshwater turtles in the summer season varied considerably upstream and downstream of the barrage ranging from 201 to 290 turtle individuals. Soft shell turtles such as *Nilssonia gangetica, Nilssonia hurum, Lissemys punctata* were captured only in summer. *Pangshura smithii* (n=331) was observed to be the most abundant species encountered at all sites, followed by *Pangshura tentoria* (n=168) in both upstream and downstream of Narora barrage. The sites upstream of barrage was found to be rich in diversity with a total of 11 recorded species of freshwater turtles.

The 4 inch mesh gill net was found to be the most effective method for trapping individuals of the *Pangshura* genus with over 246 captures across the study sites. A significant number of Endangered *Batagur dhonogoka* (n=13) were encountered dead during surveys, due to drowning by fishing nets placed overnight, both upstream and downstream of the barrage which could indicate their vulnerability to fishing pressures due to nocturnal activity patterns.

7.5 SUMMARY OF FINDINGS

- Visual encounter surveys indicate that *Pangshura smithii* species is fairly abundant in the sites sampled in UP and were seen basking on sand bars and sandy river banks, even in sites of medium to high disturbance. Net sampling yielded maximum captures in the four inch mesh gill nets. No encounters of turtles in the states of Jharkhand and West Bengal could be attributed due to the river being really wide and deep, indicating the need to intensify sampling efforts. However, immense anthropogenic pressures, past and present poaching events, could also be the deciding factors.
- Intensive sampling across 29 sites along the Ganga River gives us a basic understanding on the presence of common species such as *Pangshura smithii* encountered in 14 sites followed by *Pangshura tentoria* encountered in 7 sites. No sightings of *Batagur kachuga* indicate the status of this species in the Ganga River is still inconclusive and it should still be considered a high priority species. Low encounter rates along the main Ganga River of rare species such as *Chitra indica, Nilssonia hurum, Geoclemys hamiltonii, Hardella thurjii, Melanochelys trijuga* indicate their presence in certain sites and their current population status needs to be explored further.
- Bijnor, Kachla and Kannauj sites in Uttar Pradesh have the optimum riparian habitat for turtle presence and were found to have the highest turtle diversity during the study. However sites like Varanasi in Uttar Pradesh, Hooghly and Howrah in West Bengal were seen to have the least suitable habitat for turtles with high anthropogenic disturbances such as pollution, cement ghats, intense ferry and boat activity and people presence along the river. Fishing nets were indicated to be a big threat to freshwater turtles by the local fishermen followed by nest predation of turtles by mainly feral dogs.
- Sites Tigri Ghat and Narora in the middle stretch of river Ganga (Zone 2) which are also a part of the Ramsar site, have the highest diversity of freshwater turtles as well as the presence of juvenile *Chitra indica*, which is a species known to prefer optimum undisturbed riparian habitats with deep river depths and presence of large sandy banks and sand bars. This indicates these sites as high priority for turtle conservation, especially for these habitat specific indicator species of the Ganga River .
- Intensive site sampling for five months at site Narora using capture recapture and visual encounter methods resulted in encounters of 11 of the 15 freshwater turtles species found in the river indicating this site to be protected as a 'Turtle Priority Area' as well as a site for long term monitoring of these turtle populations.

Acknowledgements

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STATUS OF WATERBIRDS DIVERSITY AND DISTRIBUTION IN THE GANGA RIVER

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ABSTRACT

Rapid riverscape changes pose challenges to our efforts to understand and predict the consequences on aquatic biodiversity. The vulnerability of species, especially of riverine birds to such changes can be extensive, as their response capacity is likely be surpassed by multiple threats, such as habitat loss, fragmentation, altered disturbance regimes, and interactions between them can have adverse effects. The present study was, therefore, undertaken to assess the waterbirds status in the Ganga River during post-monsoon and post-winter seasons to provide baseline information on their diversity and distribution. For this, we classified the Ganga River into six habitat zones and 32 intensive sampling sites with a 5 km sampling

segment at every 75 km interval were sampled. A combination of linear walks along the banks and boat surveys were conducted to enlist the diversity of waterbirds, 86 species of which 16 species in RET category, were recorded during the survey. Anatidae and Scolopacidae (11 species) were the most abundant family followed by Ardeidae (10 species) and Laridae (8 species). Overall, *Microcarbo niger* (18.21%) showed maximum relative abundance followed by *Anastomus oscitans* (14.46%) and *Dendrocygna javanica* (11.73%). *Microcarbo niger* has also shown a wide distribution range and were recorded from 30 sites. The maximum species richness (67 species) and species diversity (2.83±0.06) were recorded in zone-2 (Haridwar-Narora). The mosaic of habitats of the Ganga River that sustain diverse waterbird species are under various levels of anthropogenic pressures that directly affect the waterbirds.

Keywords: The Ganga River, Riverscape, Aquatic Biodiversity, Waterbirds, Species Diversity

Painted Stork (*Mycteria leucocephala*)

8.1 INTRODUCATION

Avifauna are a vital component of an ecosystem, which signify its health and stability. They are considered as useful biological indicators, due to their ecological versatility inhabiting diverse habitats as herbivores, carnivores and omnivores (Koskimies, 1989). Birds that are ecologically dependent on wetlands have been broadly defined as 'waterbirds' (Wetlands International, 2012; Kumar et al., 2005). They are dependent on healthy aquatic ecosystems for resources such as breeding, roosting and foraging. Their abundance and diverse assemblages are generally highly productive ecologically important systems; making them a good health indicator of the overall ecosystem (Gopi and Hussain, 2014; Murray-Darling Basin Authority, 2017). They have many features in their biology that make them unique and significant viz. colonial breeding, congregatory behaviour and long distance migrations (Burnett, 2016).

The Ramsar wetland type M includes all the permanent rivers, streams, creeks including the waterfalls (Ramsar, 2009). The river ecosystem comprises of river channels and its floodplains forming a mosaic of habitats with the riparian area at the transition zone between land and water. These linear ecosystems provide an important site for shelter, foraging, breeding, stopover sites and refugia habitats for waterbirds (Naugle et al., 2000). The dynamic biophysical nature of rivers provides unique habitats to both aquatic flora and fauna, which in turn attracts several communities of waterbirds for feeding (Oakley et al., 1985). They act as a host to migratory waterbirds, during severe winter in their breeding ranges (Dudgeon, 2000). Despite being rich in avifauna, rivers are poorly documented, even with regard to basic ecological and conservation parameters, such as species composition, relative abundance, diversity indices, density and feeding guilds (Kantrud and Stewart, 1984).

The Ganga is the longest river (2525 km) in India with different characteristics such as depth, flow, bank characteristics, and river islands throughout the river stretch (Sanghi and Kaushal, 2014). The Ganga River is home to a wide variety of life forms ranging from primitive phytoplankton to highly evolved species (Bashir et al., 2012) including several species of waterbirds, such as endangered black-bellied tern (*Sterna acuticauda*); near threatened river tern (*Sterna aurantia*),painted stork (*Mycteria leucocephala*) and Oriental darter (*Anhinga melanogaster*); vulnerable Indian skimmer (*Rynchops albicollis*) and sarus crane (*Antigone antigone*).

In early records, Zoological Survey of India (1991) mentioned 101 species, which were associated with the Ganga River. Few studies conducted across the Ganga River such as Jha (2006), recorded 10 rare waterbirds from the Farakka barrage, Sinha et al. (2009) found 166 species of birds in the Bihar stretch, Bashir et al. (2012) found 55 species between Bijnor and Narora, Chowdhury (2014) found 56 species in Farakka barrage, but none of the studies conducted so far are holistic and provide information of the complete stretch. So far, there is no detailed information available on the population status of waterbirds in the Ganga River.

The increasing human population, mechanized boats, commercial exploitation of the birds, socio-economic condition of the inhabitants; disturbances in nesting and feeding grounds of birds in the floodplains due to extensive loss of vegetation cover, urbanization, encroachment, riverbed agriculture and use of chemical pesticides have resulted in declining population of migratory birds as well as resident birds (Sinha et al., 2009).

8.2 METHODOLOGY

The complete stretch of the Ganga River was divided into six habitat zones based on topography, geography, ecology and reconnaissance survey i.e. i) Upper Ganga (Gangotri-Haridwar), ii) Upper-middle Ganga A (Haridwar-Narora), iii) Upper-middle Ganga B (Narora-Kanpur), iv) Middle Ganga (Kanpur-Varanasi), v) Middle-lower Ganga (Varanasi-Farakka), and vi) Lower Ganga (Farakka-Gangasagar). Altogether, 32 intensive sampling sites were selected after every 75km, manifesting all the six zones throughout the entire course of the river based on topography, geomorphology and terrain types (Figure 8.1). These 32 sites might be used as permanent monitoring sites in future studies.

The intensive study was conducted in a 5km stretch of selected 32 intensive sampling sites during post monsoon, 2017 (October-November) and post-winter, 2018 (March-May) season. Surveys were

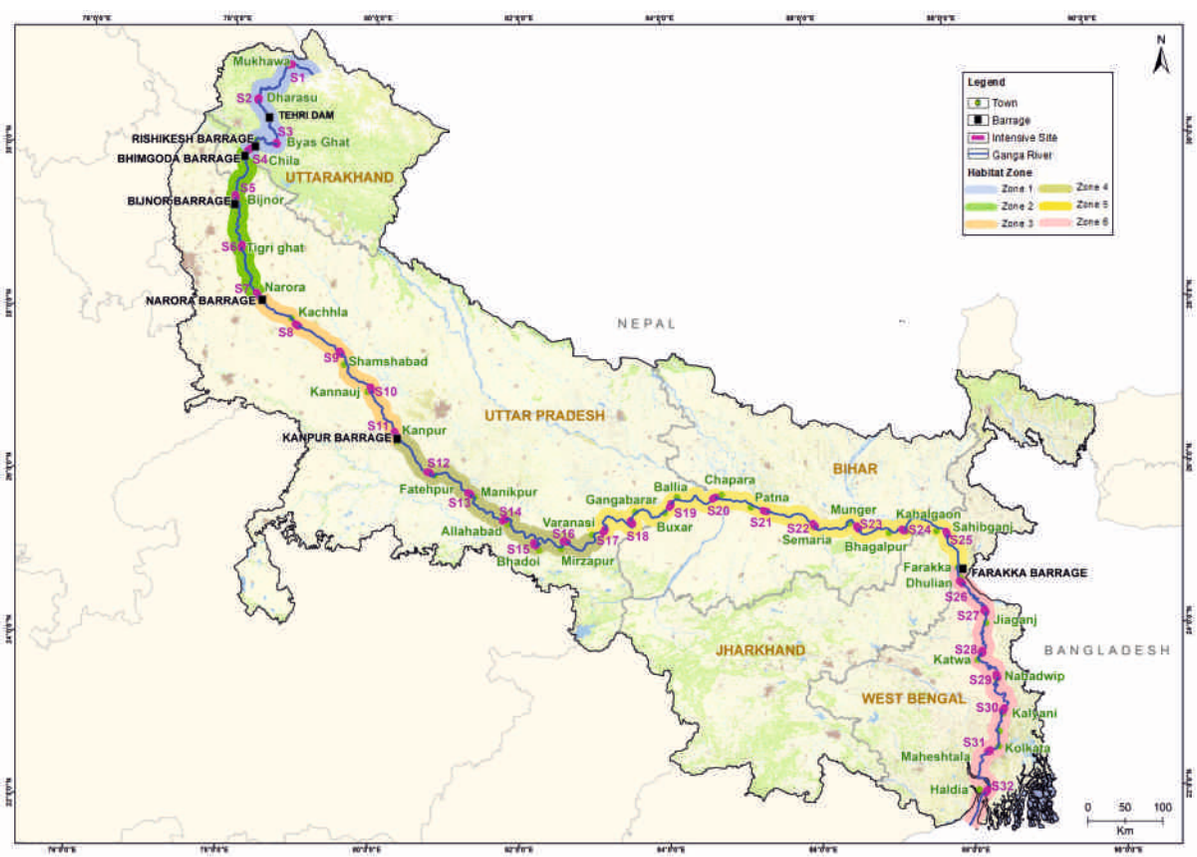
done between 0700hrs to 1200 hrs through boat using total count method and block count method (for large, single-species flock) which also include linear walks along the riverbanks and river islands. Field data collection was done using 50×10 binoculars and direct visual observation. Photographs were also taken wherever possible as a supporting evidence and cross-referenced with the field guide (Grimmett et al., 2013) for identification. The birds were classified as waterbirds based on the "Waterbirds of India, ENVIS Bulletin: Wildlife & Protected Areas. Vol. 16" (Gopi and Hussain, 2014) and "Checklist of Indian Waterbirds" (Kumar et al., 2003). The residential status is further classified based on "Waterbirds of India, ENVIS Bulletin: Wildlife & Protected Areas. Vol. 16" (Gopi and Hussain, 2014). The feeding guilds were categorised based on "Handbook of Indian Wetland Birds" (Kumar et al., 2005).

Data collection during field survey at Chhapra, Bihar

Statistical analysis

We have used species richness and Shannon diversity index for the diversity comparisons across the sampled sites, six zones and three stretches (Magurran, 2004). All the analysis were conducted in R statistical programming (version 3.4.1; R Core Team, 2018) software using package 'vegan' (Oksanen et al., 2018).

Figure 8.1: . Map depicting study sites and river habitat zones along the Ganga River



Overall, 23,447 individuals belonging to 10 orders, 25 families, 66 genera and 86 species, were recorded across all the 32 intensive sampling sites of the Ganga River. Overall Anatidae and Scolopacidae (11 species) were the most abundant family followed by Ardeidae (10 species) and Laridae (10 species) (Figure 8.2). The family Phalacrocoracidae had the most number of individuals (6,486) followed by Ciconiidae (3,939) and Anatidae (3,693). Stretch wise comparison shows that Ardeidae was the most abundant family in the lower stretch (9 species) and upper stretch (8 species), while in middle stretch Anatidae (11 species) and Scolopacidae (11 species) were the most abundant family. In upper stretch (Gangotri-Haridwar) 1,035 individuals of 35 species belonging to 29 genera and 16 families were recorded from four sites (Mukhawa-Chilla). In middle stretch (Haridwar-Farakka) 20,617 individuals of 79 species, belonging to 24 families and 60 genera were recorded from 21 sites (Bijonr-Sahibganj). In the lower stretch (Farakka-Gangasagar), 1,795 individuals of 30 species belonging to 14 families and 26 genera were recorded form 7 sites (Farakka-Haldia).

Suitable waterbird habitat with high anthropogenic pressure

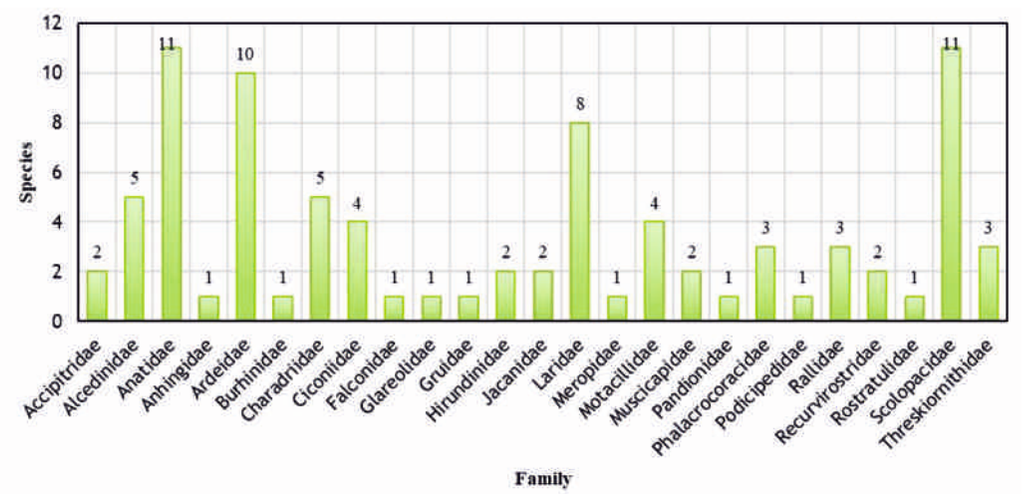


Figure 8.2: Family wise species representation of waterbirds across all the 32 sites in the Ganga River

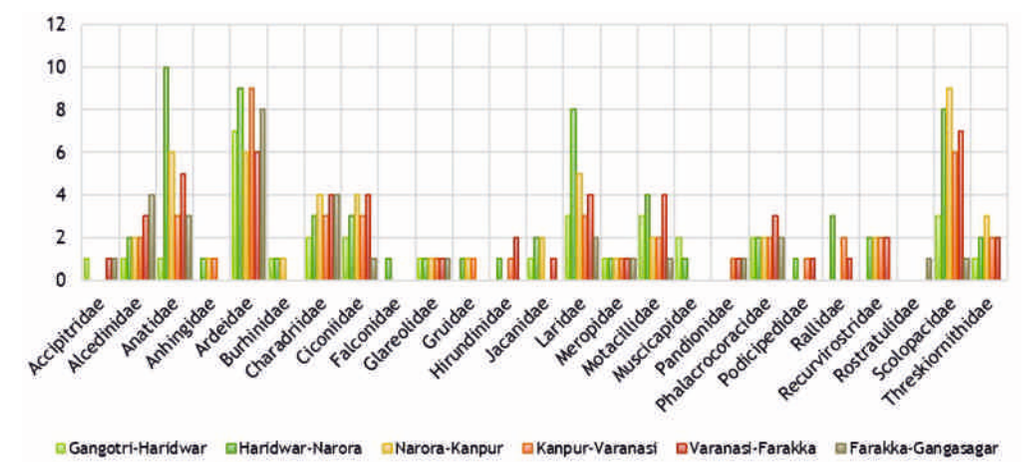


Figure 8.3: Zone-wise family representation of waterbirds in the Ganga River

Feeding habit, conservation and residential status of waterbirds are given in Appendix I. Out of the 86 species, 43 species were resident, 16 species were resident with local movement, 3 species were resident with winter influx, and 24 species were winter migrant as reported in the Waterbirds of India (Gopi and Hussain, 2014). Of the 86 bird species, 37% species were carnivores, 13% species were piscivores/insectivores, 12% species were omnivores, 13% species were insectivores, 9% species were piscivores/carnivores,7% species were herbivores/carnivores, 4 % species were carnivores/herbivores, 2% species were piscivores, 2% species were insectivores/frugivores, 2% species were herbivores/insectivores and 1% species were herbivores. (Figure 8.4).

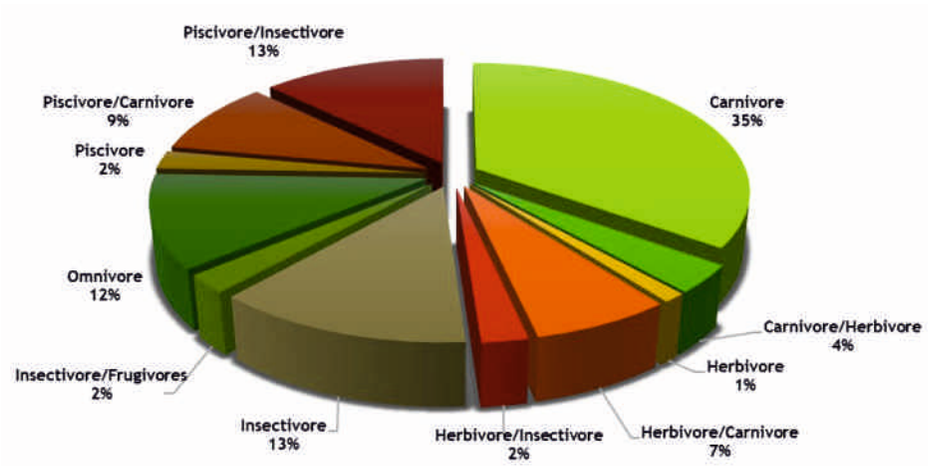


Figure 8.4: Feeding guild composition of Waterbird communities across all the 32 sites in the Ganga River

RET Species

Out of all the recorded species, 4% are Endangered, 10% are Near Threatened, 5% are Vulnerable (Table: 8.1) and the rest of the species are of Least Concern (BirdLife International, 2017).

