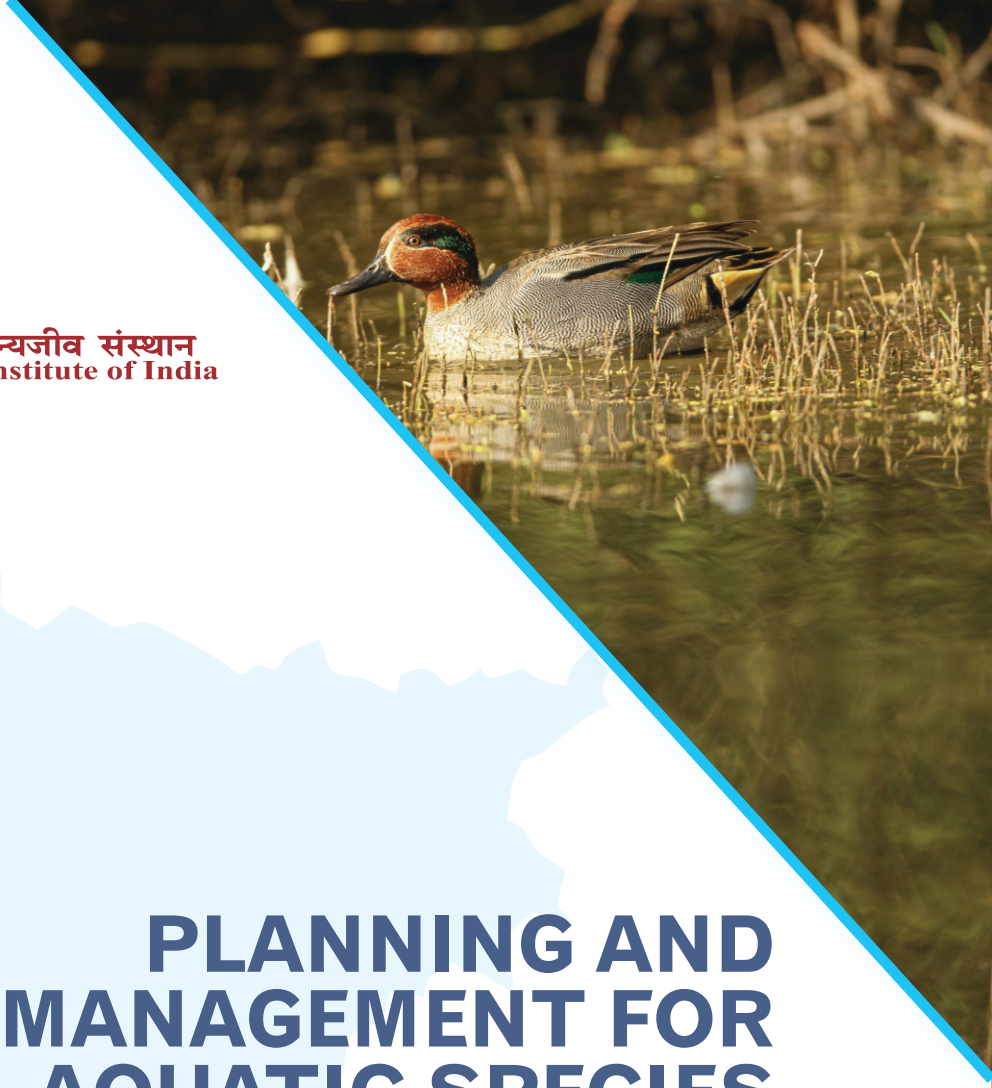

नमामि गंगे

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

PLANNING AND MANAGEMENT FOR AQUATIC SPECIES CONSERVATION AND MAINTENANCE OF ECOSYSTEM SERVICES IN THE GANGA RIVER BASIN FOR A CLEAN GANGA

INTERIM PROJECT PROGRESS REPORT

2020-2024

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Interim Project Progress Report 2020-24, Bihar

Project Investigators
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content

01 ECOLOGICAL SURVEY

16 ECO-TOXICOLOGICAL ASSESSMENT

23 CAPACITY BUILDING INITIATIVE

28 COMMUNITY BASED CONSERVATION

37 MANAGEMENT FRAMEWORK

47 IN NEWS

49 REFERENCE

51 ANNEXURE

1.

ECOLOGICAL SURVEY

1.1. Population status of Gangetic dolphin

The Gangetic dolphin (*Platanista gangetica*), a top predator, influences the food chain structure and thereby plays a critical role in maintaining the vital ecological processes of the river ecosystems and serve as a potential indicator they inhabit of river health. Historically, the species was commonly distributed in the major river systems between longitudes 77°E and 89°E in India, Nepal and Bangladesh, the Gangetic dolphin experienced ~30% decline in population and a range reduction between the late 19th century and early 21st century. Now the species is restricted to disjunct stretches of the Ganga-Brahmaputra-Barak River system in India from the estuarine deltas upstream till Himalayan foothills Karnali, Sapta Koshi and Narayani River systems in Nepal and Meghna, Karnaphuli, Sangu rivers systems in Bangladesh. In the state of Bihar, Gangetic dolphin was found throughout the Ganga River and its tributaries.

Methodology

A boat-based visual encounter survey was conducted across seven rivers, namely Ganga, Ghaghra, Gandak, Son, Bagmati, Kosi and Mahananda, covering a total length of approximately 1595 km in Bihar, during both pre- and post-monsoon seasons every year between 2020-2024, to assess the occurrence and encounter rates of the Gangetic dolphin. Gangetic dolphin population was estimated using N-mixture model (Das et al., 2022) (Table 1.1).

Result

The Gangetic dolphin population in Bihar shows varying encounter rates (ER) across river stretches. The Ganga (Sitab Diara-Manihari) has the highest sightings (420) with an ER of 1.18 ± 0.13 dolphins/km, while the Ghaghra (Geyaspur-Revelganj) has the highest ER at 1.44 ± 0.48 dolphins/km. The Kosi (0.96 ± 0.18 dolphins/km) and Bagmati (1.12 ± 0.24 dolphins/km) rivers have moderate ERs, while the Gandak has lower ER, particularly near border areas like Bihar-Nepal (0.2 ± 0.04 dolphins/km) (Table 1.1).