Table 8.1: RET Species recorded in the 32 intensive sampling sites of the Ganga River

Order	Family	Common Name	Scientific Name	IUCN Status
Accipitriformes	Accipitridae	Steppe Eagle	*Aquila nipalensis*	EN
		Pallas's Fish Eagle	*Haliaeetus leucoryphus*	EN
Anseriformes	Anatidae	Common Pochard	*Aythya ferina*	Vu
Charadriiformes	Burhinidae	Great Thick-knee	*Esacus recurvirostris*	NT
	Charadriidae	River Lapwing	*Vanellus duvaucelii*	NT
	Laridae	Indian Skimmer	*Rynchops albicollis*	Vu
		Black-bellied Tern	*Sterna acuticauda*	EN
		River Tern	*Sterna aurantia*	NT
	Scolopacidae	Black-tailed Godwit	*Limosa limosa*	NT
		Eurasian Curlew	*Numenius arquata*	NT
Ciconiiformes	Ciconiidae	Woolly-necked Stork	*Ciconia episcopus*	Vu
		Black-necked Stork	*Ephippiorhynchus asiaticus*	NT
		Painted Stork	*Mycteria leucocephala*	NT
Gruiformes	Gruidae	Sarus Crane	*Antigone antigone*	Vu
Pelecaniformes	Threskiornithidae	Black-headed Ibis	*Threskiornis melanocephalus*	NT
Suliformes	Anhingidae	Oriental Darter	*Anhinga melanogaster*	NT

Relative abundance

Overall, *Microcarbo niger* (18.21%) showed maximum relative abundance followed by *Anastomus oscitans* (14.46%) and *Dendrocygna javanica* (11.73%). In upper stretch (Zone-1) *Glareola lactea* (42.71%) showed maximum relative abundance followed by *Mycteria leucocephala* (15.46%). In the middle stretch (Zone 2-5), *Microcarbo niger* (20.26%) showed maximum relative abundance followed by *Anastomus oscitans* (16.38%). In the lower stretch (Zone-6), *Dendrocygna javanica* (81.56%) showed maximum relative abundance followed by *Bubulcus ibis* (4.07%). Overall relative abundances for species of conservation importance were very low such as *Haliaeetus leucoryphus* (0.01%), *Aquila nipalensis* (0.02%), *Limosa limosa* (0.03%), *Ephippiorhynchus asiaticus* (0.05%), *Anhinga melanogaster* (0.06%), *Ciconia episcopus* (0.07%), *Threskiornis melanocephalus* (0.17%), *Tringa stagnatilis* (0.22%), *Rynchops albicollis* (0.23%), *Sterna acuticauda* (0.31%), *Sterna aurantia* (0.46%).

Black-necked Stork (*Ephippiorhynchu asiaticus*)

Species occurrence patterns across the Ganga River

Overall, *Microcarbo niger* showed wide distribution range recorded from 30 sites followed by *Egretta garzetta* from 28 sites, *Ardeola grayii* from 26 sites, *Ceryle rudis*, *Halcyon smyrnensis* and *Vanellus indicus* from 25 sites. 12 species including *Megaceryle lugubris*, *Pelargopsis capensis, Aythya ferina, Anas acuta, Vanellus cinereus, Gelochelidon nilotica, Rostratula benghalensis* showed a narrow distribution range and were recorded only from one site. Zone-wise species distribution showed that 16 species including *Microcarbo niger, Dendrocygna javanica, Bubulcus ibis, Egretta garzetta, Ardeola grayii, Ceryle rudis, Halcyon smyrnensis, Vanellus indicus* were recorded from all the six habitat zones while 18 species including *Haliaeetus leucoryphus, Megaceryle lugubris, Pelargopsis capensis, Anas acuta, Vanellus cinereus* were recorded only from one habitat zone.

Waterbirds diversity across the sampled sites, six zones and three stretches

Lesser Whistling Duck (*Dendrocygna javanica*)

Species Richness

Site-wise maximum species richness was; 55 species in Bijnor (S-5), 40 species in Samshabad (S-9) and 37 species in Narora (S-7). However, minimum species richness 4, 7 & 8 species were recorded at Mukhawa (S-1), Haldia (S-32) and Maheshtala (S-31) respectively (Figure 8.5). Zone wise maximum species richness was 67 species in Haridwar-Narora (Zone-2) followed by 53 species in Varanasi-Farakka (Zone-5) and 52 species in Narora-Kanpur (Zone-3) (Figure 8.6). However, minimum species richness was 30 species found in Farakka-Gangasagar (Zone-6). Stretch wise maximum species richness was 79 species recorded in the middle stretch (Haridwar-Farakka) followed by 35 species and 30 species in the upper (Gangotri-Haridwar) and lower stretch (Farakka-Gangasagar), respectively.

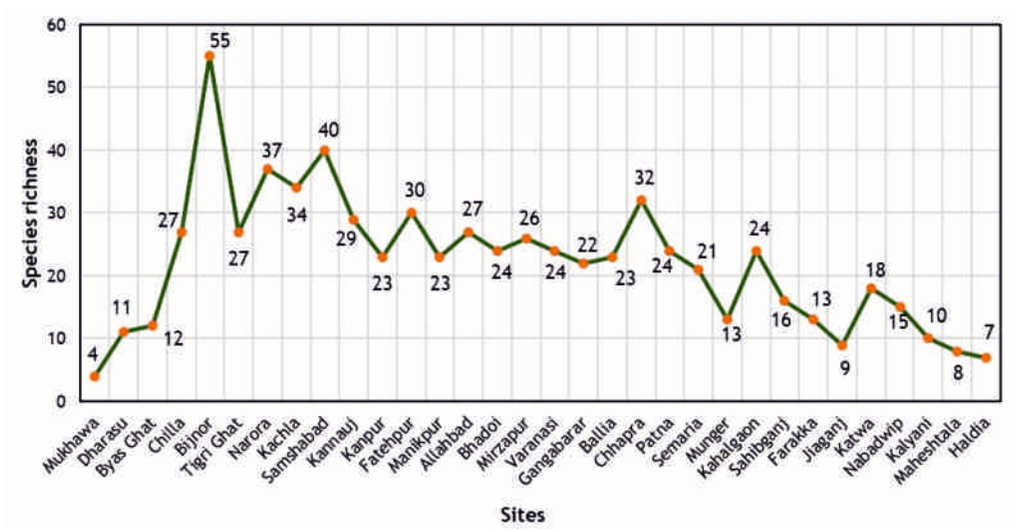


Figure 8.5: Species richness of waterbirds across all the 32 sites in the Ganga River

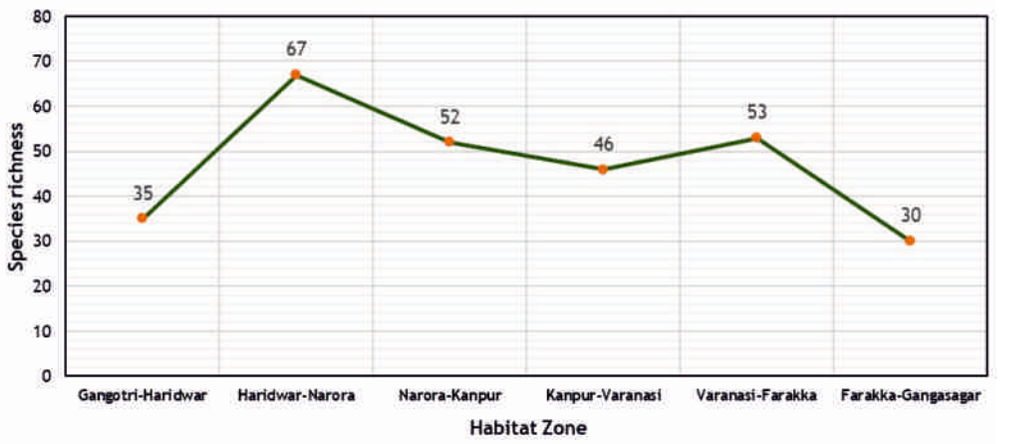


Figure 8.6: Species richness of waterbirds across the identified six habitat zones in the Ganga River

Species diversity

Site-wise maximum diversity was 3.47 in Bijnor (S-5), 3.03 in Kachla (S-8) and 2.84 in Fatehpur (S-12). However, minimum diversity was 0.48 recorded at Katwa (S-28) (Figure 8.7). Zone wise maximum diversity was 2.83±0.61 in Haridwar-Narora (Zone-2) followed by 2.66±0.42 in Narora-Kanpur (Zone-3) and 2.21±0.46 in Kanpur-Varanasi (Zone-4). However, minimum diversity was 1.65±0.61 found in Farakka to Gangasagar (Zone-6) (Figure 8.8). Stretch-wise maximum diversity was 2.27±0.53 recorded in the middle stretch (Haridwar-Farakka) followed by 1.81±0.37 and 1.65±0.61 in the upper (Mukhawa-Haridwar) and lower stretch (Farakka-Gangasagar), respectively. Overall, the diversity index across the river was 2.08±0.59.

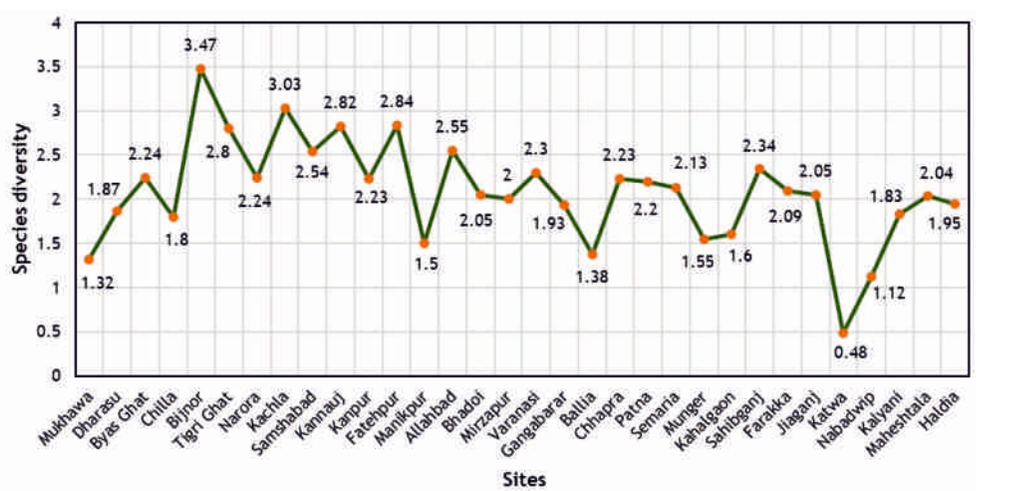


Figure 8.7: Species diversity of waterbirds across all the 32 sites in the Ganga River

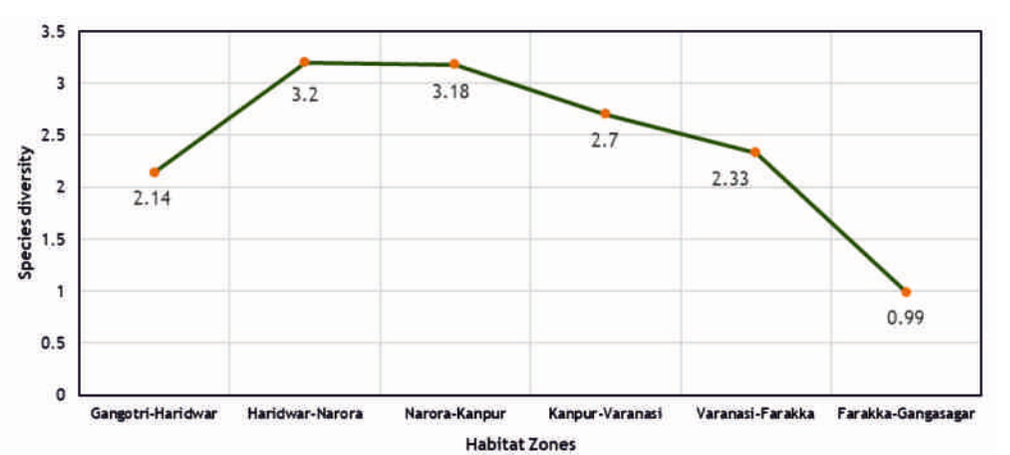
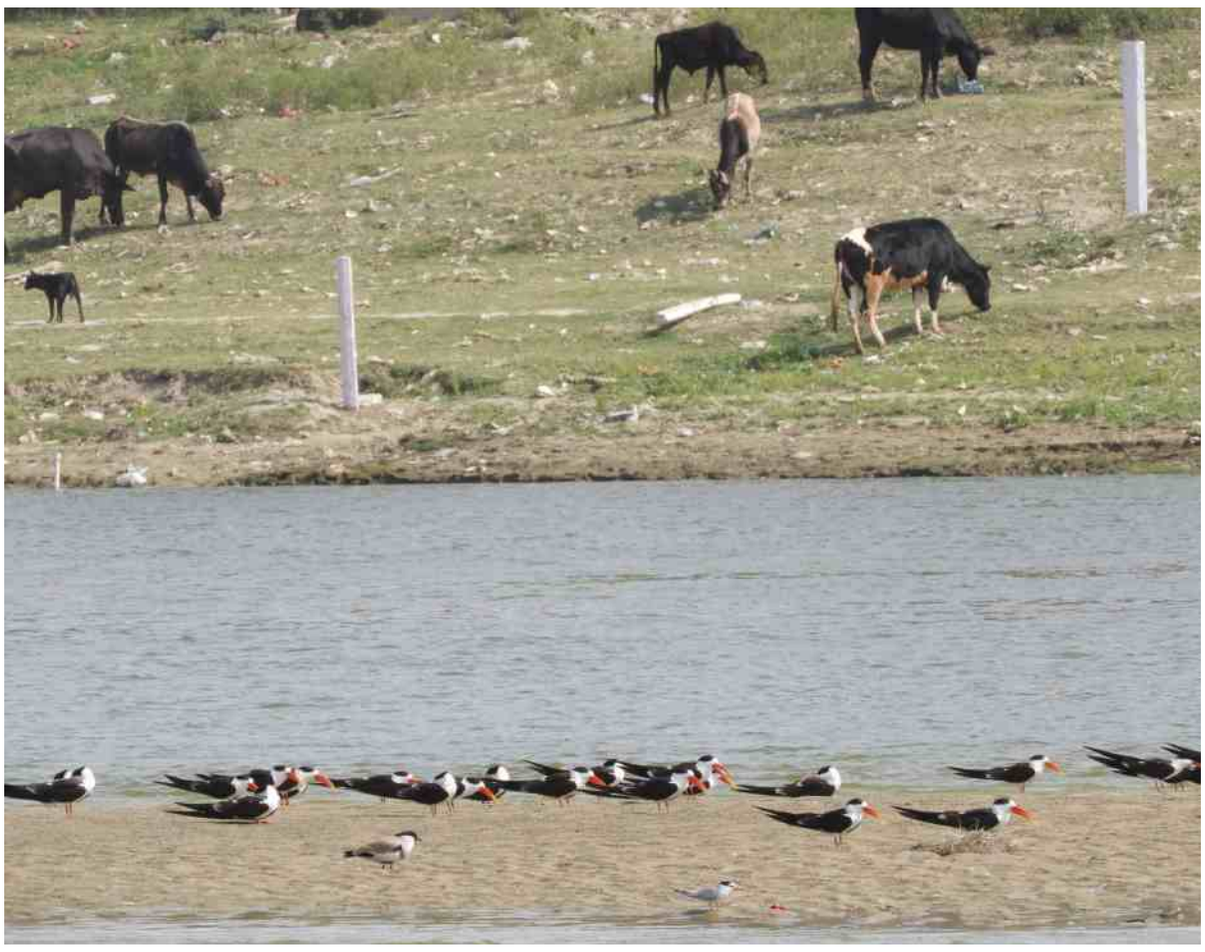


Figure 8.8: Species diversity of waterbirds across identified six habitat zones in the Ganga River.

8.4 THREATS TO WATERBIRDS DIVERSITY

1. The increase in the amount of human habitation along the Ganga River has resulted in the expansion of human settlements, encroachment for temporary cultivation along riverbanks and riverbeds for agricultural activities, dumping of non-biodegradable waste and garbage, which cause pressure on nesting, foraging and roosting habitats of waterbirds.
2. After the monsoon season, inhabitants along the Ganga River clear the vegetation from the riverbanks, river islands, chaurs or diara and the shallow areas to prepare the fields for agriculture, which sometimes result in the destruction of nests of various waterbirds.
3. Use of inorganic fertilizers and toxic pesticides in agricultural fields in and along the Ganga River is gradually polluting the rivers ecosystem.
4. Fluctuation in water level leads to erosion and flooding of sandy islands and continuous change in the micro level topography of the river system.
5. The islands having rich vegetation attract the grazing animals and make the waterbirds susceptible to trampling by the herds of cattle. This causes a major problem for eggs and hatchling of breeding birds, especially in dry seasons and during the low water level. Most of the time the cattle herder isn't capable enough to control these herds, which makes it a bigger challenge to limit their movement on nesting sites.
6. Feral dogs are also a serious threat as they are very aggressive and predate the waterbirds, and also their nests.
7. Commercial exploitation of waterbirds in rural areas is still a serious threat for the conservation of both migratory and residential bird species.

Livestock grazing in Indian Skimmer habitat near Allahabad



8.5 DISCUSSION

In the entire stretch of the Ganga River, 86 species of waterbirds were recorded from 32 intensive sampling sites. The species richness was the highest for Bijnor (S-5), Narora (S-7) and Samshabad (S-9) of middle stretch of the Ganga River, while the lowest was recorded from Mukhawa (S-1, upper stretch), Farakka and Haldia (S-26, S-32, lower stretch). Such variations in species richness were mainly due to the availability of resources for foraging, sheltering, roosting and breeding; factors like water temperature, flow, weather and seasonality was also vital for this variation in species richness.

RET Species in Bijnor, Narora and Samshabad: ***Aythya ferina, Anhinga melanogaster, Esacus recurvirostris, Vanellus duvaucelii, Mycteria leucocephala, Ciconia episcopus, Antigone antigone, Rynchops albicollis, Sterna aurantia, Sterna acuticauda, Numenius arquata, Ephippiorhynchus asiaticus*** **and** ***Limosa limosa.***

The distribution of 34% of the bird species was seasonal with some of them occurring in either post-monsoon or post-winter seasons. Although, the species richness and diversity in the post-winter season was higher than the post-monsoon season due to a multitude of factors like presence of stable and exposed riverine islands, low water level, availability of aquatic vegetation and foraging ground. The absence of these favourable factors and partially inundated islands acts as a limiting factor, thus the richness is low during the post-monsoon season.

Species richness, relative abundance and diversity values of the waterbirds are observed high in the middle Ganga stretch, which also include species of global significance. It also indicates that this stretch is biologically rich and merits a need for its conservation and management. The bird species such as bar-headed geese, common sandpiper, marsh sandpiper, common redshank etc. were found less in number as these birds are winter migratory species and the survey was conducted in post-monsoon and post-winter seasons.

As per the "Handbook of Indian Wetland Birds", we have categorised the waterbirds into 11 feeding guilds namely piscivores, carnivores, herbivores, insectivores, piscivores/insectivores, omnivores, piscivores/carnivores, herbivores/insectivores, carnivores/herbivores, herbivores/carnivores and insectivores/frugivores based on their diet preference. Carnivores were the highest (32 species) amongst all these categories while herbivores were the lowest (one species). Zonal representation (six habitat zones) of feeding guilds across the complete stretch of the Ganga River is shown in Figure 8.9.

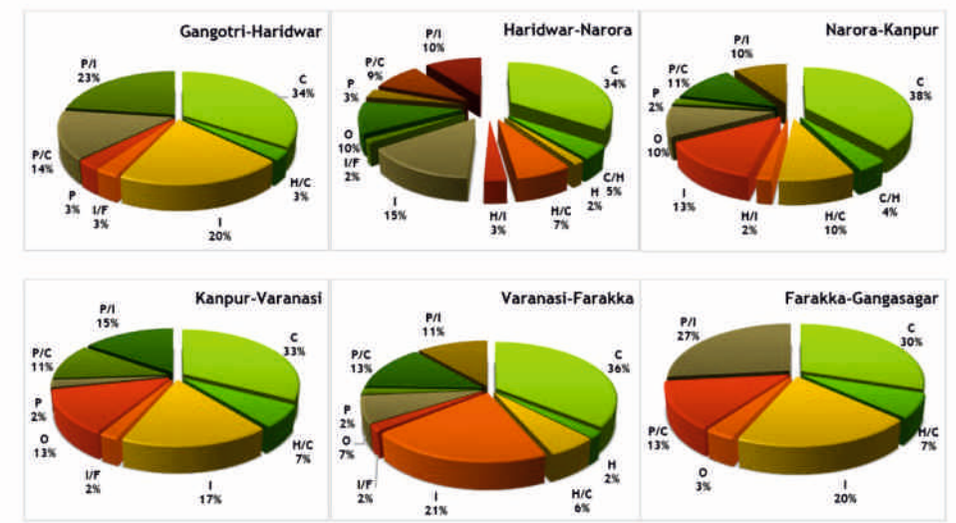


Figure 8.9: Zonal representation of feeding guilds across the selected six habitat zones in the Ganga River

Abbreviation: P- Piscivore, C- Carnivore, I-Insectivore, H-Herbivore, O-Omnivore, P/I-Piscivore/Insectivore, I/H-Insectivore/Herbivore, P/C-Piscivore/Carnivore, H/I-Herbivore/Insectivore, C/H- Carnivore/Herbivore, H/C-Herbivore/Carnivore

In general, observations from the multiple surveys show that the habitats of waterbirds are highly disturbed by anthropogenic activities and pollution causing a decline in the population of the waterbirds and threatening their existence, which might also lead to extinction. Hence, a scientific conservation strategy and enhanced efforts are required.

Future course of action

1. To undertake a long-term monitoring (3-4 years) of Indian skimmers (*Rynchops albicollis*) through satellite telemetry study. Initially, our focus is to track six individuals of Indian skimmers (*Rynchops albicollis*) for deciphering their local/regional movement pattern and identifying key areas for monitoring and conservation of this species.
2. To elucidate the relationship between explanatory variables (habitat type, abiotic factors etc.) and response variables (population trend, species diversity, distribution etc.) along the Ganga River.
3. To undertake a bird banding and tagging study on waterbirds of Ganga River along with Indian skimmer (*Rynchops albicollis*) to elucidate their movement pattern and collect other ecological information.

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We are thankful to the Ganga Project Directorate, Ministry of Water Resources, Government of India, for providing financial assistance for the study. We would like to express our sincere gratitude to Dr. Ruchi Badola and Dr. J. A. Johnson for their constant support, guidance, valuable suggestions and encouragement. We would like to thank the entire faculty members for their guidance and support in every aspect. Special thanks are due to Aftab Alam Usmani, Mujahid Ahamd, Megha Shruti and Rahim Shaikh for helping us in the data collection during the field survey. We also thank Sk. Zeeshan Ali and Aishwarya Ramachandran for the map preparation and GIS inputs. We are very grateful to Dr. Rohitashva Shukla for his kind guidance, valuable suggestions and critical comments during the entire course of report preparation. Last, but not the least, we thank the entire Ganga team for their assistance in every possible form.

Preferred waterbird habitat with visible disturbance

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Table 8.2: Feeding habits, conservation and residential status of waterbirds

Order	Family	Common Name	Scientific Name
Accipitriformes	Accipitridae	Steppe Eagle	*Aquila nipalensis*
		Pallas's Fish Eagle	*Haliaeetus leucoryphus*
	Falconidae	Peregrine Falcon	*Falco peregrinus*
	Pandionidae	Osprey	*Pandion haliaetus*
Anseriformes	Anatidae	Northern Pintail	*Anas acuta*
		Mallard	*Anas platyrhynchos*
		Indian Spot-billed Duck	*Anas poecilorhyncha*
		Bar-headed Goose	*Anser indicus*
		Common Pochard	*Aythya ferina*
		Lesser Whistling Duck	*Dendrocygna javanica*
		Red-crested Pochard	*Netta rufina*
		Comb Duck	*Sarkidiornis melanotos*
		Northern Shoveller	*Spatula clypeata*
		Garganey	*Spatula querquedula*
		Ruddy Shelduck	*Tadorna ferruginea*
Charadriiformes	Burhinidae	Great Thick-knee	*Esacus recurvirostris*
	Charadriidae	Kentish Plover	*Charadrius alexandrinus*
		Little Ringed Plover	*Charadrius dubius*
		Grey-headed Lapwing	*Vanellus cinereus*
		River Lapwing	*Vanellus duvaucelii*
		Red-wattled Lapwing	*Vanellus indicus*
	Glareolidae	Little Pratincole	*Glareola lactea*
	Jacanidae	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*
		Bronze-winged Jacana	*Metopidius indicus*
	Laridae	Brown-headed Gull	*Larus brunnicephalus*
		Pallas's Gull	*Larus ichthyaetus*
		Whiskered Tern	*Chlidonias hybrida*
		Common Gull-billed Tern	*Gelochelidon nilotica*
		Indian Skimmer	*Rynchops albicollis*
		Black-bellied Tern	*Sterna acuticauda*
		Little Tern	*Sterna albifrons*
		River Tern	*Sterna aurantia*
	Recurvirostridae	Black-winged Stilt	*Himantopus himantopus*
		Pied Avocet	*Recurvirostra avosetta*
	Rostratulidae	Greater Painted Snipe	*Rostratula benghalensis*
	Scolopacidae	Common Sandpiper	*Actitis hypoleucos*
		Little Stint	*Calidris minuta*
		Temminck's Stint	*Calidris temminckii*
		Black-tailed Godwit	*Limosa limosa*
		Eurasian Curlew	*Numenius arquata*
		Ruff	*Calidris pugnax*
		Common Redshank	*Tringa totanus*
		Spotted Redshank	*Tringa erythropus*

APPENDIX I

IUCN Status*	Residential Status**	Feeding Guilds***
EN	WM	C
EN	R	C
LC	R/WM	C
LC	WM	C
LC	WM	H/C
LC	WM	H/C
LC	R/LM	H/C
LC	R/WM	H
Vu	WM	H/C
LC	R/LM	H/C
LC	WM	O
LC	R/LM	O
LC	WM	C/H
LC	WM	H/C
LC	WM	O
NT	R/LM	C
LC	R/LM	C
LC	R	C
LC	WM	C
NT	R	C
LC	R	C
LC	R	I
LC	R	H/I
LC	R	H/I
LC	R/WM	C
LC	WM	C
LC	R	C
LC	WM	C
Vu	R/LM	C
EN	R	C
LC	R	C
NT	R	C
LC	R	O
LC	WM	C
LC	R	O
LC	WM	C
LC	WM	C
LC	WM	C
NT	WM	C/H
NT	WM	C
LC	WM	O
LC	WM	C
LC	WM	C

Sarus Crane (*Antigone antigone*)

Order	Family	Common Name	Scientific Name
		Common Greenshank	*Tringa nebularia*
		Green Sandpiper	*Tringa ochropus*
		Marsh Sandpiper	*Tringa stagnatilis*
Ciconiiformes	Ciconiidae	Asian Openbill	*Anastomus oscitans*
		Wooly-necked Stork	*Ciconia episcopus*
		Black-necked Stork	*Ephippiorhynchus asiaticus*
		Painted Stork	*Mycteria leucocephala*
Coraciiformes	Alcedinidae	Common Kingfisher	*Alcedo atthis*
		Pied Kingfisher	*Ceryle rudis*
		White-throated Kingfisher	*Halcyon smyrnensis*
		Crested Kingfisher	*Megaceryle lugubris*
		Stork-billed Kingfisher	*Pelargopsis capensis*
	Meropidae	Blue-tailed Bee-eater	*Merops philippinus*
Gruiformes	Gruidae	Sarus Crane	*Antigone antigone*
	Rallidae	White-breasted Waterhen	*Amaurornis phoenicurus*
		Common Coot	*Fulica atra*
		Purple Swamphen	*Porphyrio porphyrio*
Passeriformes	Hirundinidae	Barn Swallow	*Hirundo rustica*
		Plain Martin	*Riparia paludicola*
	Motacillidae	White Wagtail	*Motacilla alba*
		Grey Wagtail	*Motacilla cinerea*
		Citrine Wagtail	*Motacilla citreola*
		White-browed Wagtail	*Motacilla maderaspatensis*
	Muscicapidae	White-capped Water Redstart	*Chaimarrornis leucocephalus*
		Plumbeous water redstart	*Rhyacornis fuliginosa*
Pelecaniformes	Ardeidae	Great Egret	*Ardea alba*
		Intermediate Egret	*Ardea intermedia*
		Little Egret	*Egretta garzetta*
		Cattle Egret	*Bubulcus ibis*
		Grey Heron	*Ardea cinerea*
		Purple Heron	*Ardea purpurea*
		Indian Pond heron	*Ardeola grayii*
		Striated Heron	*Butorides striata*
		Black-crowned Night Heron	*Nycticorax nycticorax*
		Cinnamon Bittern	*Ixobrychus cinnamomeus*
	Threskiornithidae	Eurasian Spoonbill	*Platalea leucorodia*
		Indian Black Ibis	*Pseudibis papillosa*
		Black-headed Ibis	*Threskiornis melanocephalus*
Podicipediformes	Podicipedidae	Little Grebe	*Tachybaptus ruficollis*
Suliformes	Anhingidae	Oriental Darter	*Anhinga melanogaster*
	Phalacrocoracidae	Little Cormorant	*Microcarbo niger*
		Great Cormorant	*Phalacrocorax carbo*
		Indian Cormorant	*Phalacrocorax fuscicollis*

IUCN Status*	Residential Status**	Feeding Guilds***
LC	WM	C
LC	WM	C
LC	WM	C
LC	R	C
Vu	R	C
NT	R	P/C
NT	R/LM	C
LC	R	P/I
LC	R	P/I
LC	R	C
LC	R	P
LC	R	C
LC	R	I
Vu	R	O
LC	R	O
LC	R	O
LC	R	O
LC	R	I
LC	R	I
LC	R	I
LC	R	I
LC	R	I
LC	R	I
LC	R	I/F
LC	R	I/F
LC	R/LM	P/C
LC	R/LM	P/C
LC	R/LM	P/C
LC	R	I
LC	R	P/I
LC	R/LM	P/C
LC	R/LM	P/I
LC	R	P/I
LC	R/LM	P/I
LC	R/LM	P/I
LC	R	C/H
LC	R	C
NT	R/LM	C
LC	R	C
NT	R/LM	P
LC	R	P/C
LC	R	P/C
LC	R	P

Bar-headed Goose (*Anser indicus*)

*Birdlife International (2017)

** Gopi, G.V. and S. A. Hussain (Eds.) 2014. Waterbirds of India, ENVIS Bulletin: Wildlife & Protected Areas. Vol. 16; Wildlife Institute of India, Dehradun-248001, India. 368pp.

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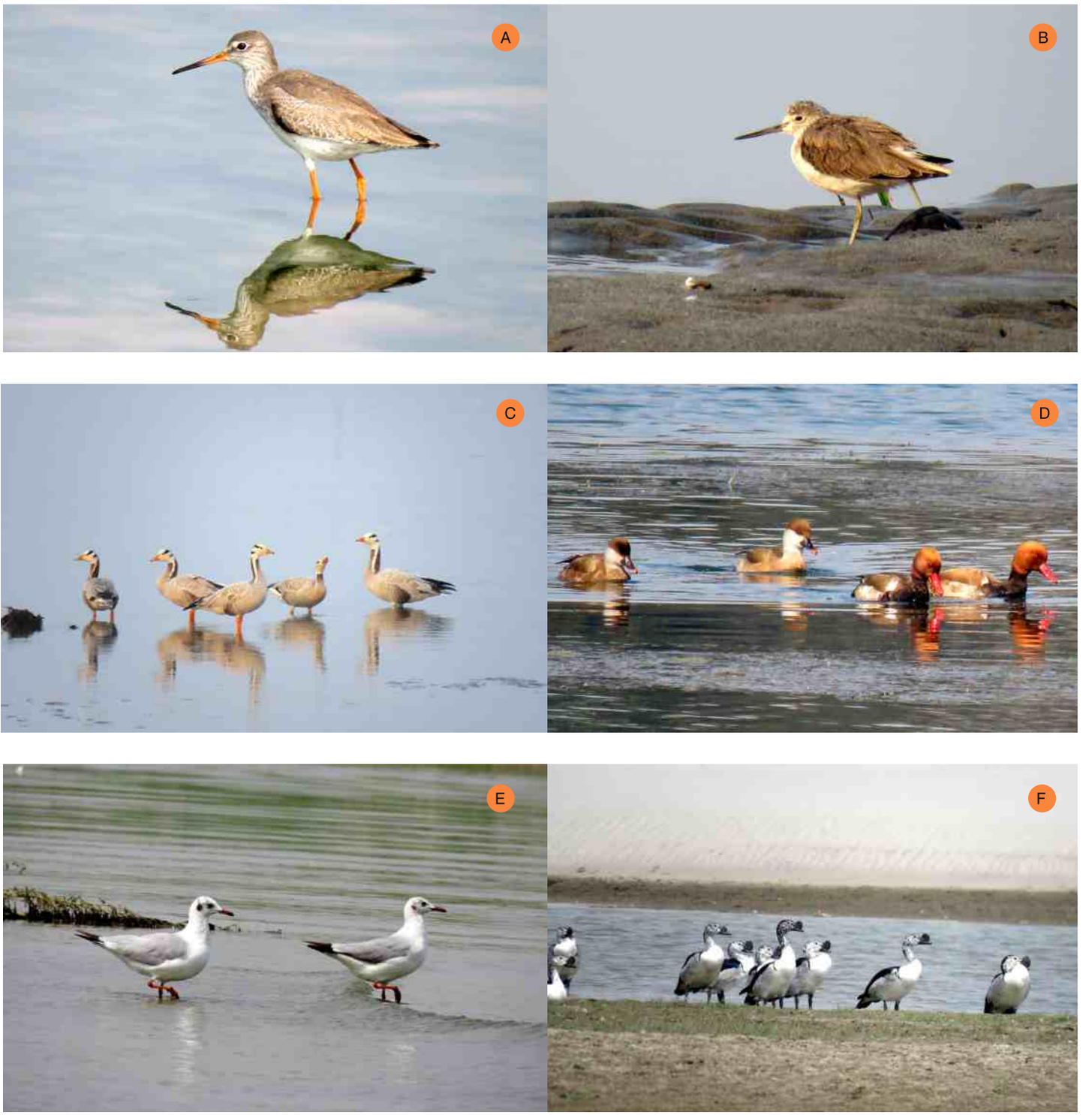
Abbreviation:

EN-Endangered,
Vu-Vulnerable,
NT-Near threatened,
LC-Least Concern
R- Resident,
R/LM, Resident with local movement,
R/WM, Resident with winter influx,
WM-Winter migratory

C-Carnivore, **H**-Herbivore,
O-Omnivore, **P**-Piscivore,
I-Insectivore,
P/I-Piscivore/Insectivore,
I/H- Insectivore/Herbivore,
P/C-Piscivore/Carnivore



Photographs depicting waterbirds in their habitats: A) Common Redshank *Tringa totanus*, B) Common Greenshank *Tringa nebularia*, C) Bar-headed Geese *Anser indicus*, D) Red-crested Pochard *Netta rufina*, E) Brown-headed Gull *Larus brunnicephalus*, F) Comb Duck *Sarkidiornis melanotos*

PLATE - II

Photographs depicting waterbirds in their habitats: G) Great Egret *Ardea alba*, Little Egret *Egretta garzetta* H) Eurasian Spoonbill *Platalea leucorodia*, I) Little Egret *Egretta garzetta*, J) Little Pratincole *Glareola lactea*, K) Oriental Darter *Anhinga melanogaster*, L) Painted Stork *Mycteria leucocephala*

STATUS OF AQUATIC MAMMALS WITH SPECIAL REGARDS TO GANGETIC RIVER DOLPHIN *(PLATANISTA GANGETICA)* IN THE GANGA RIVER

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ABSTRACT

Riverine systems are abode to unique habitat mosaics that support distinct biota and provide numerous life sustaining ecosystem services, creating a strong imperative for their rejuvenation, restoration and conservation. The riverine biota of the Ganga River are under threat due to water pollution, extensive fishing, and shift in natural flow regime, invasion of exotic species, climate change impacts and human-induced habitat loss. Boat based visual encounter method was performed to enumerate the occurrence and encounter rate of Gangetic River dolphin (*Platanista gangetica*) in the Ganga River during pre winter (Oct-Nov 2017) and pre monsoon (Apr-Jun 2018) seasons. The present study revealed that dolphin sightings were highly clustered and had a clumped distribution. Out of 32 intensive sampling sites, dolphin sightings were recorded in 11 and 12 representative sites during post monsoon and pre- monsoon season respectively.

9

During pre-monsoon survey (2018), dolphin encounter rate was estimated to be 1.43 (individuals/km) in Zone 5 (Varanasi- Farakka) followed by 0.6 (individuals/km) in Zone 6 (Farakka- Gangasagar) and 0.4 (individuals/km) in Zone 2 (Haridwar- Narora). The result of generalized linear model showed that dissolved oxygen (DO), channel depth, fishing and human activities are the most influential predictors affecting dolphin occurrence. Dolphin occurrence was positively related to dissolved oxygen (DO) and channel depth (R^2 = 0.308), whereas fishing and human activities were negatively associated with dolphin occurrence. In a broader prospective, the study reinforces the idea that each stretch has its unique set of habitat characteristics, enabling spatial variation in dolphin occurrence.

Keywords: The Ganga River, Aquatic Mammals, Gangetic River Dolphin, Eco-geographical Factors.

9.1 INTRODUCTION

Riverine systems are abode to unique habitat mosaics that support distinct biota and provide numerous life sustaining ecosystem services (Schroter et al. 2005), creating a strong imperative for their rejuvenation, restoration and systematic conservation. The Ganga River harbours a unique assemblage of biodiversity due to its passage through three distinct biogeographic zones (Rodgers & Panwar, 1988) and distinctive habitat features. It supports more than 25,000 floral and faunal species and serves as a lifeline of over 500 million people. The Ganga River is also a repository of a wide range of obligate aquatic mammalian species, including the Gangetic River dolphin (*Platanista gangetica*), three species of otters viz. the smooth-coated otter (*Lutrogale perspicillata*), Eurasian otter (*Lutra lutra*) and the small-clawed otter (*Amblonyx cinereus*), and myriads of other threatened freshwater species. During the second half of the 20th century, the Ganga River and its major tributaries have undergone tremendous changes due to the construction of dams and barrages and other anthropogenic use, leading to degradation of the riverine habitat (Sinha 1997), and consequently threatening the survival of major indicator species of the Ganga River. Globally, the riverine biota are under threats due to water pollution, extensive fishing, and shift in natural flow regime, invasion of exotic species, climate change impacts and human-induced habitat loss (Richter et al. 1997; Abell et al. 2007). The dynamic systems of the Ganga River are often poorly protected, and require conservation measures through systematic planning.

In order to restore the ecological integrity of the Ganga River system, National Mission for Clean Ganga (NMCG) and Wildlife Institute of India (WII) has initiated a project entitled “Biodiversity Conservation and Ganga Rejuvenation”. An intensive biodiversity assessment survey was conducted to derive the state of biodiversity in the Ganga River. During the survey due focus was made on gathering data on occurrence as well as encounter rate of Gangetic river dolphin and otters along with habitat drivers following specific protocols developed by WII so as to prepare baseline information on faunal assemblages of Ganga River. The present chapter addresses the current status of Gangetic River dolphin in select stretches of the Ganga River.

9.2 THE GANGETIC RIVER DOLPHIN

The Gangetic river dolphin (*Platanista gangetica*) commonly known as 'susu' occurs in the Ganga-Brahmaputra-Meghna and Karnaphuli - Sanghu River system of India-Nepal and Bangladesh (Anderson, 1879; Kasuya & Haque, 1972; Jones, 1982; Mohan, 1989; Reeves & Brownell, 1989; Shrestha, 1989; Reeves et al., 1993; Smith, 1993). The Gangetic river dolphin occurs in the human dominated floodplain rivers in South Asia and faces threats from habitat loss and fragmentation due to damming of rivers for hydropower and irrigation (Baruah et al., 2012; Braulik et al., 2012), deliberate killing for their oil (Sinha, 2002), river pollution (Kannan et al., 1997) and reduction of their prey (Kelkar et al., 2010). Dolphins are often perceived as indicator of healthy freshwater ecosystem and act as population trend indicators in degraded freshwater ecosystems in the Indian subcontinent (Behera et al., 2013). Despite its enormous importance, river dolphins have received little conservation attention (Behera et al., 2013). As a result, multiple factors continue to threaten their survival. Due to the decline in historical range distribution of this species, Gangetic river dolphin was listed as 'Endangered' in the 1996 International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 1996). It is legally protected and included in Schedule I of the Indian Wildlife (Protection) Act 1972, as per the list amended up to 02 Oct. 1991 (Jena and Gopalakrishnan, 2012; Sinha and Sharma, 2003) and in Appendix I of the Convention on International Trade in Endangered Species (CITES) to prevent trade in dolphin products (Sinha and Sharma, 2003).