Table 1.1 Gangetic dolphin population in the Indian state of Bihar

River	Stretch	Survey length (Km)	Dolphin sightings	ER ± SEM
Ganga	Sitab Diara - Manihari	355	420	1.18 ± 0.13
Ghaghra	Geyaspur- Revelganj (UP-Bihar Border)	85	122	1.44 ± 0.48
Kosi	Piprahi - Kursela	235	226	0.96 ± 0.18
Gandak	Mangalpur - Bhuidharwa, Basahi - Patna	210	132	0.63 ± 0.09
	Bankasia, Bulahwa, Dasahwa - Baghachaur (UP-Bihar Border)	45	30	0.67 ± 0.21
	Bihar - Nepal Border (Susta)	10	2	0.2 ± 0.04
Mahananda	Gelabari - Chakla, Baluganj - Shahpur	130	80	0.62 ± 0.13
	Dubanochi, Phulwari - Charaiya, Gauripur - Bholamari (Bihar-WB Border)	60	43	0.72 ± 0.14
Bagmati	Jagmohra - B P Mondal bridge, Dumari	60	68	1.12 ± 0.24

Conservation Priority Stretches (CPS)

In light of the increasing demand for river resources and the growing threats to freshwater ecosystems, it is crucial to prioritize stretches for conservation, termed henceforth Conservation Priority Stretches (CPS). This is essential to prevent habitat degradation and species loss. Managing interventions in these extensive river stretches is complicated due to the intricate relationship between societal dependence and human impacts on riverine ecosystems.

We employed a flagship-*cum*-indicator species-based approach to identify CPS. This approach primarily involves species of conservation significance and considers ecological integrity criteria. Within the rivers displaying suitable habitats, the Ganga River exhibited the most extensive contiguous and highly suitable river segment, followed by the confluence areas of the Ganga River with its tributaries (Table 1.2 and Figure 1.1). The identified river stretches with high biodiversity value present an opportunity for targeted conservation efforts, offering solutions to preserve optimal sections of rivers for sustained ecosystem services. This framework can serve as a model for biodiversity conservation while simultaneously meeting societal needs, ensuring the connection between natural resources and human ecological requirements is maintained.

Table 1.2 Conservation Priority Stretches in the state of Bihar

State	River	CPS-1 Length (km)	Districts in Bihar
Bihar	Ganga	160	Buxar, Saran, Patna, and Bhagalpur
	Son	5	Bhojpur and Patna
	Gandak	5	Saran and Vaishali
	Kosi	70	Saharasa, Samastipur and Khagaria
	Bagmati	50	Samastipur and Khagaria
	Total	**290**	

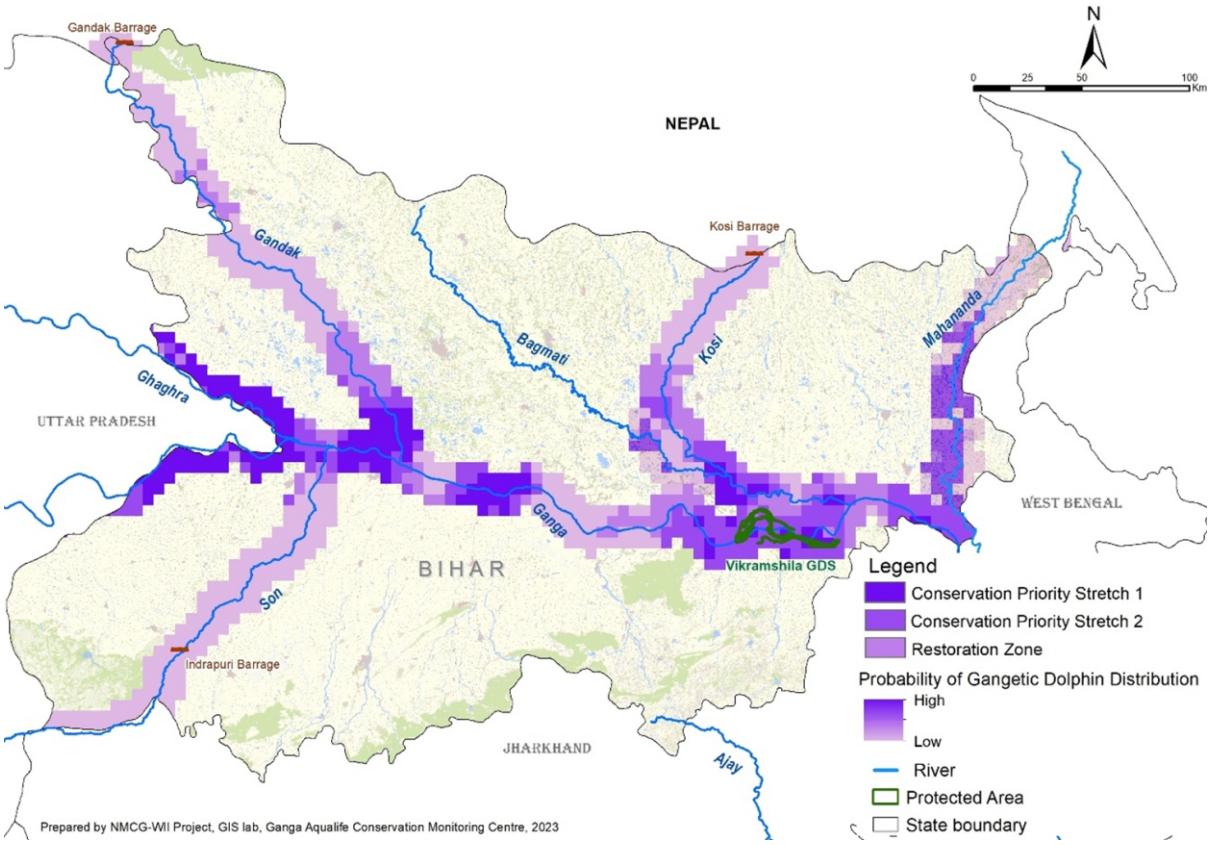


Figure 1.1 Conservation Priority Stretches in Bihar

1.2 Status of waterbirds

Birds are an important constituent of the riverscape, comprising of streams, floodplains, and riparian zones along a river channel (Sullivan et al., 2007). These riverscapes provide essential dispersal pathways, shelter, and breeding and nesting sites for birds, thus supporting high avifaunal diversity (Sinha et al., 2019). However, riverscapes are exposed to anthropogenic pressures due to their productivity and developmental activities, making then the most threatened ecosystems in the world (Revenga et al., 2005). This exposure leads to the loss of ecosystems and their associated diversity. Riverscapes are poorly managed from a conservation perspective. Additionally, existing knowledge on bird diversity in these ecosystems is incomplete and insufficient to assess the impacts of anthropogenic pressures on bird diversity loss (Yashmita-Ulman, 2022). The Ganga River is one of the largest rivers, with many tributaries flowing through 2,525 km from northern to eastern India (Singh et al., 2018).