Historical and mythological evidences confirmed that the Gangetic river dolphin had been in a close relationship with human beings. During the era of the Mauryan Emperor King Ashoka, in 230 B.C., the Gangetic river dolphin was known as 'Ganga-Puputaka' and enjoyed the status of a 'protected animal' through a decree known as 'Fifth Pillar Edict' (Sinha, 1997). There is a dearth of evolutionary knowledge on Gangetic river dolphin, however, the first scientific documentation came into existence through the contribution of Roxburgh (1801).

9.3 METHODOLOGY

The complete stretch of the Ganga River was divided into six habitat zones based on topography, geography, ecology and the findings of the reconnaissance survey: i) upper stretch (Gaumukh to Haridwar), ii) upper middle stretch A (Haridwar to Narora), iii) upper middle stretch B (Narora to Kanpur), iv) middle stretch (Kanpur to Varanasi), v) lower middle stretch (Varanasi to Farakka), and vi) lower stretch (Farakka to Gangasagar). Altogether, 32 sampling sites were selected after every 75 km along the entire course of the Ganga River based on topography, geomorphology and terrain types. These 32 sites were identified as permanent monitoring sites and monitored continuously to asses population trend. Boat-based direct count method was adopted (Smith and Reeves, 2000; Sinha and Sharma, 2003) to estimate encounter rate of dolphins in the select study stretches of the Ganga River. The survey team consisted of four persons stationed in different directions: two forward-facing observers; one rear-facing observer and one data recorder. The motorized boat travelled downstream at a constant speed of 8-10 km/hr with the forward-facing observers recording the dolphins

A surfacing female adult dolphin with a neonates.

Critical habitat of dolphin.

along the right and the left side of the boat. The rear observer was responsible for recording the animals missed by the forward-facing observers. A fourth observer served as data recorder and also searched for dolphins when not filling out the data forms. Keeping the environmental extremities such as water surface undulation, wind blow, sun glare, or the chance of rain increased in mind, the surveys were usually carried out under daylight (08:00–12:00 and 15:00-17:00 hours) (Oliveira et al., 2017). Focus was also made to avoid bias of double counting of individuals in a group, considering spatiotemporal assortment, body size, and snout morphology (long and up curved in female individuals) of individual dolphin with the help of additional observers (Mohan et al., 1997; Behera and Rao, 1999; Bashir et al., 2010b). Individuals were identified as neonate, sub-adult and adult age classes based on the visual size and with every sighting habitat parameters such as water depth, channel width, water temperature, air temperature and habitat types were recorded. Physicochemical parameters as well as threats to dolphins were also assessed. To distinguish ecological factors affecting the occurrence of dolphins, we used generalized liner model in R (Version 3.5.1). Before performing this analysis, we generated a correlation matrix (Pearson correlation= 0.75) of 15 eco geographical and environmental variables and identified highly correlated variables (Zurr et al., 2010). We chose the variables that were ecologically meaningful and easier to interpret. The explanatory variables used for analysis were channel depth, channel width, air temperature, water temperature, dissolved oxygen (DO), conductivity, total dissolved solute (TDS), salinity, pH, nitrate (NO_3^-), agriculture, fishing, boating, human activities and sand mining.

9.4 RESULTS

The survey covered a total of 28 intensive sites comprising a length of 165 km of the Ganga River. Dolphins were encountered in 12 sites, and accounted for 37.5% of the total sampling area. The present study revealed that dolphin sightings were highly clustered and had a clumped distribution. Sightings occurred in 11 representative sites i.e., S 6 (Tigri), S7 (Narora), S8 (Kachhla), S19 (Ballia), S20 (Chhapra), S22 (Maukama), S23 (Munger),S24 (Kahalgaon), S25 (Sahebganj), S29 (Mayapur) and S30(Triveni) within Zone 2 (Haridwar-Narora), Zone 3 (Narora- Kanpur), Zone 5 (Varanasi- Farakka) and Zone 6 (Farakka- Gangasagar) during post monsoon survey 2017. During pre-monsoon survey, 2018 dolphin sightings were recorded from 12 representative sites viz., S7 (Narora), S18 (Ghazipur), S20 (Chhapra), S21 (Patna), S22 (Maukama), S23 (Munger), S24 (Kahalgaon), S26 (Bhagalpur), S28 (Katwa), S29 (Mayapur), S30 (Triveni) and S31 (Batanagar) within Zone 2 (Haridwar-Narora), Zone 5 (Varanasi- Farakka) and Zone 6 (Farakka- Gangasagar) (Table 9.1). Altogether 27 dolphins (1 neonate, 10 sub adults and 16 adults) were recorded from 11 locations during post-monsoon survey 2017 whereas 64 dolphins (22 neonates, 13 sub adults and 29 adults) were recorded from 18 locations during pre-monsoon survey 2018 (Table 9.2).

Table 9.1: Site wise representation of Gangetic river dolphin (*Platanista gangetica*) presence for the year 2017 & 2018

Zone	Zone Name	Site	Site name	Dolphin (2017)	Dolphin (2018)
1	Upper Stretch (Gaumukh to Haridwar)	S1	Harshil	-	-
		S2	Maneri	-	-
		S3	Dharasu	-	-
		S4	Rishikesh	-	-
2	Upper Middle Stretch A (Haridwar to Narora)	S5	Bijnor	-	-
		S6	Tigri	+	-
		S7	Narora	+	+
3	Upper Middle Stretch B (Narora to Kanpur)	S8	Kachhla	+	-
		S9	Farrukhabad	-	-
		S10	Kannauj	-	-
		S11	kanpurnagar	-	-
4	Middle Stretch (Kanpur to Varanasi)	S12	Fatehpur	-	-
		S13	Pratapgarh	-	-
		S14	Allahabad	-	-
		S15	Tella	-	-
		S16	Mirzapur	-	-
		S17	Varanasi	-	-
5	Lower Middle Stretch (Varanasi to Farakka)	S18	Ghazipur	-	+
		S19	Ballia	+	-
		S20	Chhapra	+	+
		S21	Patna	-	+
		S22	Maukama	+	+
		S23	Munger	+	+
		S24	Kahalgaon	+	+
		S25	Sahebganj	+	-
		S26	Bahagalpur	-	+
6	Lower Stretch (Farakka to Gangasagar)	S27	Jiaganj	-	-
		S28	Katwa	-	+
		S29	Mayapur&Nabadwip	+	+
		S30	Kalyani&Triveni	+	+
		S31	Batanagar	-	+
		S32	Haldia&Kulpi	-	-

Table 9.2: Gangetic River dolphin (*Platanista gangetica*) sightings recorded across selected sites of the Ganga River for the year 2017 & 2018

Zone	Sites	Dolphin Number (2017)				Dolphin Number (2018)			
		Adult	Sub adult	Neonate	Total	Adult	Sub adult	Neonate	Total
2	S6	1	0	0	1	0	0	0	0
	S7	2	1	0	3	2	0	1	3
3	S8	1	0	0	1				
5	S18		2	0	1	3			
	S19	2	2	0	4	0	0	0	0
	S20	1	2	1	4	1	1	1	3
	S21	0	0	0	0	2	0	0	2
	S22	1	0	0	1	5	3	8	16
	S23	1	0	0	1	2	1	3	6
	S24	3	2	0	5	6	4	5	15
	S25	1	0	0	1	0	0	0	0
	S26	0	0	0	0	2	2	1	5
6	S28	0	0	0	0	2	0	2	4
	S29	2	2	0	4	1	0	0	1
	S30	1	1	0	2	2	1	0	3
	S31		2	1	0	3			
	TOTAL	**16**	**10**	**01**	**27**	**29**	**13**	**22**	**64**

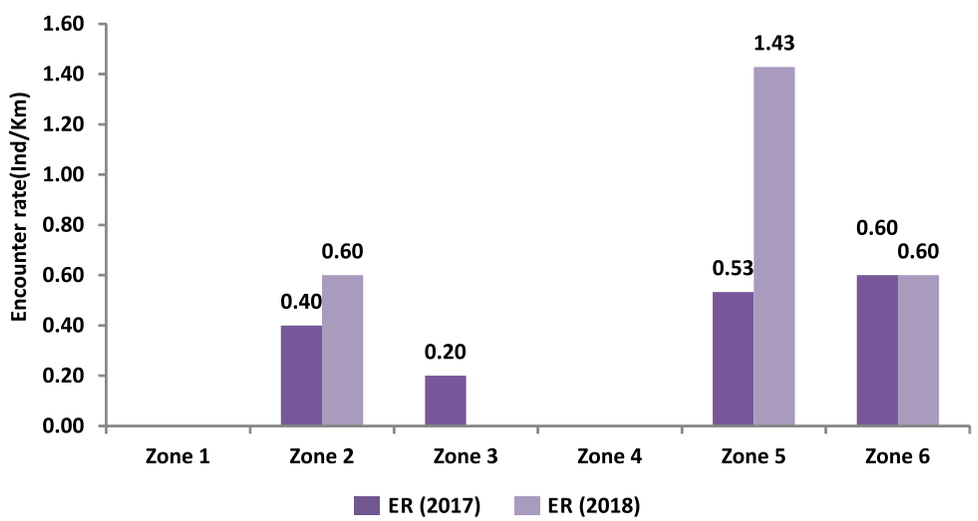

Figure 9.1: Encounter rate of Gangetic River dolphin (*Platanista gangetica*) (Individuals/km) across six habitat zones of the Ganga River during post monsoon and pre-monsoon seasons 2017-18

The dolphin encounter rate during post monsoon season, was estimated to be 0.6 (individuals/km) in Zone 6 followed by 0.53 (individuals/km) in Zone 5 and 0.4 (individuals/km) in Zone 2. Least encounter rate was estimated to be 0.2 (individuals/km) in Zone 3. During pre-monsoon survey, 2018 the dolphin encounter rate was estimated to be 1.43 (individuals/km) in Zone 5 followed by 0.6 (individuals/km) in Zone 6 and 0.4 (individuals/km) in Zone 2 (Figure 9.1). The mean dolphin individuals across both the sampling season enumerated be 33 ± 1.46 (SE) in Zone 5 followed by 9 ± 0.94(SE) in Zone 5 and 3.5 ± 0.4 (SE) in Zone 2. Least mean dolphin individuals encountered to be 0.5 ± 0.4 (SE) in Zone 1 (Figure 9.2). The mean dolphin individuals encountered within adult size class was 14.5 ± 1.07 (SE) in Zone 5 followed by 5 ± 1.13 (SE) in Zone 6 (Farakka- Ganga sagar) and 2.5 ± 0.57 (SE) in Zone 2 (Haridwar-Narora). The least mean adult individuals encountered was 0.5 ± 2.83 (SE) in Zone 3. The mean dolphin individuals encountered within sub adult size class was 8.5 ± 0.83 (SE) in Zone 5 followed by 2.5 ± 0.57 (SE) in Zone 6 and 0.5 ± 2.83 (SE) in Zone 2 (Haridwar-Narora). Similarly, the mean dolphin individuals encountered within neonate size class was 10 ± 2.55 (SE) in Zone 5

followed by 1.5 ± 2.83 (SE) in Zone 6 (Farakka- Ganga sagar) and least was recorded in Zone 2 with a mean of 0.5 ± 2.83 (SE) individuals (Figure 9.3).

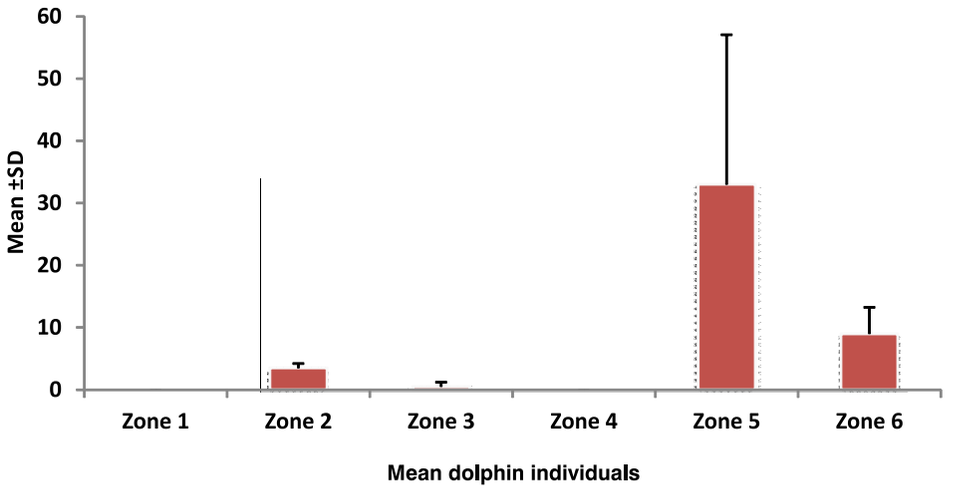

Figure 9.2: Mean Gangetic River (*Platanista gangetica*) dolphin individuals sighted across six zones of the Ganga River

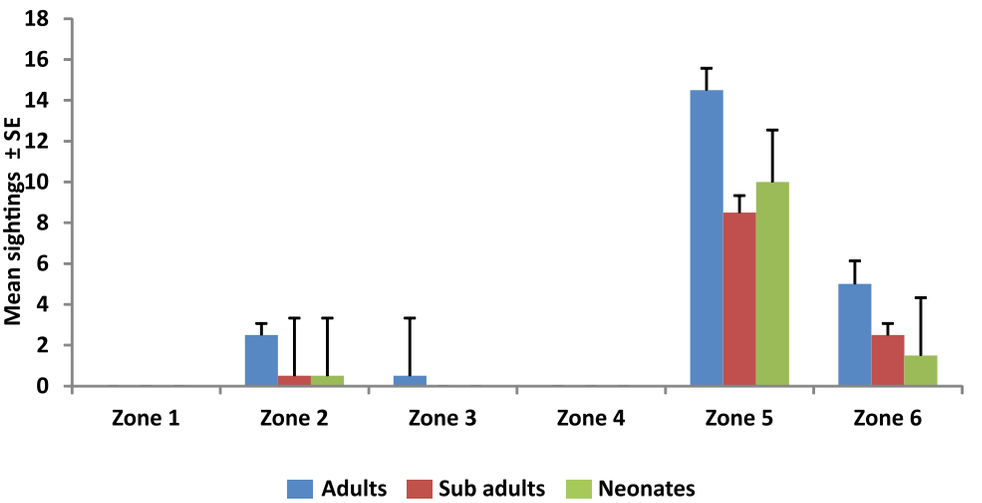

Figure 9.3: Mean Gangetic River dolphin (*Platanista gangetica*) individuals encountered within each size class across six zones of the Ganga River

A surfacing female dolphin in the mid channel of the Ganga River

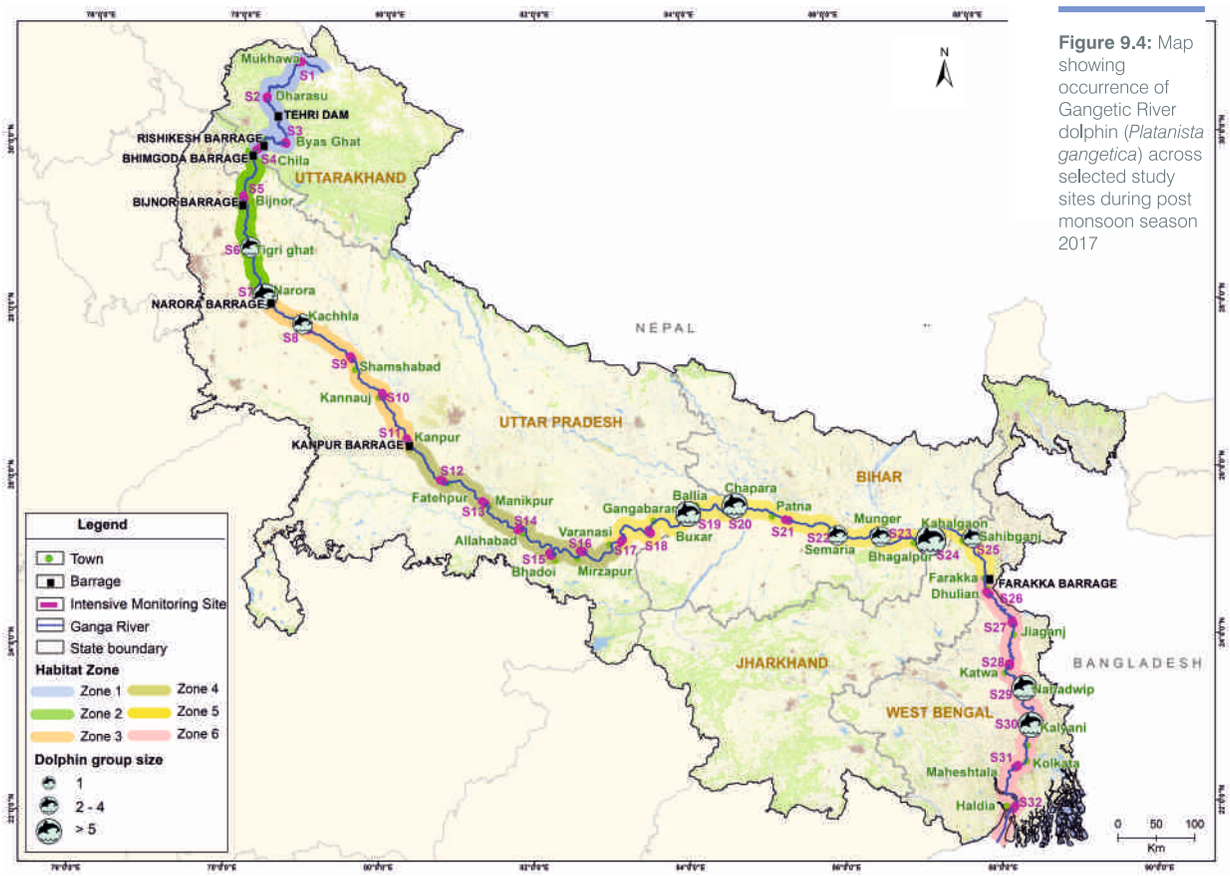

Figure 9.4: Map showing occurrence of Gangetic River dolphin (*Platanista gangetica*) across selected study sites during post monsoon season 2017

Preferred dolphin habitat

The abundance and occurrence of dolphin was not uniform throughout the selected study stretches; rather they were distributed as groups ranging from 1-9 individuals with a mean group size 3 ± 1.29 (SE), in 29 locations across two sampling seasons. During post monsoon survey, 2017 Ganges River dolphin sightings occurred in 11 sporadic locations (group size ranging from 1-5 individuals). Maximum sightings (59.26%) occurred between Varanasi and Farakka (Zone 5) (Figure 9.4). A total of 18 sightings of Gangetic river dolphin occurred during pre monsoon survey, 2018 with a group size ranging from 1-9 dolphin individuals. Highest Gangetic river dolphin sightings (76.92%) occurred between Varanasi and Farakka (Zone 5) (Figure 9.5).

Figure 9.5: Map showing occurrence of Gangetic dolphin across study sites during pre monsoon season 2018

Habitat use

53% of the dolphin sightings recorded within channels with clayed banks followed by channels with sandy banks (32%) and least sightings were recorded from channels with loamy banks (15%) (Figure 9.6). Dolphin sightings were recorded within a depth range of 1.5 m-15 m and 87.09% of the sightings recorded within the depth of more than 5 metre whereas only 12.09% of the sightings were confined to depth of less than 5 metre. Dolphin occurrence showed a positive trend with increasing channel depth. Dolphin sightings were frequent in the areas with characteristic features like steep banks, deep pools and moderate fishing intensities.

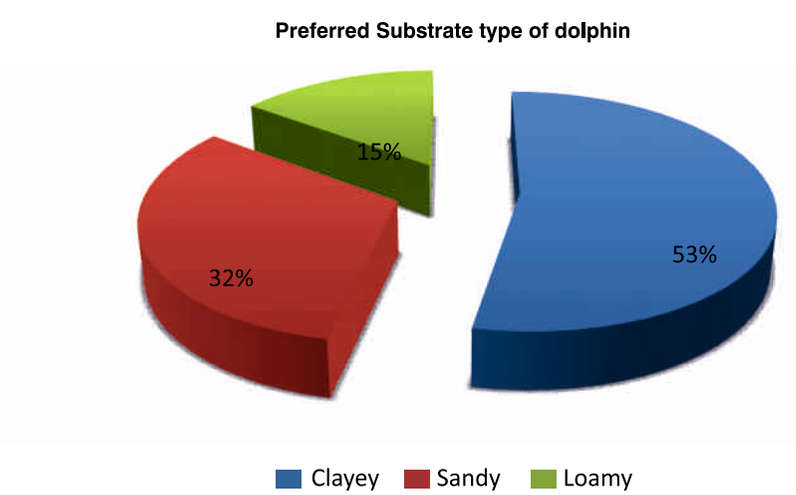

Figure 9.6: Substrate types preferred by Gangetic River dolphin (*Platanista gangetica*) across six zones of the Ganga River

Factors affecting occurrence of dolphins

The result of the generalized linear model showed that dissolved oxygen (DO), channel depth, fishing and religious activities are the most influential predictors affecting dolphin occurrence. Dolphin occurrence was positively related to dissolved oxygen (DO) and channel depth whereas fishing and human activities were negatively associated with dolphin occurrence (Table 3). Our results also revealed that channel depth has a positive association with dolphin occurrences ($R^2 = 0.308$) (Figure 9.7).

Table 9.3: Summary statistics loglikelihood (logL), Akaike Information Criteria (AICc), relative support for hypothesis (Δ AICc) of candidate regression model explaining dolphin presence.

Model	logLik	AICc	Δ AICc
Dolphin~DO+C_Depth+D_Fishing+D_RA+NO3	-181.634	375.4	0
Dolphin~DO+C_Depth+D_Fishing+D_RA	-182.665	375.4	0.02
Dolphin~DO+C_Depth+D_Fishing	-196.428	400.9	25.51
Dolphin~C_Depth+D_Fishing	-204.786	415.6	40.2
Dolphin~C_Width+C_Depth+DO+W_temp	-284.757	579.6	204.2
Dolphin~D_Fishing	-309.507	623	247.62
Dolphin~C_Depth	-311.893	627.8	252.39
Dolphin~C_Width	-329.127	662.3	286.86
Dolphin~NO3+V_Pollu+D_RA+D_Boating+D_SM+D_Agri	-340.134	694.5	319.05
Dolphin~D_RA+D_Boating+D_SM+D_Agri	-360.812	731.7	356.31
Dolphin~SAL+pH+NO3+W_temp+A_temp	-364.086	740.3	364.9
Dolphin~CON+TDS	-399.016	804.1	428.66
Dolphin~1	-417.931	839.9	464.47

Summary of model (Dolphin~DO+C_Depth+D_Fishing+D_RA+NO3)

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-3.3089	0.5232	-6.325	0.000000000254***
DO	3.0098	0.7778	3.87	0.000109***
C_Depth	20.266	2.3132	8.761	< 2e-16***
D_Fishing	-118.572	17.2519	-6.873	0.00000000000629***
D_RA	-120.42	42.3204	-2.845	0.004435**

0.00000001 '***'

Movement of large vessels in the Ganga River

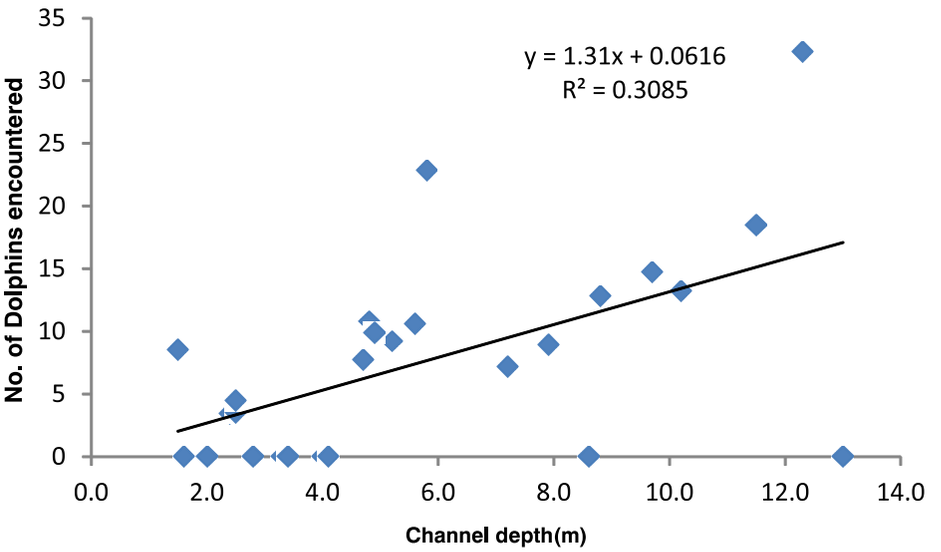

Figure 9.7: Association between channel depth (m) and dolphin abundance across six zones of the Ganga River

9.5 DISCUSSION

Restricted occurrence and low abundance of Gangetic river dolphin in the upper stretch of the Ganga River was attributed to shallow channel type with low water discharge. Large concentrations of dolphins occurred downstream of Ghazipur. The observed pattern of dolphin abundance and occurrence was likely due to the increase in channel depth (Miller, 2003; Bashir et al., 2010b) and channel width with muddy substrates (Kelkar et al., 2010). The high water discharge in the lower stretch of the Ganga River (downstream of Ballia) as evident from large river confluence like Ghagra, Son Gandak and Kosi rivers enabling higher productivity is one of the reasons influencing dolphin occurrence (Sinha et al., 2000 and Kelkar, 2008). The present study revealed that the sites within Zone 1 (Gaumukh- Haridwar), Zone 2 (Haridwar –Narora), Zone 3 (Narora- Kanpur) and Zone 4 (Kanpur-Varanasi) of the Ganga River are highly fragmented (presence of barrages), and unsuitable for dolphins as it not only has limited depth profile and low water discharge across the seasons (post monsoon and pre monsoon) but has also resulted in less abundant and rare occurrence of Gangetic river dolphins. The present study also showcased that various ecological factors including channel depth, channel width, water quality (DO, NO_3 and water temperature) influence Gangetic river dolphin occurrence and abundance (Shrestha, 1995; Smith et al., 1998; Sinha et al., 2000). The factors believed to restrict abundance and occurrence of Gangetic River dolphin were extensive fishing and religious activities sand mining and river bed agriculture (Behera, 1995; Mohan et al., 1997; Sinha et al., 2000; Choudhary et al., 2006; Bashir et al., 2012).

Large meanders in the Ganga River are home to Ganges River Dolphin.

9.6 CONCLUSION

In a broader perspective, the study reinforces the idea that each stretch has its unique set of habitat characteristics, enabling spatial variation in dolphin occurrence. Water depth plays a central role in enhancing dolphin abundance across the entire length of the Ganga River. The study also revealed that extensive fishing, large ferry crossing for navigation and religious activities were detrimental to occurrence and abundance of Gangetic River dolphins across all the sites. Based on the present outcomes our future endeavour will be to derive best population estimates using robust methods; and derive population trend along the entire stretch of the Ganga River.

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Surfacing dolphins in the Ganga River

ASSESSMENT OF PHYSICO-CHEMICAL PARAMETERS AND ORGANOCHLORINE PESTICIDES IN WATER AND SEDIMENT OF THE GANGA RIVER: PRELIMINARY STATUS AND TRENDS

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ABSTRACT

The water quality of the Ganga River is deteriorating at a faster pace due to occurrence of various organic and inorganic anthropogenic stressors. These stressors are severely affecting the freshwater ecosystem as its biodiversity. One of the key contributors of organic contamination in the Ganga is the excessive discharge of banned and regulated pesticides. In the present phase of the study, water quality (physico-chemical parameters) and pesticide load (Organochlorine Pesticides) were assessed in the Ganga River as a first step to facilitate clean Ganga mission.

Among Physico-Chemical Parameters (PCPs) pH, water temperature, dissolved solids, dissolved oxygen, nitrates, ammonium and specific conductivity were monitored, whereas pesticide

10

contamination was quantified for 20 Organochlorine Pesticides (OCPs) in water and sediment across the Ganga River. The physico-chemical parameters were assessed for two seasons viz., post-monsoon (October-December 2017) and post-winter (March-May 2018), whereas OCPs load has so far been analysed for post monsoon season only. All the PCPs were measured by using digitally calibrated probe meters, whereas OCPs were analysed through GC-ECD.

The levels of PCPs were generally higher than the acceptable limits in some downstream stretches, particularly after Narora, Uttar Pradesh. In case of OCPs pollution load, ΣOCP concentration ranged from 0.028 μg/L to 16.228 μg/L in water and from 6.328 μg/kg to 703.413 μg/kg in sediment samples. The most frequently detected OCPs in water and sediments were Heptachlor followed by Heptachlor epoxide. In few sites, the concentration of some OCPs was higher than the permissible level set for Aquatic Life Criteria (ALC) by international agencies.

Results revealed that there were significant seasonal and spatial variations in physico-chemical parameters, which demonstrated the effects of environmental flow, agriculture activity and industrial settlements. In case of OCPs load, high variation in contamination pattern at different sampling sites was observed. The notable contamination was recorded at Ballia, Uttar Pradesh for water, and at Hashimpur, West Bengal for sediments. The initial trend suggests that OCP concentration increased in the order of sediments>water.

Keywords: Physico-chemical Parameters, Organochlorine Pesticides, Water, Sediment, Fish, Ganga River

10.1 INTRODUCTION

The key water quality parameters that have to be considered for surface water quality monitoring are dissolved oxygen, temperature, pH, dissolved solids, nitrates, conductivity and ammonium etc. Each of these parameter gives important information on the state of aquatic systems. For instance, physico-chemical parameters provide an understanding of the effects of pollution load or stressors on the ecosystem's chemical and physical processes. This section includes the results and trends of physico-chemical parameters recorded during two sampling seasons through the surveys conducted across the Ganga River in five states viz., Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal. The survey was conducted for two seasons:

1. Post-monsoon (October 2017-December 2017) and
2. Post-winter (March 2018-May 2018).

10.2 STUDY METHODOLOGY

32 intensive sampling points were selected from the Ganga as it traverses across five states viz., Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal, to give a reflection of the quality of water. At each intensive sampling site, an area of 5 Km stretch was selected as representative of that site and physico-chemical parameter were evaluated at an average interval of 1 Km. For the present study, all of the above parameters have been evaluated by using digital calibrated probe meters **ProDSS** and **YSI**.

10.3 FINDINGS AND DISCUSSION

Evaluation of water quality parameters at Kachla, Uttar Pradesh

pH

pH is the negative logarithm of the hydrogen ion (H^+) concentration of a solution and it is a measure of whether the liquid/solid is alkaline or acidic. In fresh water bodies, hydrogen ion is governed by the equilibrium between carbonate ions, carbon dioxide and bicarbonate. The pH scale ranges from 1.0 (very acidic, when more [H^+]), 7 (neutral, when [H^+] = [OH^-]) to 14 (very alkaline, when more [OH^-]). Atmospheric deposition due to acid rain and wastewater discharges are some of the key contributors that can change the pH. It is likely to increase during day largely due to the consumption of carbon-dioxide for photosynthetic activity and falls during night due to respiratory processes. pH affects many biological and chemical activities in the water bodies e.g., different organisms flourish within different pH ranges. However, most of the aquatic animals prefer a pH range of 6.5 to 8.5. A pH outside this range could reduce the biodiversity in the water systems as it may stress the physiological systems of many organisms and can reduce their reproduction potential. Additionally, a low pH can result in high mobility and bioavailability of toxic contaminants for uptake by different aquatic plants and animals. This can result in circumstances that are highly toxic to aquatic life, particularly to vulnerable or sensitive species.

Symbol (physical parameter)	pH
Units used for analytical results	pH units
Method(s) used for analysis	Digital calibrated water quality probe meter with pH sensitive probe. Calibrated at 3 point calibration range at 4.0 (acidic), 7.0 (neutral) and 10.0 (basic)
QC/QA	QC (Standards checked) after analysis
Aquatic life criteria	6.5-8.5 is preferable

A zone-wise assessment of pH for both seasons is discussed below.

pH in six zones

In the present study the pH range in post-monsoon season, extends from about, 7.49 to over 8.76 between all the five zones whereas, in post-winter sampling, the range of pH extends from around, 7.93 to over 8.95. Figure 10.1 shows the comparative view of post-monsoon and post-winter pH results of all the six zones. The relatively higher values of pH in post-winter season may be attributed to discharge of unregulated and untreated industrial and sewage effluents whereas moderately alkaline pH fluctuation within a narrow range in post-monsoon months may be attributed to the considerable dilution of water which increases the buffering effects of the systems. As seen in Figure 10.1, the pH values in all the three sites (S5-S7) covered in Zone 2 (post-monsoon and post-winter), are within the permissible range (6.5-8.5) for aquatic life criterion.

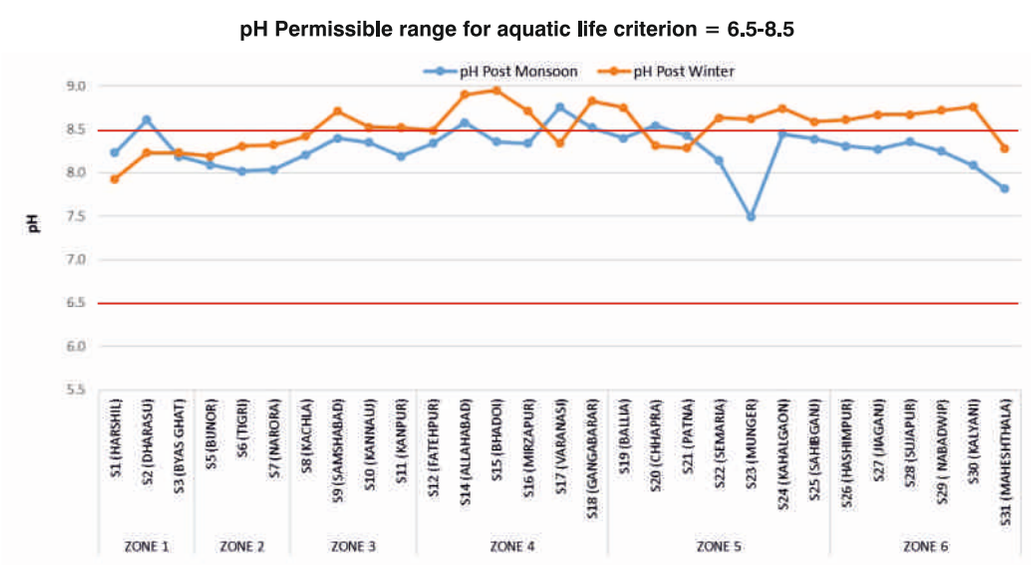

Figure 10.1: pH range recorded in six zones along the bank of Ganga River in post-winter & post-monsoon

Dissolved Oxygen (DO- mg/L)

Dissolved oxygen (DO) is a measure of oxygen in its dissolved form. DO levels decline if more oxygen is consumed than is produced, and some sensitive and vulnerable animals may weaken, diverge, or die. Different biological and chemical processes can result in decline of DO, for example biological decomposition of effluents from wastewater and sewage treatment plants, that contain high amount of organic materials, by microorganisms. The levels of dissolved oxygen can fluctuate seasonally or within a period of 24-hour. They also fluctuate with altitude and water temperature, as warm water reportedly holds less oxygen than cold water, and at higher altitudes water holds relatively less oxygen.

Symbol (physical parameter)	DO
Units used for analytical results	mg/l O_2
Normal method(s) used for analysis	Digital calibrated water quality probe meter with DO sensitive probe
QC/QA	QC (Standards checked) after analysis
Aquatic life criteria	>5 mg/l is preferable

A zone-wise assessment of DO is discussed below.

DO in six zones

Figure 10.2 shows the comparative view of post monsoon and post winter DO results of all the six zones. DO values during the wet season (post-monsoon) were higher than those during the dry period (post-winter season) and significantly different. Dilution factor post the rainy season is responsible for increasing the levels of oxygen as compared to post winter season. However, the dramatic fluctuations in DO levels during post-winter sampling, in sites located along the industrial and agricultural belt (S13 in Zone 4 and S31 in Zone 6) is indicative of anoxic discharges, untreated sewage, organic discharges, and partially treated sewage which utilises DO.

As seen in Figure 2, the DO levels from S5-S7 (Zone 4), in both the sampling seasons (post-monsoon and post-winter), are well above the minimum permissible level for aquatic life criteria (⩾5 mg/L). The presence of all the five species of conservation significance was recorded in this stretch.

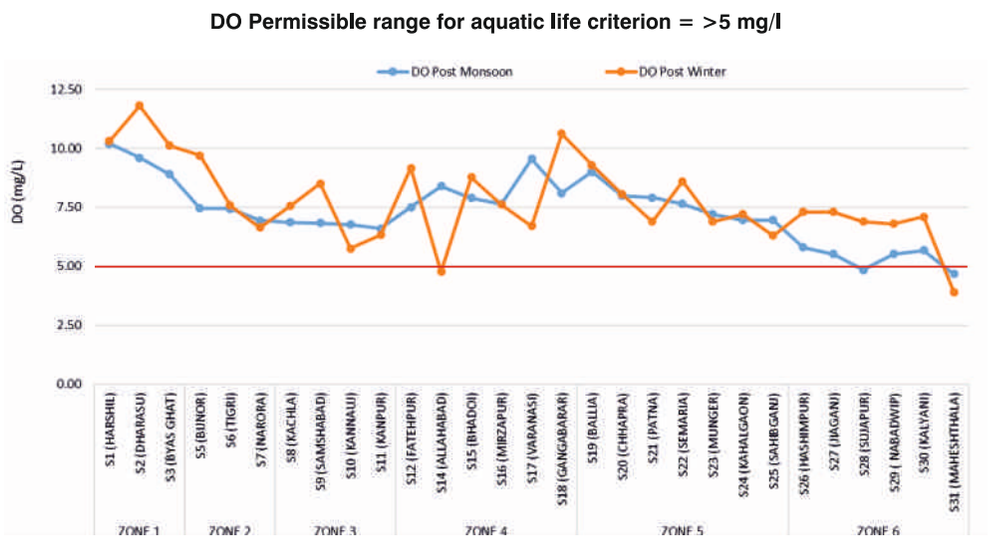

Figure 10.2: DO range in six zones along the bank of Ganga River in post-winter & post-monsoon

Discharge of sewage waste in Ganga River

Total Dissolved Solids (TDS, mg/L)

In water bodies, total dissolved solids (TDS) consist of different ions (chlorides, calcium, nitrate, phosphorus, iron, sulphur, etc.,) that traverse through a 2 μm filter paper. The levels of TDS can affect the water equilibrium in the cells of aquatic species which in turn can disturb their cell density and eventually the ability to maintain their position in the water system. Elevated levels of TDS can serve as transporters of toxicants, which can readily adhere to suspended particles. This is particularly problematic in areas such as agricultural belts where high amount of pesticides are being used, and in areas where there is high discharge of untreated industrial effluents.

Symbol (physical parameter)	TDS
Units used for analytical results	mg/l Dissolved solids
Normal method(s) used for analysis	Digital calibrated water quality probe meter with TDS sensitive probe
Occurrence/Origin	Agricultural runoffs, industrial and sewage discharge
QC/QA	QC (Standards checked) after analysis
Aquatic life criteria	<500 mg/l is preferable

A state-wise assessment of TDS is discussed below.

TDS in six zones

In the present study, the range of TDS, in post-monsoon season, extends from around 88.68 mg/L to over 278.88 mg/L between all the six zones whereas, in post-winter sampling, the range of TDS extends from around, 110.15 mg/L to over 422.50 mg/L. Figure 10.3, shows the comparative view of post monsoon and post winter TDS results of all the six zones.

The mean values (Figure 10.3) for the total dissolved solids (TDS) were higher in low precipitation season (post-winter) than in the high precipitation season (post-winter). The lower values of this parameter in post-monsoon season suggest that the runoff water contributes to its dilution in the rainy season. As seen in Figure 10.3, the TDS level in all zones, in both the sampling season (post-monsoon and post-winter), were recorded to be well above the minimum permissible level for aquatic life criteria (<500 mg/L).