Bihar's extensive riverine network, including the Ganga, Ghaghra, Gandak, Son, Bagmati, Kosi and Mahananda rivers, is home to a rich diversity of avian species. These rivers and their associated ecosystems, such as floodplains, sandbanks, and riparian zones, provide vital habitats for various riverine birds, which play important ecological roles as indicators of ecosystem health and contributors to biodiversity. Despite their ecological importance, waterbirds in Bihar face significant threats from habitat degradation, sand mining, wetland encroachment, overfishing, pollution, and hunting (Singh et al., 2016). Conservation initiatives in the region have focused on wetland restoration and community engagement to mitigate these pressures (Chakravarty et al., 2018). Research and monitoring are essential to understand population trends and inform conservation strategies for sustaining waterbird diversity in Bihar.

The river islands and wetlands are a natural feature of fluvial systems in the Indo-Gangetic floodplains. These river islands and wetlands are often inhabitated by a range of invertebrate and vertebrates, including island nesting species avifaunal taxa. However, information on the usage of the river islands in the Ganga basin by the waterbirds for nesting is limited to few sporadic studies.

Methodology

A boat-based ecological assessment was undertaken to know the status and diversity of the waterbirds in select rivers of Bihar viz., Ganga, Ghaghra, Gandak, Son, Bagmati, Kosi and Mahananda. Surveys were also conducted in three wetlands of Bihar viz., Mokama Taal, Jakhar Jheel and Naubhatta East Pul. Surveys were conducted in the post-monsoon season

from November to February, every year between 2020 to 2022. Additionally, surveys were undertaken to assess the nesting usage of the river islands along the Ganga and Gandak rivers channels between 2023 and 2024 in pre-monsoon season. Waterbird surveys were carried out during optimum day light (0800 hrs to 1600 hrs) following river transects. To determine the status and diversity of waterbirds, total count method was used (Sutherland, 2006; Sutherland et al., 2004; Nagarajan and Thiyagesan, 1996). Bird identification and counts were made using a 15x40 spotting scope and 8x42 binoculars. The birds were identified using bird field guide (Kumar et al., 2005; Grimmett et al., 2016). Feeding guilds were categorised as per direct observations and available literatures (Kumar et al., 2005).

Results

Waterbirds in Rivers of Bihar

A total of 92 species of waterbirds were reported from the surveyed rivers of Bihar. The highest species richness was observed in the Ganga and Kosi rivers, each supporting 64 species, followed by Gandak (n=55), Mahananda (n=51), Son (n=45), Bagmati (n=35), and Ghaghra (n=23) (Table 1.3). In Ganga River, we documented 57 waterbird species with a Shannon-Wiener Diversity Index (H') of 2.917 during post-monsoon 2020 and 40 species (H' index of 2.462) in 2021 (Table 1.3; Figure 1.2). Aside from the Ganga River, our data revealed that Kosi River had the highest H' index value of 3.057 during 2021; 46 species were recorded at that time, and Ghaghra River had the lowest H' index value of 1.896 and 24 species recorded during post monsoon 2022 (Figure 1.2) in the Bihar stretch of the river. Among these species, three are Endangered, four are Vulnerable and nine are Near Threatened under the category of the IUCN Red List of Threatened Species (Table 1.4; Figure 1.3 & Figure 1.4).

Table 1.3 Diversity index, evenness index and species richness index of waterbirds of the following rivers surveyed in Bihar during post monsoon 2020, 2021 and 2022

Rivers	Post monsoon 2020				Post monsoon 2021				Post monsoon 2022				Overall Species Richness
	Richness	Shannon-Weiner Index	Evenness Index	Margalef's Species richness Index	Richness	Shannon-Weiner Index	Evenness Index	Margalef's Species richness Index	Richness	Shannon-Weiner Index	Evenness Index	Margalef's Species richness Index	
Ganga	57	2.917	0.3244	6.23	40	2.462	0.2933	4.67		-	-	-	64
Ghaghra									23	1.896	0.2775	3.064	23
Kosi	48	2.932	0.3908	6.216	46	3.057	0.4624	5.844		-	-	-	64
Gandak		-	-	-	44	2.722	0.3459	5.255	43	2.578	0.3062	5.641	55
Mahananda		-	-	-		-	-	-	51	3.052	0.407	6.165	51
Bagmati		-	-	-		-	-	-	35	2.889	0.5135	4.838	35
Son	45	2.703	0.339	5.552		-	-	-		-	-	-	45

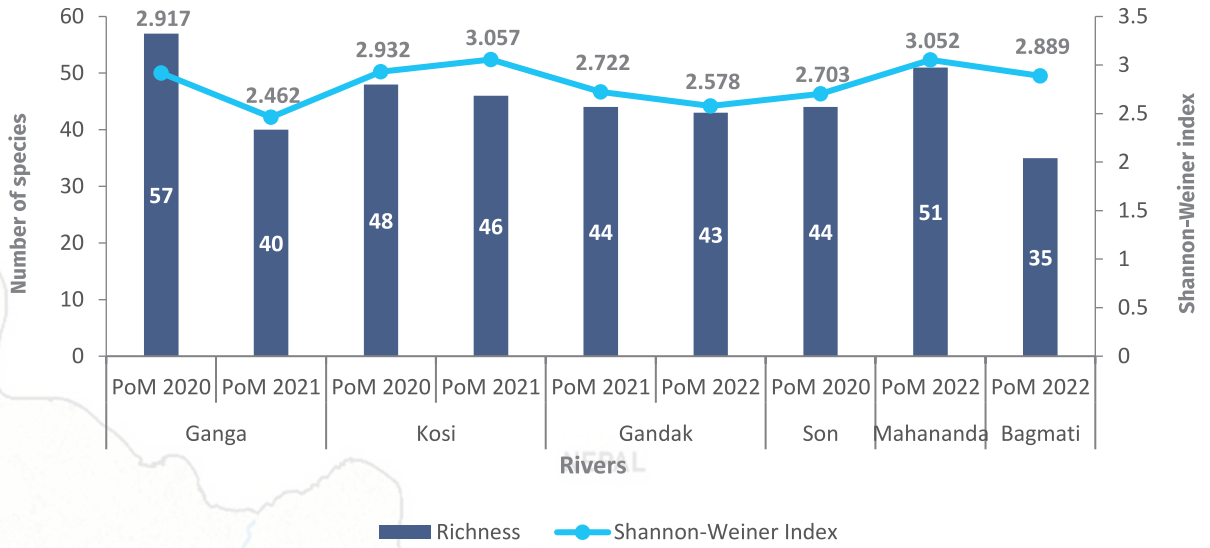


Figure 1.3 Species richness and the Shannon-Weiner diversity index of the rivers surveyed in Bihar during post-monsoon 2020, 2021 and 2022.