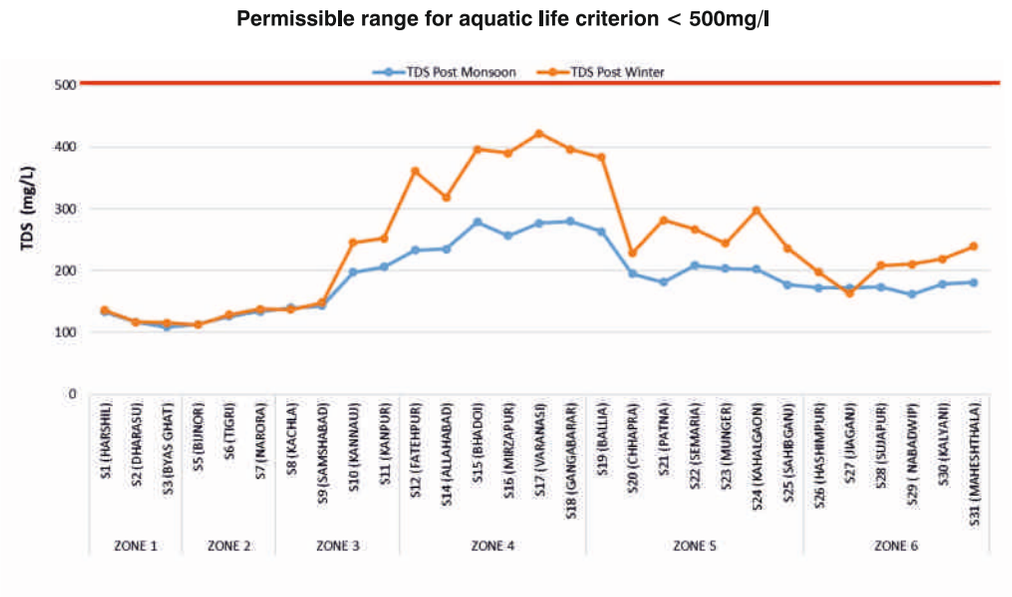

Figure 10.3: TDS range in six zones along the Ganga River during post-winter & post-monsoon surveys

Nitrates (mg/L)

Nitrates are essential plant nutrients that are present in several different forms in aquatic and terrestrial ecosystems. Some of these forms of nitrogen include nitrites, ammonia, and nitrates. The source of nitrates (NO_3^-) in water bodies is relatively little of mineral origin, and most of the nitrate found in rivers is from organic and inorganic sources, like agricultural runoffs and waste discharges, though, microbacterial oxidation and nitrogen fixation by plants can also produce nitrate. In excess amount nitrates can cause substantial water quality problems like enhanced eutrophication, and variations in the different plants and animals that inhabit the water systems. This sequentially can affect the other important water quality parameters and indicators like temperature and dissolved oxygen.

Excessive levels of NO_3^- may result in hypoxia due to low levels of dissolved oxygen, and under specific conditions it may result in toxicity to animals at levels >10 mg/L. The natural level of nitrate and ammonia in fresh water systems is usually at low concentration of < 1 mg/L, however in wastewater treatment effluents, it can shoot up to 30 mg/L.

Symbol (physical parameter)	
Units used for analytical results	mg/l of N or mg/l of NO_3^-
Normal method(s) used for analysis	Digital calibrated water quality probe meter with NO_3^- sensitive probe
Occurrence/origin	Oxidation of ammonia, Agricultural fertilizer runoffs, industrial and sewage discharge
QC/QA	QC (Standards checked) after analysis
Aquatic life criteria	<10 mg/l is preferable

A zone-wise assessment of NO_3^- in post-winter and post-monsoon is discussed below.

Nitrate in six zones

In the present study, the range of nitrates, extends from 0.08 mg/l to over 12.08 mg/l during post-monsoon season. However, in post-winter sampling, the range of nitrates extends from around 0.05 mg/l to over 16.70 mg/l.

The reason for the high nitrate values at some sites in zone 5 (post monsoon), and zone 6 (post-winter) could be attributed mainly to agricultural runoffs.

Figure 10.4 shows the comparative view of post-monsoon and post-winter nitrate results of all the six zones. Comparatively low nitrate levels were observed during post monsoon season due to dilution effect. The high and concentrated nitrate levels recorded during post-winter season may be attributed to high evaporation (low water level), and lower flow volume. As seen in Figure 10.4, nitrate levels from S5 to S7, in both the sampling season (post-monsoon and post-winter), are well below the minimum permissible level for aquatic life criteria (<10 mg/l) and the presence of all the five species of conservation significance indicates that aquatic biodiversity of this stretch among the highest.

Bathing & washing activities on the bank of Ganga River

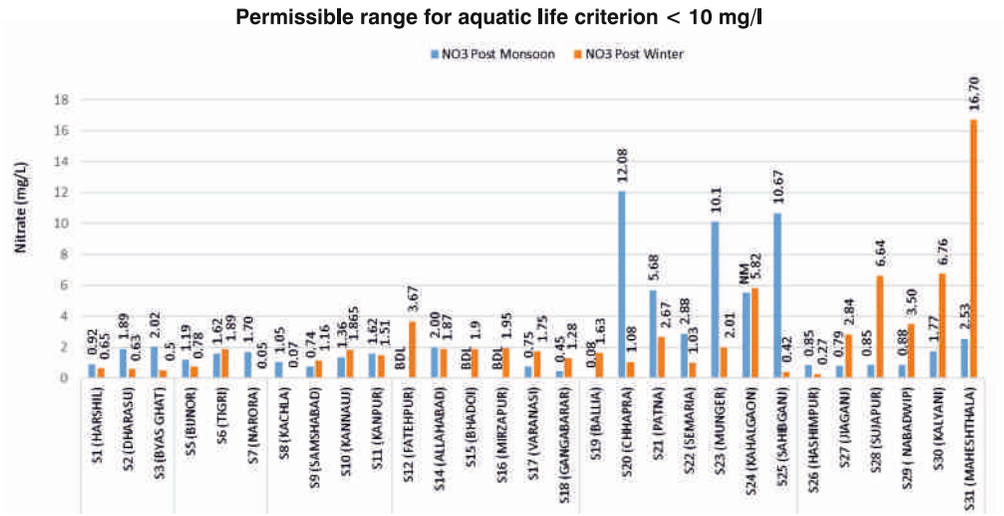

Figure 10.4: Nitrate concentration range recorded in six zones along the bank of Ganga River in post-winter & post-monsoon

*BDL = Below Detection Limits(0.02 mg/L, Ion Chromatography), NM = Not measured (Due to technical issues)

Specific Conductivity (μS/cm)

The ability of water to pass an electrical current is defined as conductivity, and it is measured in microsiemens per centimetre (μS/cm) or micromhos per centimetre (μmhos/cm). The temperature affects the conductivity measurements, therefore the standard method for reporting conductivity is the measurement of conductivity recorded at or corrected to 25°C and is defined as specific conductance (uS/cm). One of the important factors that can affect specific conductivity (SPC) in water is the presence of dissolved solids or ions. Similarly, conductivity is directly proportional to change in temperature i.e. elevated water temperatures result in higher conductivity. Industrial, agricultural and sewage discharges to streams can change the conductivity due to the presence of ions. The aquatic life criteria suggests that fresh water systems that have conductivity in the range of 150 to 500 μS/cm, support good mixed fisheries.

Symbol (physical parameter)	Specific Conductivity (SPC)
Units used for analytical results	μS/cm
Normal method(s) used for analysis	Digital calibrated water quality probe meter with conductivity sensitive probe
QC/QA	QC (Standards checked) after analysis
Aquatic life criteria	150 to 500 μS/cm is preferable

A zone-wise assessment of specific conductivity in both seasons sampling is discussed below.

Specific conductivity in six zones

Figure 10.5 shows comparative view of post monsoon and post winter specific conductivity results of all the six stretches along with the presence of five species of conservation significance in those stretches at recorded readings. In the present study the range of specific conductivity in post-monsoon season extends from around, 168.10 μS/cm to over 446.50 μS/cm. Due to the dilution of the water source in post-monsoon season, at almost all the sites, the conductivity was found to be within the prescribed or permissible range of <500 μS/cm. However, in post-winter sampling, the range of specific conductivity extends from around 171.10μS/cm to over 693 μS/cm. Additionally, in post-winter, at most of the sites in

Zone 4 (especially those located along the industrial and agricultural belt) the specific conductivity exceeded the prescribed or permissible range of <500 μS/cm for aquatic life criteria. The reason for sudden high increase in specific conductivity could be attributed to continuous inflow of agricultural runoff, domestic and industrial discharge accompanied with high evaporation, low water level and lower flow volume in dry seasons which may result in high concentration of ions.

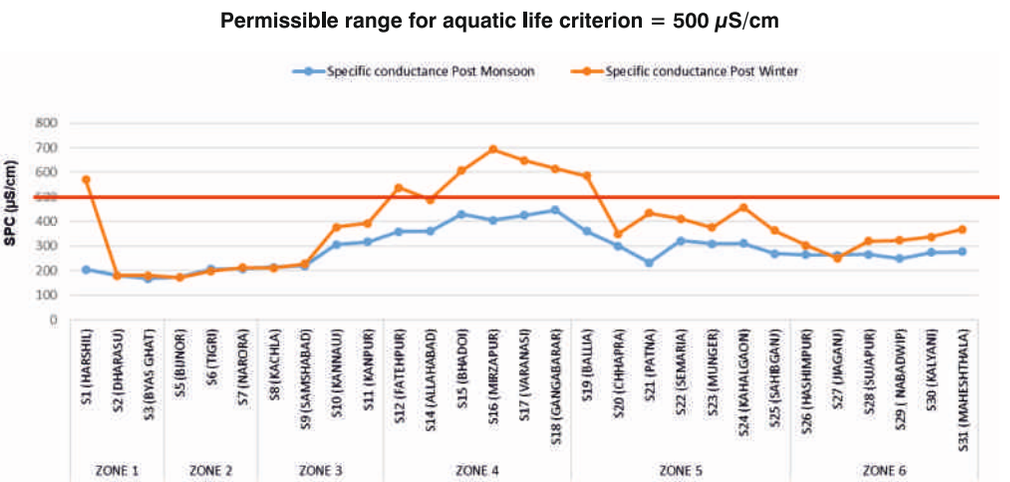

Figure 10.5: Nitrate concentration range recorded in six zones along the bank of Ganga River in post-winter & post-monsoon

Ammonium (mg/L)

Discharges from waste water treatment plants, industrial effluents and agricultural runoff can result in elevated ammonium levels. It also utilizes and exerts pressure on oxygen levels in water as it is converted to oxidised forms of nitrogen. Elevated concentrations of ammonium may act as important source of nitrogenous fertilizer for aquatic plants resulting in eutrophication and reduced oxygen concentration due to increased biological oxygen demand. Additionally, toxicity of ammonium to aquatic life at certain concentrations is directly related to pH, salinity, and water temperature, e.g., at elevated pH levels in water, ammonium hydroxide is extremely toxic to aquatic life.

Symbol (physical parameter)	$N\text{-}NH_4$
Units Used for Analytical Results	mg/l
Normal method(s) used for analysis	Digital calibrated water quality probe meter with ammonium sensitive probe
QC/QA	QC (Standards checked) after analysis
Aquatic Life Criteria	0.5 mg/l is preferable

In the present study, due to technical issues during post- monsoon, sampling assessment of ammonium was done in sites S1 to S17 (Zone 1, Zone 2 and Zone 3), whereas in post-winter the ammonium levels were assessed from sites S18 to S30 (Zone 4 and Zone 5). The range of ammonium, in post-monsoon sampling, extends from around, 0.02 mg/l to over 0.45 mg/l whereas in post-winter the ammonium levels ranges from 0.09 mg/l to over 5.52 mg/l (Figure 10.6).

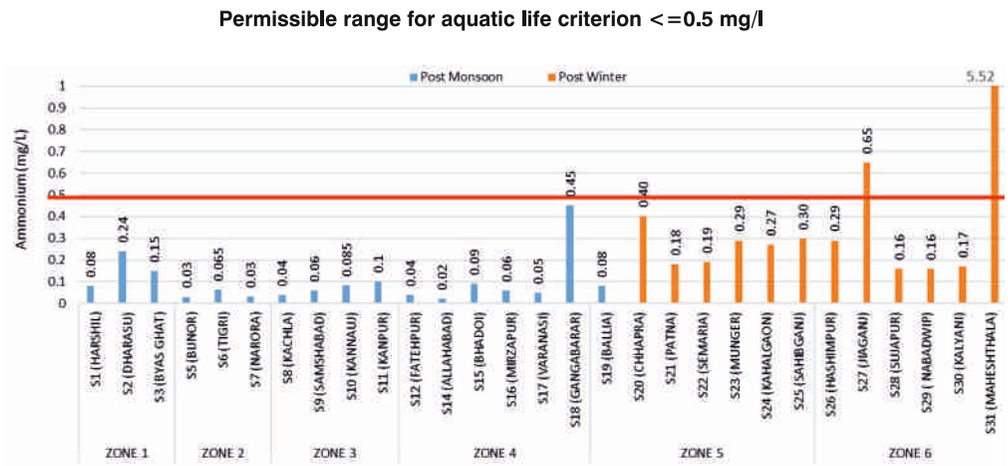

Figure 10.6: Ammonium range in six zones along the bank of Ganga River in post-winter & post-monsoon

10.4 CONCLUSION

There were significant seasonal and spatial variations in water quality parameters of the Ganga River which demonstrated the effects of environmental flow, precipitation, agriculture activity and industrial settlements. The levels of water quality parameters monitored were generally higher than the acceptable limits in some downstream stretches, particularly after Narora, which indicate that downstream stretches get more and more influenced by flow conditions, agriculture expansion and industrial settlements.

The aquatic community in rivers integrates all impacts - the effects of pollution as well changes in hydro-morphology. The results of the present study, indicate that the appearance and distribution of aquatic organisms in rivers is significantly influenced by flow conditions, and water quality status of the aquatic environment.

Of all the sites studied, the water quality parameters from S4 to S6 (~175 km) in Zone 2 were within permissible range and presence of five species (Gangetic Dolphin, Turtles, Smooth Coated Otter, Mugger and Gharial) of conservation significance were also recorded within this stretch indicating that aquatic biodiversity of this stretch is the highest of the total river. The results also indicate that compared to other sampling sites covered, Zone 2 appears to be relatively unpolluted with fairly consistent environmental flow, hence supporting important aquatic biodiversity.

High anthropogenic activities on the bank of Ganga River

10.5 ECOTOXICOLOGY ANALYSIS – ORGANOCHLORINE PESTICIDES IN WATER AND SEDIMENT FROM THE GANGA RIVER

Ganga is the longest river in India and lifeline for millions of people as well as for aquatic flora and fauna. However, the water quality of Ganga is deteriorating at a fast pace due to various anthropogenic stressors (organic and inorganic), that can severely jeopardize the ecological fitness of its freshwater ecosystem. One of the key contributors of organic contamination in the Ganga is the excessive discharge of banned and regulated pesticides from point and diffuse sources. India is among the top ten producers and consumers of pesticides in the world and in terms of percentage usage, Organochlorine Pesticides (OCPs) together with Organophosphorous pesticides (OPPs) constitute ~70% of total pesticide usage in India. Due to their complex structure and chemical properties, most of these pesticides are persistent in environment, bio-accumulative and toxic (PBT) to non-target species. In particular, aquatic species are at a higher risk because pesticide exposure can be life-long and through multiple routes. Thus bioaccumulation is frequent, that can ultimately affect their survival. Therefore, it becomes highly imperative to quantify their load in abiotic matrices and body burden in biotic matrices in order to develop effective mitigation measures.

This study provides preliminary information on the current contamination status on the presence and quantification of residues of persistent Organochlorine Pesticides (OCPs) in different zones of Ganga River. These results include levels, trends and distribution of organochlorine pesticides residue in abiotic components recorded during post-monsoon sampling seasons through the surveys conducted across Ganga river in five states viz Uttarakhand, Uttar Pradesh, Bihar Jharkhand and West Bengal. The survey was conducted in post-monsoon (October 2017-December 2017).

Discharge of sewage waste in the Ganga River at Varanasi, Uttar Pradesh

Methodology

32 intensive sampling points were selected from Ganga River as it traverses through the five states viz., Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal, to give a reflection of the quality of water. At each intensive sampling site, an area of 5 Km stretch was selected as representative of that site and composite samples were collected at an average interval of 1 km.

Collection and storage of water and sediment samples:

Collection and storage of samples was performed as per CPCB guidelines (CPCB, 2008). For collection of water sample, amber coloured high density polyethylene bottles (1l) were used. These were rinsed with the solvent used for extraction before use. While collecting samples each bottle was washed with the river water thrice. Then from depth of about 30 cms water was collected up to the brim of the bottle. Care was taken to avoid formation of air bubbles. After collection these were labelled properly. The sediment samples were collected in a zip lock bag from beneath an aqueous layer from the depth starting from 6-8 cm up to 10-15 cm directly using a hand held device. The sediment collecting sample bags were tightly capped, adequately labelled and properly placed in sample container to allow easy transportation to the laboratory. Samples were stored at low temperature to prevent degradation of pesticides.

Extraction of pesticide residue:

Chemical, solvents and glassware

The solvents and chemicals used during the analysis were of highest purity HPLC grade from Merck™. The glassware used was cleaned thoroughly with extran detergent followed by washing under running water. It was then rinsed with distilled water and acetone before drying in oven at 60°C -70°C. The glassware was rinsed with hexane/acetone before use.

Extraction method:

Water

All the water samples were extracted for the presence of pesticide residues as per EPA method 1699 (USEPA, 2007). Briefly, 1 L of sample was filtered by 0.45 μm filter paper and taken in a separatory funnel and extracted with 35 ml Dichloromethane (DCM). The lower organic layer was extracted and this process was repeated twice. This was followed by a wash with 25ml hexane and 15 ml saturated sodium chloride. The lower aqueous layer was discarded and upper organic layer was added to the 105 ml extract. This extract was then put for column chromatography (as per sec 3.3). After column chromatography, the extract thus obtained was dried in rotary evaporator at 112 rotations per minute and at a temperature of 42 °C. After drying the glassware was rinsed with 5 ml hexane to remove any traces of pesticide residues on the glassware inner surface. This extract was transferred to centrifuge tubes for storage until further analysis by gas chromatography.

Sediment

All the sediment samples were extracted for the presence of pesticide residues as per EPA method 1699 (USEPA, 2007) with slight modification. Samples were sieved and homogenized, where large debris (e.g., gravel, sticks) were removed, and were kept at 4°C until analysis was performed. Briefly, 10 g of dried and finely grounded sediment was placed between the glasswools in soxhlet extraction unit. In the round-bottom flask 250-ml of Hexane :acetone in ratio of 4:1 by volume were added and the extraction was carried out for 10 h. The extract was then filtered through anhydrous sodium sulfate and then concentrated to 2 mL in a rotary vacuum evaporator before the clean-up.

Clean-up and column chromatography

Clean-up (sediment) was performed as per sec 13.8 of EPA-1699 method by subjecting the extract to column clean up, so as to remove any interfering pigments in water samples. To prepare the column, a dab of glass wool was plugged at the bottom of the column. Then a layer was added a 5 gm layer of florisil followed by 1 cm layer of sodium sulphate. Care was taken to ensure no breakage between the layers. The extract was poured from the sides of the container and not directly so that it does not make a hole in the layer. The packed column was washed and eluted with 15 ml of hexane and avoiding the exposure of sodium sulfate layer to the air. The 2 ml concentrated extract was placed and 20 ml of 30% diethyl ether in hexane was dispensed into the column and the eluate was collected in a pear shaped rotary flask. The eluates were evaporated to dryness using a rotary vacuum evaporator and the residues were dissolved in HPLC grade hexane (5ml) for gas chromatographic analysis.

eppendorf

Detection and quantification:

The sample extracts of water were analyzed for residues of organochlorine pesticides by Gas Liquid Chromatography (GLC). Analysis was carried out on a Schimadzu Model 2010 Gas Chromatograh (GC) equipped with 63Ni Electron Capture detector (ECD) and a capillary column Restek Rtx-5 (30mm x 0.25mm). The instrument was supported by Lab Solutions software for the analysis of different organochlorine pesticides. Quality control check as per section 9.0 of USEPA 1699 was maintained through analysis of samples spiked with known concentration of target analytes to evaluate and document data quality, to monitor method performance, and analysis of standards and blanks as tests of continued performance. Finally, as per the quality control requirements all the records for calibrations, labeled compound recovery and analysis of blanks were maintained.

Quality Control (QC):

Appropriate quality assurance/quality control (QA/QC) analysis was performed. A blank sample was run before each batch of real samples to check for interferences cross and contamination. The blank concentrations were<MDL (method detection limit). Standard deviation of random duplicate sample analysis was $<\pm5\%$. Linear calibration curves were obtained with the r2 value of 0.999 and calibration verification standard deviation was $<\pm5\%$. The target compounds concentrations were determined or quantified by external standard method using the peak height and area of the standards at five level calibration curves. Matrix spiked recovery study was undertaken by spiking the known working standard solutions of OCPs with samples which were extracted and analyzed in the same way as the real samples. The matrix spiked recoveries for water were in range of 78-103% for studied compounds whereas for soil were 80-105%. After each 10 samples standard quality check was performed. The results of the analysis were reported in μg/l for water and in μg/kg for sediment.

A total of 20 Organochlorine pesticides were analysed in water and sediments samples.

Pesticides analyzed

1 a-BHC
2 g-BHC
3 b-BHC
4 d-BHC
5 4,4 DDT
6 4,4 DDD
7 4,4 DDE
8 HEPTACHLOR
9 HEPTACHLOR EPOXIDE
10 t-CHLORDANE
11 c-CHLORDANE
12 ALDRIN
13 DIELDRIN
14 ENDRIN
15 ENDRIN ALDEHYDE
16 ENDOSULFAN I
17 ENDOSULFAN II
18 ENDOSULFAN SULFATE
19 METHOXYCHLOR
20 ENDRIN KETONE

Findings

Concentration levels of OCPs in water

The total OCPs concentration in water ranged from 0.028 μg/L -16.228 μg/L (Figure 10.7). For the different OCPs, Heptachlor and Heptachlor epoxide were the most abundant and detected in almost all the samples. In some sites, the concentrations detected were higher than the permissible level set by the threshold aquatic life criteria by USEPA.

Concentration levels of OCPs in sediment

Figure 8 provides detailed information about the concentrations of individual OCPs in sediment of Ganga River along the entire stretch. The total concentrations of OCPs revealed a wide range of fluctuation. The total OCPs concentration in sediment ranged from 6.328 μg/kg to 703.413 μg/kg (Figure 10.8). For the different OCPs, Heptachlor and Heptachlor epoxide were the most abundant and detected in almost all the samples followed by a-BHC and b- BHC. Additionally, the frequency of occurrence of different target pesticides in zone 4. zone 5 and zone 6 were higher than any other zones. In some sites, the concentration detected were higher than the permissible level set by the threshold aquatic life criteria (USEPA,2017).

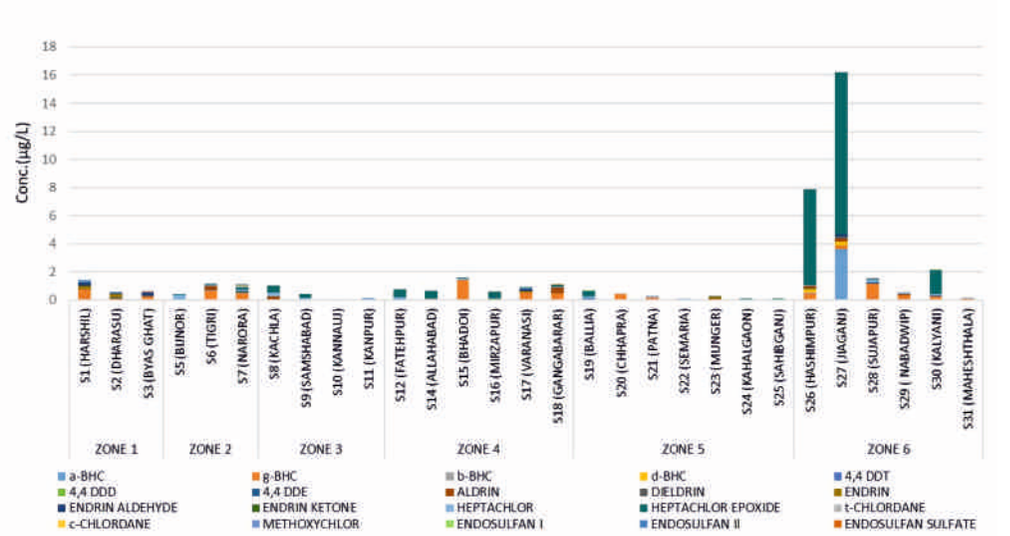

Figure 10.7: OCP concentration in water of Ganga River in post-monsoon

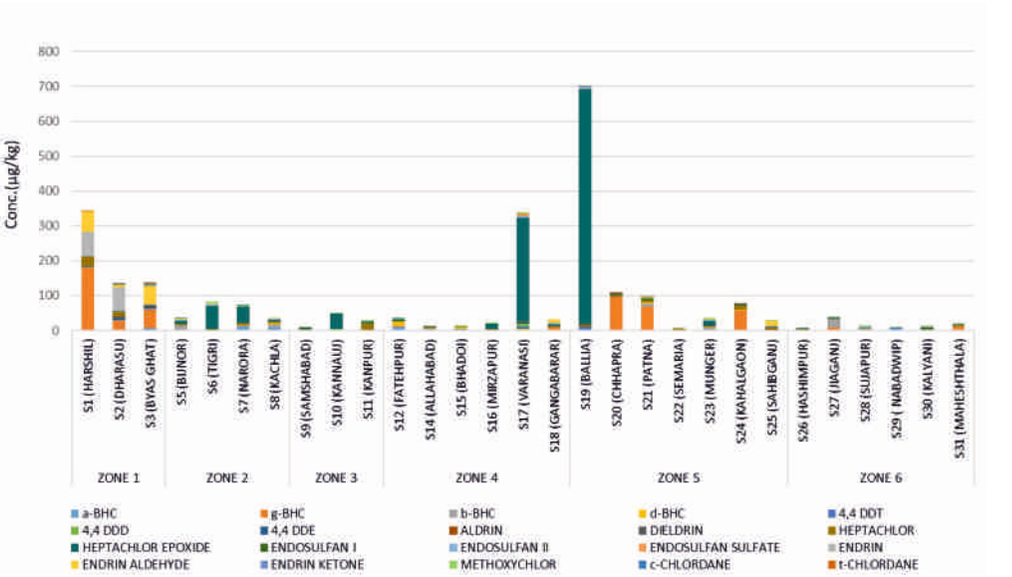

Figure 10.8: OCP concentration in sediments of Ganga River in post-monsoon

Acknowledgment

We are highly thankful to the Director, Wildlife Institute of India, Dean/FWS, Wildlife Institute of India and Dr. J.A. Johnson, Wildlife Institute of India for their support and guidance. We would also like to extend our acknowledgement to Asif Ahmed Malik, Rahul Rana, Megha Shruti, Dr. Ajit Kumar, Anuja Mital, Sk. Zeeshan Ali, Dr. Prabhakar Yadav, Bitupan Boruah, Aprajita Mishra, field assistants, local fishermen and villagers for their contribution during sampling and field survey.

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Photo Credits: Megha Shruti Sinha, P. Gangaiamaran and Ruchika Sah

Disposal of waste water in the Ganga River (Sisamau Drain), Kanpur, Uttar Pradesh

GENETIC STATUS, DIVERSITY AND GENE FLOW OF ENDANGERED GOLDEN MAHSEER (*TOR PUTITORA*) IN THE GANGA RIVER

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ABSTRACT

The Ganga is the longest river in India and has rich diversity of aquatic fauna. Alterations of the habitat, overfishing, construction of dams, pollution, and reduction in water level seems to be the largest threat to aquatic fauna and loss of genetic diversity. Some species were observed with shift in their distribution ranges and many freshwater species are listed in CITES and Wildlife (Protection) Act 1972. Therefore, our aim was to derive the current trend in genetic variability and gene flow of the endangered and selected species, which might have been disrupted due to fragmentation of the longitudinal connectivity of the river. 1200 biological samples were collected from the upper, middle and lower stretch of the Ganga, covering 1056 fish samples belonging to 83 species; 141 turtle samples covering 11 species and 3 samples of dolphins. Here, we

11

assessed the genetic diversity and gene flow among golden mahseer, *Tor putitora* (n=101) using complete Cytochrome *b* (Cyt *b*) gene analysis. Analysis of complete Cyt *b* gene revealed overall high haplotype diversity (Hd) in both the populations (Hd: 0.832). Four haplotypes were shared between the two populations. The pairwise F_{ST} comparison revealed very low genetic distance of Bhagirathi from Ganga populations. The Tajima's D and Fu's Fs statistics were negative for both the populations. Excess of singleton variable sites was detected in golden mahseer, suggesting recent population expansion. Based on mtDNA results, we found high genetic diversity and reasonable level of gene flow between the populations of golden mahseer. This could be due to the artificial ranching in the Bhagirathi River. These results were crucial for conservation, breeding, and management programs. The microsatellite loci developed for golden mahseer were successfully amplified and genotyped.

Keywords: Cyt *b*, Mitochondrial DNA, Golden Mahseer, Genetic Variability, Gene Flow

Tor putitora (Golden mahseer)

11.1 INTRODUCTION

The Ganga is the largest river in India covering 2,525 kms and the fifth longest in the world. About 45,000 kms extended water bodies crisscross the length and breadth of the country. The aquatic wildlife of the Ganga River is under stress due to rapidly increasing population, reduction in water levels, growing standards of livelihood, and exponential expansion of industrialization and urbanization have exposed the water possessions, leading to habitat degradation. Increasing temperature and inconsistent rainfall are resulting in a fast decline in the river flow. Construction of dams and barrages have significantly affected habitat, abundance, and population structure of aquatic vertebrate fauna since the last 45–50 years (Lakra et al., 2010; Gupta et al., 2014). Such barriers and restricted movement is rendering them isolated into separate sub-populations. Rapid industrialization increases the quantity of effluents being disposed to natural water bodies and is one of the major sources of the ecological toxicity, which imperils riverine biota and depreciates water quality.

The Ganga River nurtures one of the principal and largely diverse fish populations globally, which consists of about 20% of all of the freshwater species in India. It contains more than 143 species of fishes fit in to 11 orders, 72 genera, and 32 families (Sarkar et al., 2012). The fish catches from the river have declined remarkably as well as the composition of species changed additionally in favor of non-major carp and assorted species.

The Golden Mahseer (*Tor putitora*), designated as 'flagship' species belonging to the family Cyprinidae, is an efficiently vital cold-water fish of Himalayan region (Gupta et al., 2014; Everard and Kataria, 2011; Jayaram, 1999). It is considered as a significant sport, "elusive and intelligent" fish species due to its great size, large body scales and striking golden body color (Gupta et al., 2014). The species grow up to 54kg in Indian waters and has been deteriorating in its natural distribution span largely due to loss of natural habitation (Nautiyal et al., 2008). Thus, this species is scheduled in the "endangered" category in IUCN red list data (IUCN, 2015).

Construction of about 292 dams and barrages on the Himalayan rivers are documented to have outcome in habitat fragmentation and degradation of migratory species, reduction in water level and flow, increase in river water temperature and less turbidity of downstream waters (Pandit and Grumbine, 2012; Gupta et al., 2015; Quinones et al., 2015). These anthropogenic activities result in loss of habitat, cutting off of migration routes, changes in fish reproductive environments, little productiveness and tardy sexual development leading to declining population of golden mahseer (Bhatt et al., 2012; William et al., 2005).

Population genetics studies on golden mahseer are less explored, development of polymorphic microsatellite loci through cross-species amplification (Mohindra et al., 2004; Sati et al., 2013) and novel microsatellite markers (Sahoo et al., 2013) in golden mahseer were reported, which will help in population structure analyses of this species. Sati et al., (2013), examined the mtDNA variations between seven populations of golden mahseer using Cytochrome *b* (Cyt *b*) and ATPase6/8 region, and concluded that geographic isolation and environmental conditions are responsible for genetic variations in golden mahseer populations. In general, there is a considerable incorporation of gene pools in at least those

populations, which do not have restricted sharing and include free migratory routes.

Low genetic variability and gene flow lead to genetic bottlenecks and malfunctioning in species to endure alterations in the habitat (Lakra et al., 2007). Using various molecular markers such as mtDNA and microsatellites, a wild stock can be successfully identified and characterized for better stock management, species-recovery, and reintroduction programs (Yoon and Park, 2002). Moreover, ranching of golden mahseer through the advancement of hatcheries will be a sustainable restoration and conservation action. However, hatchery productions result in a loss in genetic equity each time on wild stocks while introducing it in natural riverine systems (Stickney,1994; Pradhan et al., 2011). In specific, loss of genetic diversity in hatchery stocks of golden mahseer was recorded in contrast to its wild stocks (Pradhan et al., 2011). Therefore, conservation of natural stock of endangered golden mahseer in the riverine systems is a major concern and there is a need for effective conservation and management of natural stock. In the present study, we assessed genetic diversity and gene flow level between the population of golden mahseer in Bhagirathi, and upper Ganga River based on nucleotide sequence variations of mtDNA Cyt b gene. This study will present significant insight into the current wild genetic structure of golden mahseer, and eventually aid in constructing appropriate strategies for stock management and conservation program.

It is often important in conservation and population genetics to establish the stock from which a particular sample has been obtained i.e. carry out the stock assignment. Species identification from unknown samples was mainly depending upon reference sequence availability. Therefore, for identifying the unknown biological samples, we generate the Indian origin reference database of aquatic species and this database can provide fundamental and valuable information's for further studies on endangered aquatic species and provide rational molecular tracking for aquatic species like fish, turtles and dolphin and its body parts.

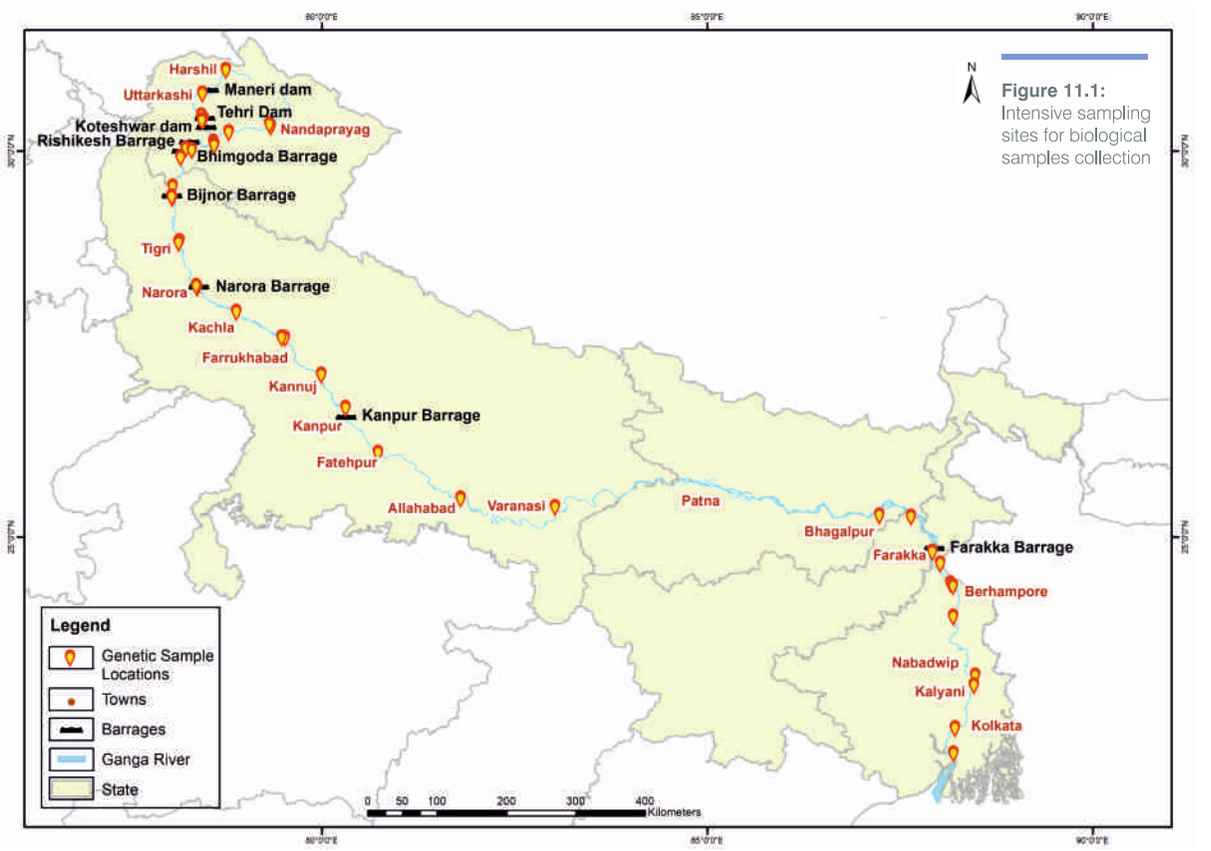

Figure 11.1: Intensive sampling sites for biological samples collection

Sample collection and DNA extraction

As part of the genetic component, a total of 32 sampling sites/segments from Harshil to Gangasagar (Fig.11.1) (2,525 km, each segment of an approx 75 km interval) of Ganga were explored, which includes 5 sites of Bhagirathi valley and 25 sites from Bijnor to Gangasagar. Experimental fishing with gill nets of 5 different mesh size (1", 2", 3", 4" and 6") was conducted at all the sampling sites for 4 hours in the day and 4 hours in the night for collection of tissue samples (fin, muscle and scutes) of targeted fish and turtle species. 1200 biological samples were collected from upper, middle and lower stretch of the river, covering 1056 fish samples belonging to 83 species, 54 genera and 24 families (Fig.11.2); 141 turtle samples covering 11 species (Fig.11.3) and 3 samples of dolphins. Blood samples were collected using vacuum tubes containing heparin salt (Vacuntainer®) whereas the tissue samples were kept in 70% ethanol and finally stored at −40 °C. All biological samples were morphologically identified; however, in few specimens, determining from which of the extant species originates, is more problematic, these were marked as unidentified so that we confirm it from DNA based analysis. Whole genomic DNA (gDNA) from 494 samples covering 351 fishes, 141 turtles, and 3 dolphins were extracted using the DNeasy Blood Tissue Kit (QIAGEN, Germany) in a final elution volume of 50-100 µL.

The project aims to derive current trends in genetic variability and gene flow of the endangered and selected species, which might have been disrupted due to fragmentation of the longitudinal connectivity of the river. Here, we present the mtDNA genetic diversity and gene flow pattern among golden mahseer (n=101) from Bhagirathi and Ganga River.

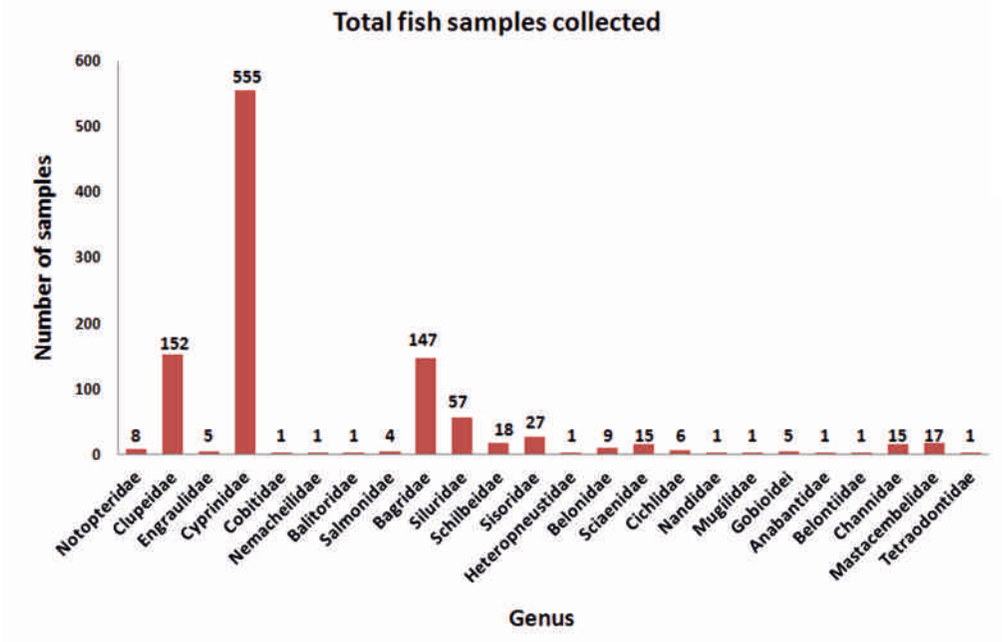

Figure 11.2: Graph showing the number of fish family collected from Ganga River

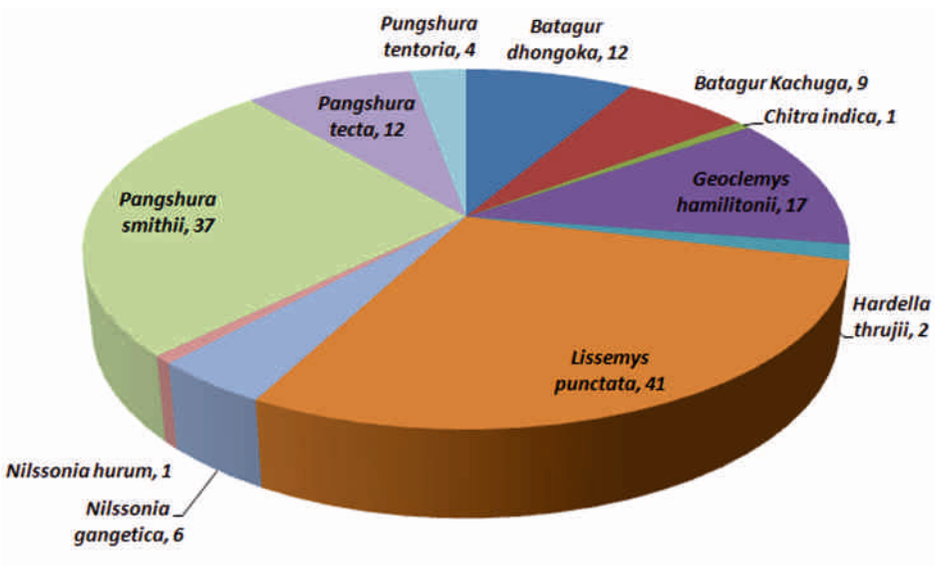

Figure 11.3: Graph showing the number of turtle's species collected from the Ganga River

PCR amplifications

For the amplification of golden mahseer samples, we targeted complete cytochrome *b* gene using the primer L14724-CytbFishF1 and H15915-CytbFishR (Xiao et al., 2001). PCR reactions were performed in 20 μl reaction of total volumes using PCR buffer (10 mM Tris–HCl, pH 8.3, and 50 mM KCl), 1.5 mM MgCl2, 0.2 mM of each dNTPs, 3 pmol of each primer, 0.5 units of AmpliTaq Gold DNA Polymerase (Applied Biosystems) and 1µl (~30 ng) of template DNA. The PCR conditions were initial denaturation at 95 °C for 10 min, followed by 36 cycles of denaturation at 95 °C for 45 sec, annealing at 52-56 °C for 40 sec and extension at 72 °C for 75 sec. The final extension was at 72 °C for 10 min. The effectiveness and consistency of the PCR reactions were monitored using positive controls. The amplified PCR amplicons were identified in 2% agarose gel by gel electrophoresis and visualized under a UV transilluminator.