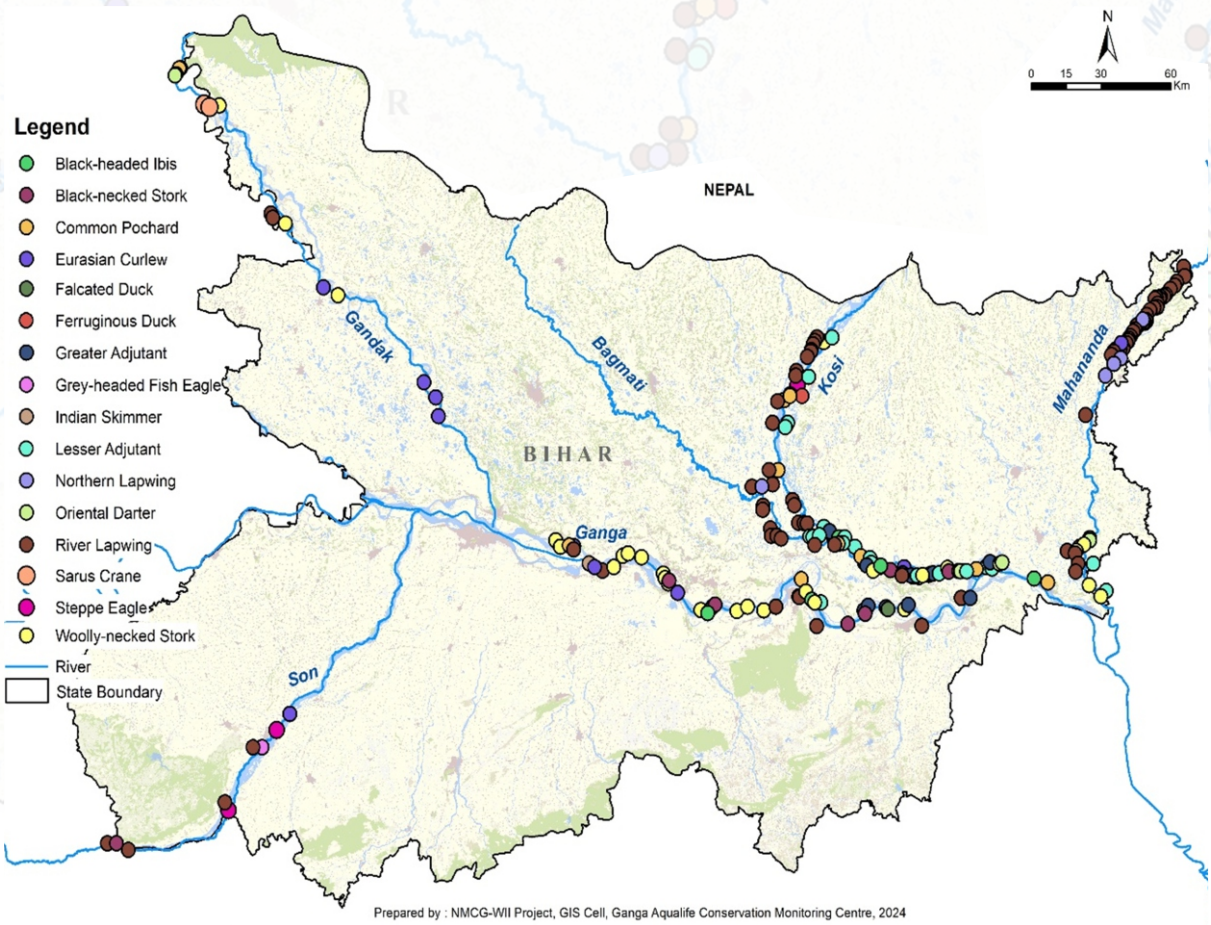


Figure 1.4 Locations of globally threatened waterbird species recorded in Bihar (2020-2022)

Table 1.4 Threatened water and water-associated bird species of Bihar (2020-2022)

Common name	Scientific name	IUCN status	IWPA status status	Presence in all surveyed rivers
Greater adjutant	*Leptoptilos dubius*	EN	Sch-I	✓
Indian skimmer	*Rynchops albicolis*	EN	Sch-I	✓
Steppe eagle	*Aquila nipalensis*	EN	Sch-I	✓
Common pochard	*Aythya ferina*	VU	Sch-I	✓
Lesser adjutant	*Leptotilos javanicus*	VU	Sch-I	✓
Sarus crane	*Grus antigone*	VU	Sch-I	✓
Woolly-necked stork	*Ciconia episcopus*	VU	Sch-II	✓
Black-headed ibis	*Threskiornis melanocephalus*	NT	Sch-II	✓
Black-necked stork	*Ephippiorhynchus asiaticus*	NT	Sch-II	✓
Eurasian curlew	*Numenius arquata*	NT	Sch-II	✓
Falcated duck	*Mareca falcata*	NT	Sch-II	✓
Ferruginous duck	*Aythya nyroca*	NT	Sch-II	✓
Grey-headed fish eagle	*Icthyophaga icthyaetus*	NT	Sch-I	✓
Northern lapwing	*Vanellus vanellus*	NT	Sch-II	✓
Oriental darter	*Anhinga melanogaster*	NT	Sch-II	✓
River lapwing	*Vanellus duvaucelii*	NT	Sch-II	✓

EN- Endangered, **VU-** Vulnerable, **NT-** Near Threatened

Island nesting birds

During the pre-monsoon survey of June 2023, a total 18 nesting events were recorded for three bird species black-winged stilt (*Himantopus himantopus*), little tern (*Sternula albifrons*) and small pratincole (*Glareola lactea*) between the Sitabdiara and Manihari (355 km). Six nesting islands were identified that were actively utilized by nesting birds. A total of 35 unhatched eggs, 9 hatchlings and 56 fledglings of three species were recorded during this survey (Table 1.5). Little tern had the highest number of nests (15 nests) with 27 unhatched eggs, 7 hatchlings and 2 fledglings. The clutch size of little tern ranged between 1 and 3. A total 2 nests with 4 unhatched eggs, 2 hatchlings, and 54 fledglings of small pratincole were recorded, while only a single nest consisting of 4 unhatched eggs of black-winged stilt was found.

During the pre-monsoon survey of May 2024 in the Ganga river, total of 226 nests were observed for five river island nesting bird species viz., black-winged stilt, little tern, red-wattled lapwing (*Vanellus indicus*), river lapwing (*Vanellus duvaucelii*) and small pratincole (Table 1.5). A total of 10 nesting islands were actively used for by nesting birds. Among the five nesting bird species, small pratincole had the highest number of nests (142 nests) with 264 unhatched eggs, 28 hatchlings and 6 fledglings, followed by little tern (76 nests) with 163 unhatched eggs and 22 hatchlings, river lapwing (four nests) with 11 unhatched eggs, black-winged stilt (three nests) with 12 unhatched eggs and red-wattled lapwing (1 nest) with 1 unhatched egg. In terms of clutch size, the black-winged stilt had a consistent clutch size of 4 eggs per nest. The little tern and river lapwing both exhibited a clutch size range from 1 to 4 eggs per nest. The red-wattled lapwing had a slightly smaller clutch size with 1 egg. Meanwhile, the small pratincole showed the high variation in clutch sizes, ranging from 1 to 5 eggs per nest.

Table 1.5 Summary of island nesting bird species and nests observed in the Bihar stretch of the Ganga River during 2023 and 2024

Year	Species name	Number of nests	Clutch size	Unhatched eggs	Hatchlings	Fledglings
2023	Black-winged stilt	1	4	4	0	0
	Little tern	15	1-3	27	7	2
	Small pratincole	2	2-3	4	2	54
	Total	**18**		**35**	**9**	**56**
	Black-winged stilt	3	4	12	0	0
	Little tern	76	1-4	163	22	0
	Red-wattled lapwing	1	1	1	0	0
2024	River lapwing	4	1-4	11	0	0
	Small pratincole	142	1-5	264	28	6
	Total	**226**		**451**	**50**	**6**

During the survey of Gandak River in June 2023, covering 245 km of the river, only 21 fledglings of small pratincole on a single island were observed (Table 1.6). Subsequently, the survey in the Gandak River during May 2024, three nests of small pratincole with 4 unhatched eggs and 1 fledgling were observed and their clutch size varied between 1 and 2 eggs per nest. During the survey, we noted wide spread presence of agricultural activities, and free-ranging dogs. The breeding period of the island nesting birds coincides with the cultivation period, which resulted in fewer bird individuals able to utilize the river banks for nesting.

Table 1.6 Summary of island nesting bird species and nests observed in the Gandak River during 2023 and 2024

Year	Species name	Number of nests	Clutch size	Unhatched eggs	Hatchling	Fledgling
2023	Small pratincole	0	0	0	0	21
2024	Small pratincole	3	1-2	4	0	1
	Total	**3**		**4**		**22**

Status of waterbirds in select wetlands

Three wetlands, namely Mokama Taal, Jakhar Jheel and Naubhatta East Pul, were surveyed in February 2024. A total of 84 species belonging to 17 orders and 37 families were recorded from the three sampled wetlands. Of which, one is listed as Vulnerable (common pochard), and two as Near Threatened (ferruginous duck *Aythya nyroca*, lesser adjutant *Leptoptilos javanicus*) on the IUCN Red List. A total of 52 water and water-associated bird species were recorded in Mokama Tal, 49 species in Jakhar Jheel and 39 species in Naubhatta East Pul. Increasing human pressure, agricultural activities, pollution, unregulated fishing practice, the invasion of water hyacinth (*Eichhornia crassipes*) and water extraction are posing a serious threat to the ecosystem and the bird species dependent on it.

Discussion

The biodiversity assessments of waterbirds in rivers and wetlands of Bihar highlight the region's critical role in avian diversity. Surveys recorded 92 species, with the Ganga and Kosi Rivers showing the highest richness (64 species each), reinforcing the Indo-Gangetic plains' ecological significance (Kumar et al., 2005; Grimmett et al., 2016). The Shannon-Wiener Index values for the Ganga (2.917 in 2020) and Kosi (3.057 in 2021) demonstrate high species diversity despite human pressures. Globally threatened species like the Endangered Indian skimmer and steppe eagle, along with Vulnerable species such as the common pochard and sarus crane, highlight these habitats' conservation importance. The presence of 12 Near Threatened species further demands targeted conservation actions, aligning with global priorities (BirdLife International, 2021). Surveys in the Ganga and Gandak rivers revealed extensive

nesting activity, especially by small pratincole and little tern, emphasizing river islands' importance as nesting and breeding sites. Clutch size variations and fledgling survival rates indicate a need for further research on breeding dynamics and threats (Sutherland et al., 2004). Wetlands such as Mokama Taal, Jakhar Jheel, and Naubhatta East Pul supported 84 species, including Vulnerable ferruginous duck and lesser adjutant. However, threats like pollution, unregulated fishing, and invasive species like *Eichhornia crassipes* undermine these ecosystems (Revenga et al., 2005). Anthropogenic pressures, such as agriculture on river islands, sand mining, and habitat degradation, significantly disrupt waterbird habitats and ecosystem services (Sinha et al., 2019). For example, agricultural practices and machinery on Gandak River islands directly impacted nesting sites. Conservation in Bihar must address these threats through habitat restoration, regulation of human activities, and community participation. Wetland restoration projects, as proposed by Chakravarty et al. (2018), could serve as effective models. Long-term monitoring of bird populations and breeding success is essential for protecting threatened species. These findings call for integrated management of rivers and wetlands to safeguard avian biodiversity. Future research should focus on waterbirds' ecological roles and responses to environmental changes to ensure habitat sustainability (Sutherland, 2006; Singh et al., 2018).