PCR product clean up and DNA sequencing

Exonuclease I (EXO-I) and shrimp alkaline phosphatase (SAP) treatments were given to the amplified PCR products (USB, Cleveland, OH) for 15 min each at 37°C and 80°C, respectively, to eliminate any residual primer. The amplified PCR products were directly sequenced using the BigDye® Terminator kit (v3.1) and analyzed on an Applied Biosystems Genetic Analyzer ABI 3700XL. All products were sequenced in both directions. The sequences were aligned and edited by Sequencer 4.7 (Gene Code Corporation). All the raw sequences were aligned using CLUSTAL W, as implemented in the BioEdit v 7.2.5 software (http://www.mbio.ncsu.edu/BioEdit/bioedit.html).

11.3 DATA ANALYSIS

Sequences obtained from forward and reverse directions were aligned and edited with SEQUENCHER®version 4.9 (Gene Codes Corporation, Ann Arbor, MI, USA). The analysis of all sequences was performed separately using the programme CLUSTAL X multiple sequence alignment (Thompson et al., 1997) and alignments were examined by visual inspection. DnaSP 5.0 (Librado and Rozas, 2009) was used to analyze the haplotype diversity (h), nucleotide diversity (p) and polymorphic sites (s). Numbers of nucleotide substitutions per site, percentage similarity matrix, and pairwise distance matrix were estimated using the Tamura-3 parameter method in MEGA 7 (Kumar et al., 2016). Spatial distribution of haplotypes was visualized by a median-joining network, which was created with the PopART software (Leigh and Bryant, 2015). To determine the demography history of golden mahseer, we performed neutrality test, Tajima's D (Tajima, 1989) and Fu's Fs test (Fu, 1997) using the programme Arlequin 3.5 (Excoffier and Lischer 2010). The P-values were obtained by 1000 simulations based on selective neutrality test. DnaSP 5.0 (Librado and Rozas, 2009) were used to

generate the mismatch distribution plot for trends in spatial demography history of golden mahseer populations. The demographic changes in the populations were examined by Raggedness index (r).

11.4 RESULTS AND DISCUSSION

Increase in hydro project dams, low water level and high temperature due to climate change affect the demography of golden mahseer. However, earlier golden mahseer was found in abundance in its distribution range, but now the extant populations have depleted and are considered as an endangered category (Singh et al., 1991). The population genetic studies on restricted species are dominant tools for deriving genetic diversity which will result in the development of conservation and management strategies for little populations. The mtDNA was the widely acceptable DNA marker and has presented insights into the demography of wild populations (Oleksiak, 2010). To understand the effect of barriers and gene flow among the golden mahseer, we investigated the genetic variability and gene flow level between the Bhagirathi and Ganga River basin using the mtDNA Cyt *b* gene.

Table 11.1: Polymorphic sites within 21 mitochondrial DNA Cyt *b* haplotypes of golden Mahseer, *Tor putitora* and the distribution of haplotypes in Bhagirathi and the Ganga River. The top three rows of numbers represent the concrete polymorphic positions with reference to complete Cyt *b* GenBank no. KC914620

			Nucleotide sites												
Haplotypes	Bhagirathi (n)	Ganga (n)	1	1	1	1	1	1	1	1	1	1	1	1	1
			4	4	4	4	4	4	4	4	4	5	5	5	5
			4	4	4	4	4	5	6	7	8	0	1	4	4
			0	4	4	7	8	4	5	3	2	1	5	1	2
			7	3	4	7	1	3	2	7	5	1	5	5	9
Hap1	17	3	A	A	T	C	T	G	T	G	G	G	C	T	T
Hap2	2	2	.	.	.	.	.	.	.	.	.	.	T	.	.
Hap3	17	6	.	.	.	.	.	A	.	.	.	.	.	.	.
Hap4	0	1	.	.	.	.	.	A	.	.	.	.	.	C	.
Hap5	1	0	.	.	.	T	.	.	.	.	.	.	.	.	.
Hap6	1	0	.	.	.	.	.	.	.	.	A	.	.	.	.
Hap7	1	0	.	.	.	.	.	A	.	.	A	A	.	.	.
Hap8	5	2	.	.	.	.	.	A	.	.	.	.	T	.	.
Hap9	4	0	C	.	.	.	.	A	.	.	.	.	.	.	.
Hap10	3	0	C	.	.	.	A	A	.	.	.	.	.	.	.
Hap11	1	0	C	.	.	.	.	A	.	.	.	.	.	C	.
Hap12	1	0	C	.	.	.	.	.	.	.	.	.	.	.	.
Hap13	1	0	C	.	.	.	.	A	.	.	.	.	T	.	.
Hap14	1	0	.	.	.	.	A	A	.	.	.	.	T	.	.
Hap15	1	0	T	.	.	.	.	A	.	.	.	.	.	.	.
Hap16	1	0	.	.	A	.	.	A	.	.	.	.	T	.	.
Hap17	1	0	.	.	.	.	.	A	.	T	.	.	T	.	.
Hap18	0	1	.	.	.	.	.	A	A	.	.	.	.	.	.
Hap19	0	1	.	.	.	.	A	A	.	.	.	.	.	.	A
Hap20	0	1	.	G	.	.	.	A	.	.	.	.	.	C	.
Hap21	0	1	.	G	.	.	A	A	.	.	A	.	.	.	.

mtDNA Cytochrome *b* sequence polymorphism and genetic diversity

The complete mitochondrial cyt *b* region of 1140 bp was obtained from 76 golden mahseer individuals comprising of 58 and 18 samples of Bhagirathi and the Ganga River respectively. After alignment, we obtained 13 variable sites among the population, thus accounting for 1.14% of the entire number of sites. Of these, six sites were singleton, and seven were parsimony informative. The 13 variable sites that were observed comprised of 8 transitions and 6 transversions. The sequences were grouped into 21 haplotypes and the number of individuals in each haplotype varied, as shown in Table 11.1. The typical nucleotide composition of total samples was T = 27.55%, C = 28.33%, A = 30.06% and G = 14.06%; these values indicate the A+T-rich region among the mitochondrial cyt *b* gene. The haplotypes with the major number of individuals (hap1, hap3) consisted of 20 and 23 individuals, respectively.

In Bhagirathi, 16 haplotypes (hap) were observed, and 9 hap were detected in Ganga river. Four haplotypes were shared between the Bhagirathi and Ganga populations. Unique haplotypes were also identified in both the populations, which are due to recent colonization in these areas. The haplotypes with the major number of individuals (hap1, hap3) consisted of 20 and 23 individuals, respectively. The haplotype and nucleotide diversities of Bhagirathi and Ganga was h=0.823; π=0.0013 and h=0.869; π=0.003, respectively. The haplotype diversities of Bagirathi and Ganga River were higher (Table 11.2) when compared with the golden mahseer of Ravi and Chenab river (h= 0.000), Satluj (h= 0.723), Walwhan Dam (h= 0.741) and Kosi River (h= 0.766) (Sati et al. 2013). Based on Kimura's 2-parameter model, the pairwise genetic distances between haplotypes fall in the range of 0.000–0.004, with the overall average at 0.001.

Network Analysis

The median-joining (MJ) network of the 21 haplotypes also represented the clear distribution pattern of haplotypes among golden mahseer populations (Fig.11.4). Four haplotypes (Hap1, Hap2, Hap3, and Hap8) were shared by individuals of Bhagirathi and Ganga; most haplotypes from Bhagirathi were distributed throughout the whole network. MJ network suggested that the golden mahseer of Bhagirathi and Ganga could have evolved from a common ancestor/stock.

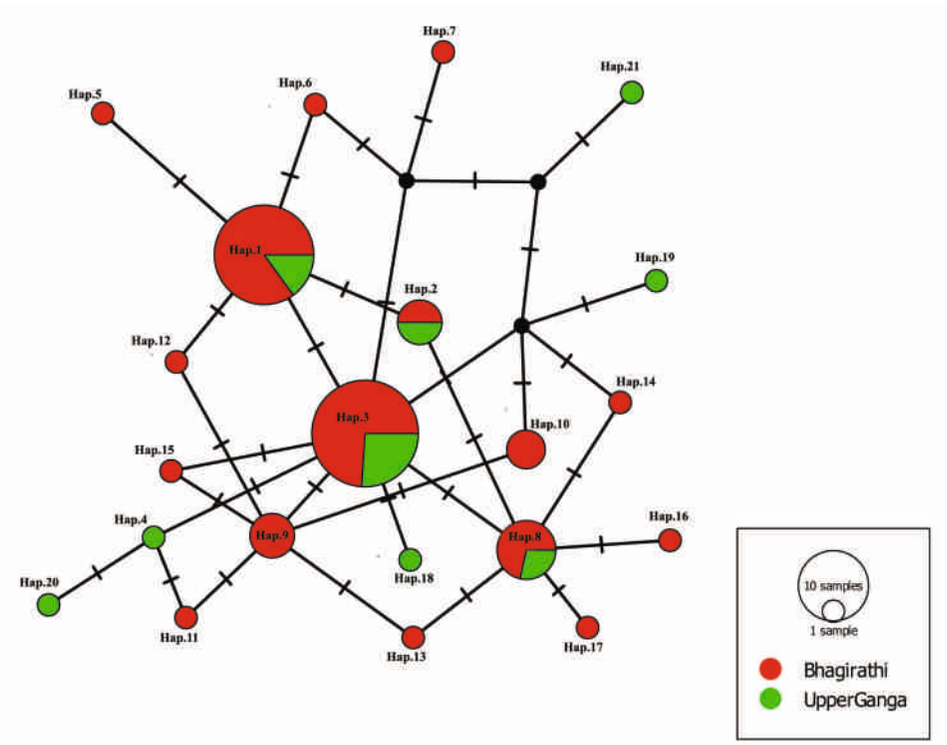

Figure 11.4: A median-joining network of golden mahseer (*Tor putitora*) haplotypes. Red circle represent samples of Bhagirathi River and Green represent samples of Upper Ganga River. The size of each circle indicates the relative frequency of the corresponding haplotype in the whole data set

Demographic history

To deduce the demographic history of golden mahseer Tajima's D and Fu's Fs tests were performed (Table 11.2), which were negative for both the populations. The negative Tajima's D values signify an excess of low-frequency polymorphisms which is due to the excess of singleton variable sites that were detected in golden mahseer, suggesting recent population expansion. The expansion scenario of the population also revealed by mismatch distribution, and also supported by Fu's F_S values where P value is statistically significant. However, the non-significant negative Tajima's D was observed for both the populations.

A historical demographic expansion model was used by obtaining the frequency of pairwise distribution among sequences. The unimodel plot of mismatch distribution showed that the populations of golden mahseer have experienced a sudden demographic expansion and the p-values of SSD and r values were not significant (Fig. 11.5). This scenario might be due to artificial ranching of golden mahseer in Tehri dam in Bhagirathi River.

Table 11.2: Sample size (n), number of haplotypes (H), haplotype diversity (hd), nucleotide diversity (π), Fu's F_S, Tajima's D, mismatch distribution test (SSD) and raggedness index (r) in two populations of golden mahseer (*Tor putitora*)

Populations	N	H	hd	π	Fu's F_S	Tajima's D	SSD	r
Bhagirathi	58	16	0.823	0.0013	-10.617(0.00)	-0.875 (0.891)	0.00397 (0.21000)	0.0761 (0.180)
Upper Ganga	18	9	0.869	0.0031	-4.287(0.001)	-0.858(0.201)	0.00379 (0.70000)	0.0752 (0.44)
Total	**76**	**21**	**0.832**	**0.0013**	**-7.452(0.0005)**	**-0.866(0.195)**	**0.00388 (0.4550)**	**0.0767 (0.310)**

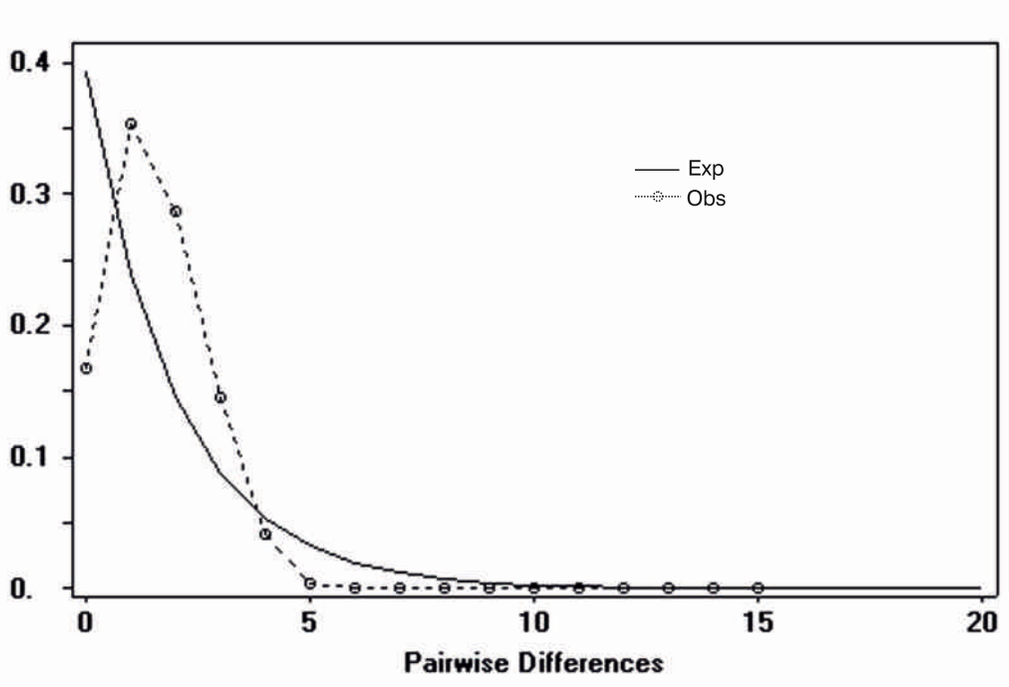

Figure 11.5: Expected (solid lines) and observed (dotted lines) mismatch distribution for golden mahseer (*Tor putitora*)

11.5 PRELIMINARY FINDINGS

Results obtained in the present study demonstrated that mitochondrial Cyt *b* gene is a suitable marker for studying variation within and among populations of golden mahseer. For comparative study of the genetic variability at the mitochondrial genes and nuclear loci, the microsatellite loci developed for golden mahseer were successfully amplified and genotyped. However, it did not compromise the outcome of the study. The selected markers are suitable for the assessment of genetic fitness in golden mahseer populations. The present work provides insights into genetic relationships and maternal gene flow among golden mahseer from Bhagirathi and Ganga River. These results were crucial for the reintroduction of golden mahseer as well as for conservation, breeding, and management programs.

Author's Contribution

Prabhaker Yadav & Ajit Kumar contributed equally in this work.

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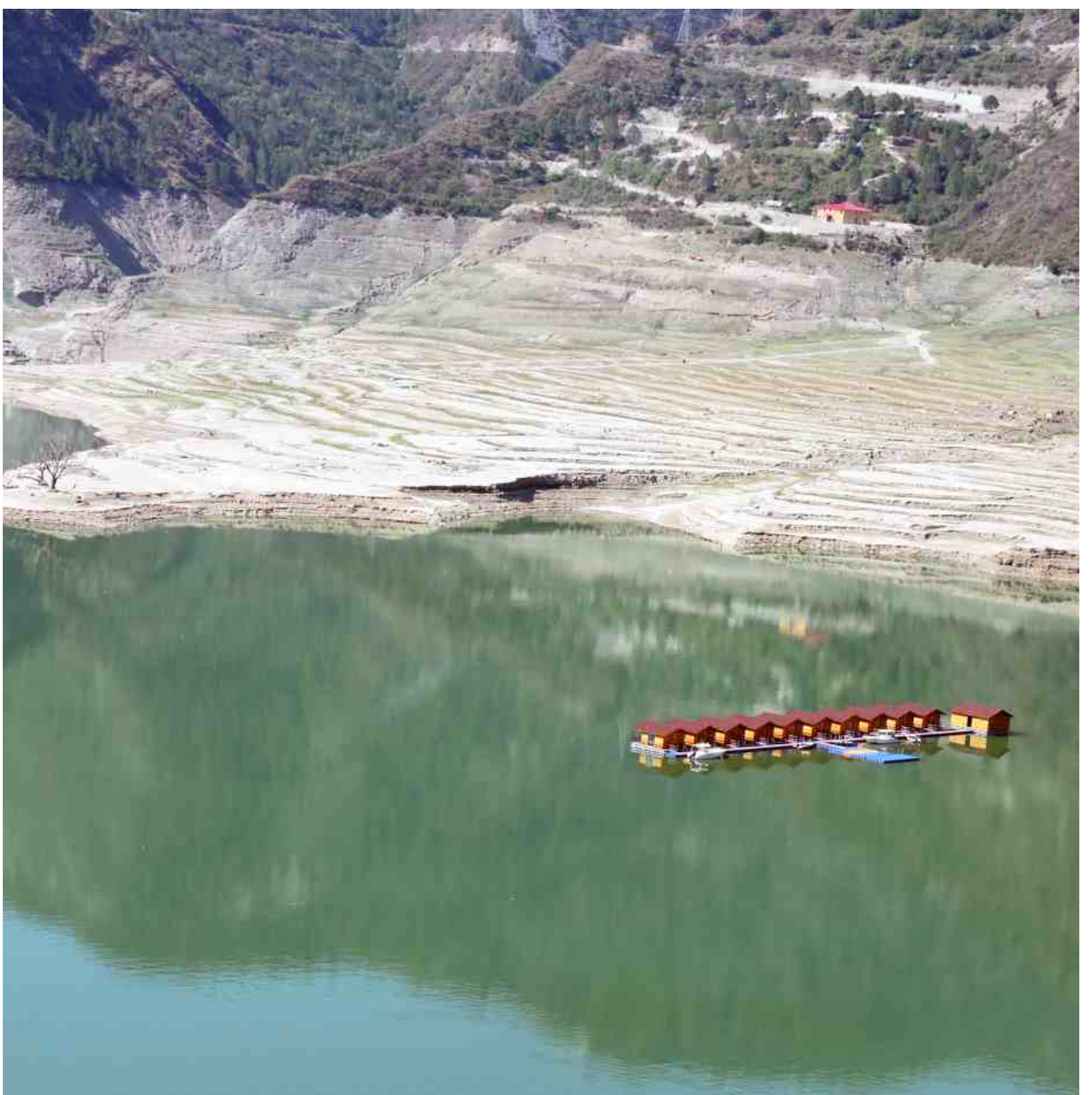

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