1.3 Status of amphibians

Amphibians are crucial to ecosystems, serving as predators, prey, herbivores, and commensal species, thereby maintaining ecosystem balance and health (Wyman, 1998; Hopkins, 2007; Böhm et al., 2013). They support higher trophic levels and control insect populations, including agricultural pests, highlighting their role in natural pest management (Poulin et al., 2001; Kanaujia and Kumar, 2017). Despite their importance, amphibians are the most threatened vertebrate group, with populations declining due to environmental stressors (Stuart et al., 2004; Sodhi et al., 2008). Globally and in India, where 406 species are described, conservation of these species is urgent (Stuart et al., 2004; Sodhi et al., 2008).

In Bihar, major rivers like the Ganga, Kosi, Son, and Mahananda support diverse amphibian habitats, yet studies documenting amphibian diversity in these areas remain sparse. Previous research focuses on localized regions, such as Pankaj and Nath (2021) in Gaya and Pankaj (2020) in Aurangabad. Sarkar, Das, and Ray (2004) identified 14 amphibian species across four families and eight genera in Bihar, emphasizing the need for broader surveys along its river systems. This study seeks to analyze amphibian diversity and distribution along Bihar's major rivers, contributing to knowledge gaps and highlighting the ecological significance of amphibians in sustaining biodiversity.

Methodology

During the study, we employed the Visual Encounter method (Crump and Scott, 1994). The fieldwork was carried out between 19:00 to 22:00 hrs. The observers walked approximately 1 km on a 5m wide transect searching along both banks of the river recording all amphibian species encountered. Additionally, air temperature, speed, and river flow during the survey were recorded, and along with it, the data on habitat, microhabitat, disturbance, and the activity of the species encountered was also recorded.

We conducted surveys for 18 sites across four rivers viz. Ganga, Kosi, Mahananda, Son that flow through the state of Bihar (Table 1.7). The survey was carried out at selected locations across rivers flowing within Bihar. Six distinct locations were chosen along the Ganga River, stretching from the upstream region of Buxar to Kahalgaon downstream. In the Kosi River, six sites were surveyed stretching between Kursela and Baluaha. In the Mahananda River, four sites were surveyed extending from Arrabari to Salmari. In Son River, two locations- Daudnagar and Koilwar, were surveyed to assess the herpetofauna diversity.

Table 1.7 Sites surveyed for assessment of amphibians

River	Sites	Town
Ganga	GR01	Buxar, (District)
Ganga	GR02	Revelganj
Ganga	GR03	Fatwah
Ganga	GR04	Simaria
Ganga	GR05	Munger
Ganga	GR06	Kahalgaon
Kosi	KS01	Kursela
Kosi	KS02	Naugachhia
Kosi	KS03	Chautham

River	Sites	Town
Kosi	KS04	Narapatti
Kosi	KS05	Itahari
Kosi	KS06	Baluaha
Mahananda	MN03	Arrabari
Mahananda	MN04	Kanki
Mahananda	MN06	Jokar
Mahananda	MN07	Salmari
Son	SN13	Daudnagar
Son	SN14	Koilwar

Result

In Bihar, a total of 15 amphibian species from four families - Bufonidae, Dicroglossidae, Microhylidae, and Rhacophoridae were observed in the riparian areas (Table 1.8). The Indian Skipper Frog (*Euphlyctis cyanophlyctis*) showed the widest distribution, observed at all 18 surveyed sites across the four rivers. The Indian Bullfrog (*Hoplobatrachus tigerinus*) was the next most frequently encountered species, recorded at 16 sites, followed by the Indian Common Toad (*Duttaphrynus melanostictus*), which was found at 15 of the 18 selected sites, indicating its strong establishment in the region as well.

In contrast, some species exhibited more restricted distributions. The Terai Wart Frog (*Minervarya teraiensis*) was found only at a single location along the Mahananda River. The Indian Balloon Frog (*Uperodon globulosus*) was noted at only two sites along the Ganga River, showing a limited spread within this river system. Similarly, the Orissa Frog (*Fejervarya orissaensis*) and the Burrowing Frog (*Sphaerotheca paschima*) were each documented at only three sites along the Ganga River.

Species richness was highest in Revelganj and Buxar sites followed by Fatwah in the Ganga River. In contrast, the species richness and diversity were lowest in Salmari in the Mahananda River.

Table 1.8 List of species encountered during the survey.

Family	Scientific name	Common name	Ganga	Kosi	Mahananda	Son
Bufonidae	*Duttaphrynus melanostictus*	Common toad	+	+	+	+
Bufonidae	*Duttaphrynus stomaticus*	Indus valley toad	+	+	+	-
Dicroglossidae	*Euphlyctis cyanophlyctis*	Indian skipper frog	+	+	+	+
Dicroglossidae	*Fejervarya orissaensis*	Odisha frog	+	-	-	-
Dicroglossidae	*Fejervarya pierrei*	Pierre's cricket frog	+	-	-	-
Dicroglossidae	*Hoplobatrachus crassus*	Jerdon's bullfrog	+	-	-	+
Dicroglossidae	*Hoplobatrachus tigerinus*	Indian bullfrog	+	+	+	+
Dicroglossidae	*Minervarya agricola*	Common cricket frog	+	+	+	+
Dicroglossidae	*Sphaerotheca paschima*	Indian burrowing frog	+	-	-	-
Dicroglossidae	*Sphaerotheca breviceps*	Burrowing frog	-	+	-	+
Dicroglossidae	*Minervarya teraiensis*	Terai wart frog	-	-	+	-

Family	Scientific name	Common name	Ganga	Kosi	Mahananda	Son
Microhylidae	*Uperodon globulosus*	Indian balloon frog	+	-	-	-
Microhylidae	*Microhyla nilphmariensis*	Nilphamarai narrow mouthed frog	+	+	+	+
Rhacophoridae	*Polypedates taeniatus*	Bengal whipping frog	-	+	+	-
Rhacophoridae	*Polypedates maculatus*	Indian tree frog	-	-	+	-

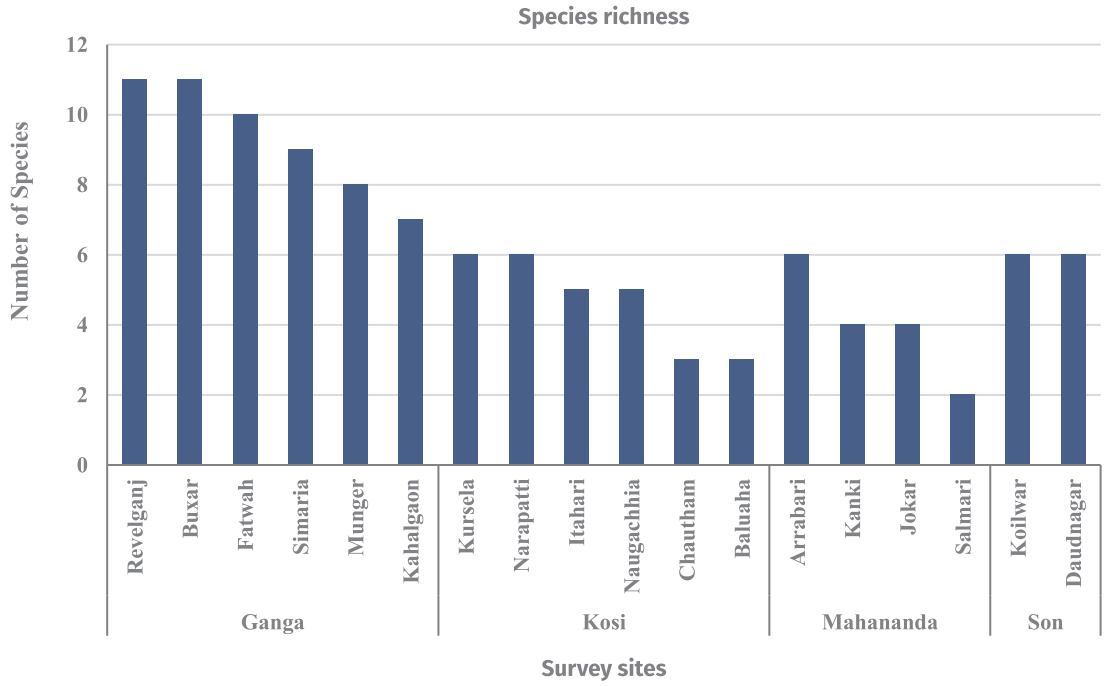


Figure 1.5 Species richness across the survey sites

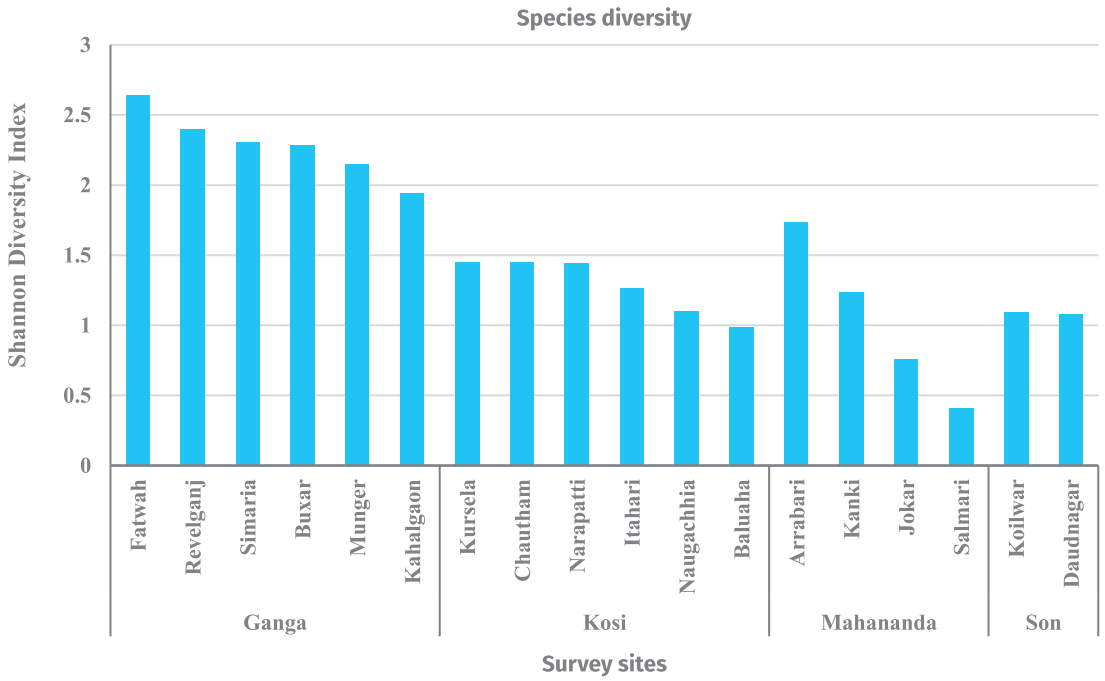


Figure 1.6 Species diversity across the survey sites

Discussion

The Gangetic floodplain is a key biodiversity hotspot with immense ecological, cultural, and economic significance. This region supports diverse ecosystems ranging from riparian forests to wetlands and harbors a vast array of flora and fauna, many of which are endangered (Sarkar et al., 2012) (Sarkar et al., 2010). The assessment of amphibian richness and diversity across the surveyed river in Bihar is crucial for conservation and management. The status and distribution underscore the critical role of diverse habitats in sustaining amphibian populations (Behangana et al., 2009; Martin et al., 2002). The widespread presence of the Indian Skipper Frog (*Euphlyctis cyanophlyctis*), the Indian Bullfrog (*Hoplobatrachus tigerinus)*, and the Indian Common Toad (*Duttaphrynus melanostictus*), suggests that some regions within the survey area still provide favorable conditions that support generalist species. In contrast, the limited distribution of species like the Terai Wart Frog (*Minervarya teraiensis*), the Indian Balloon Frog (*Uperodon globulosus*), and the Orissa Frog (*Fejervarya orissaensis*), highlights the need for targeted, habitat-specific conservation measures to support these more specialized or vulnerable species (Pratihara et al., 2014). Due to a lack of information on amphibians, the majority of the species recorded during the survey were listed in the data deficient category of the IUCN Red List (Table 1.9).

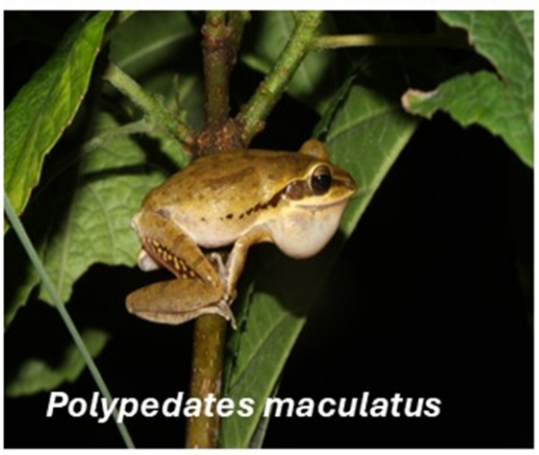
The current study provides a necessary baseline on the status of amphibians across the river surveyed in Bihar. In the future, studies to understand factors influencing amphibian richness, diversity, and distribution across habitat types, and environmental gradients are required (Buckley and Jetz, 2007). Additionally, monitoring amphibian population trends, identifying rare and endemic species, and assessment of overall ecological health are also required. Such studies will provide valuable insights into the impacts of human activities, climate change, and habitat alterations on amphibian communities. Understanding these influences will be essential for developing effective conservation strategies tailored to the unique challenges facing these ecologically sensitive regions. By filling these knowledge gaps, we can foster more informed management practices that promote the resilience and stability of amphibian populations and the health of the broader ecosystem (Liu et al., 2021; Hamer & McDonnell, 2008). The information on the status of amphibians in rivers flowing within Bihar is limited. A more extensive and systematic approach is needed to document the amphibian richness across these riverine ecosystems (Sinha et al., 2014).

Duttaphrynus melanostictus

Duttaphrynus stomaticus

Hoplobatrachus crassus

Hoplobatrachus tigerinus


Polypedates maculatus

Microhyla nilpahamariensis

Uperodon globulosus

Sphaerotheca breviceps

1.4 Vegetation survey

Bihar is a forest-deficient state with natural forests found in limited areas with forests in about 6.64% of the land (FSI, 2021). Sal (*Shorea robusta*) forests are primarily located in the West Champaran district in the Terai region in the north, and in the Kaimur, Rohtas, Aurangabad, Gaya, Jamui, Munger, and Banka districts in southern Bihar. The West Champaran district features moist deciduous Sal forests, while southern Bihar is home to dry deciduous Sal forests. Most natural forests in the state are designated as Protected Forests. According to the Champion & Seth Classification of Forest Types (1968), Bihar's forests fall into four Forest Type Groups, further subdivided into 13 different Forest Types. The major forest types in the state include Tropical Semi-Evergreen Forests, Tropical Moist Deciduous Forests, Littoral and Swamp Forests, and Tropical Dry Deciduous Forests.

The Recorded Forest Area (RFA) in Bihar spans 6,877 km^2, comprising 693 km^2 of Reserved Forest, 6,183 km^2 of Protected Forest, and 1 km^2 of Unclassed Forest. Regarding forest canopy density, Bihar has 333.13 km^2 categorized as Very Dense Forest (VDF), 3,280.32 km^2 as Moderately Dense Forest (MDF), and 3,692.54 km^2 as Open Forest (OF). A rapid biodiversity assessment, conducted nationally for natural forests from September 2018 to May 2019 as part of the forest type mapping exercise by the Bihar Forest Department, identified 113 species of trees, 42 species of shrubs, and 52 species of herbs (ISFR, 2019). The tree cover in Bihar has decreased by 260 km^2 compared to the previous assessment reported in the ISFR 2017.

Methodology

From 2020 to 2023, field surveys were conducted across four rivers in Bihar, focusing on specific stretches during different seasons. For the Ganga, surveys were conducted from Revelganj to Patna in the pre-monsoon season (March-April 2023). The Gandak stretch from Valmiki Tiger Reserve to Patna was surveyed post-monsoon (Feb-March 2023), while the Ghaghra stretch from Guthani to Chhapra was covered post-monsoon (Nov-Dec 2023). The Son River survey spanned Doriganj to Paliganj in the post-monsoon period (Nov-Dec 2022).

Result

Flora along Ganga basin (Bihar)

A total of 606 species representing 396 genus and belonging to 95 families were from Bihar (Figure 1.7). The dominant families representing riparian flora were Poaceae (80 sp.) followed by Asteraceae (55 sp.), Fabaceae (49 sp.), Cyperaceae (22 sp.), Lamiaceae (22 sp.), Acanthaceae (20 sp.), Amaranthaceae (16 sp.) and Convolvulaceae (16 sp.) (Figure 1.8). Herbs were the most common group with 342 species, followed by grasses (109 sp.), trees (67 sp.), shrubs (59 sp.), climbers (25 sp.) and climbing shrubs (3 sp.) (Figure 1.9). Habitat-wise, 516 species were semi-aquatic whereas 56 were terrestrial, 31 were aquatic and 2 were epiphytic parasites (Figure 1.10)

Based on field surveys conducted and forest types recorded in and along main-stem Ganga and its tributaries in Bihar, the dominant families representing riparian flora are Asteraceae, Fabaceae, Poaceae, Amaranthaceae, Lamiaceae, Euphorbiaceae, Moraceae, Convolvulaceae, Solanaceae, Malvaceae, Cyperaceae, Rubiaceae, Meliaceae, Combretaceae, Commelinaceae, Boraginaceae and Anacardiaceae. Dominant tree species recorded were *Shorea robusta, Borassus flabelliformis, Dalbergia sissoo, Tectona grandis, Terminalia arjuna, Cassia fistula, Acacia catechu, A. niltica, Azadirachta indica, Ficus religiosa, F. benghalensis, Bombax ceiba, Butea monosperma, Madhuca longifolia, Pithecellobium dulce, Artocarpus lacucha, Eucalyuptus* etc. Dominant shrubs were *Ipomoea carnea, Calotropis procera, Ricinus communis, Lippia alba, Abuliton indicum, Clerodendrum viscosum, Lantana camara, Urena lobata etc. Dominant grass species were Cynodon dactylon, Sachharum benghalensis, S. spontaneum, Typha aungustifolia, Phragmites karka, Vetiveria zizanioides, Cyperus rotundus, Fimbristylis* sp. etc. Aquatic species that dominated the main river streams and in seasonal rivulets were *Eicchornia crassipes, Pistia stratoites, Lemna minor, Azolla pinnata, Hydrilla verticillate, Ceratophyllum demersum, Ipomoea aquatica, Potamogeton crispus, Vallisneria natans* and *Polygonum species*. Invasive species like *Lantana camara, Cassia tora, Senna occidentalis and Chromolaena odorata* compete with native terrestrial species for resources and space, inhibiting their growth, whereas *Eicchornia crassipes* and *Pistia stratoites* were seen forming dense mats on water surface thus choking the waterways.

New records

Lindernia tamilnadensis is a new record from Bhagalpur district of Bihar (Khan et al., 2024).

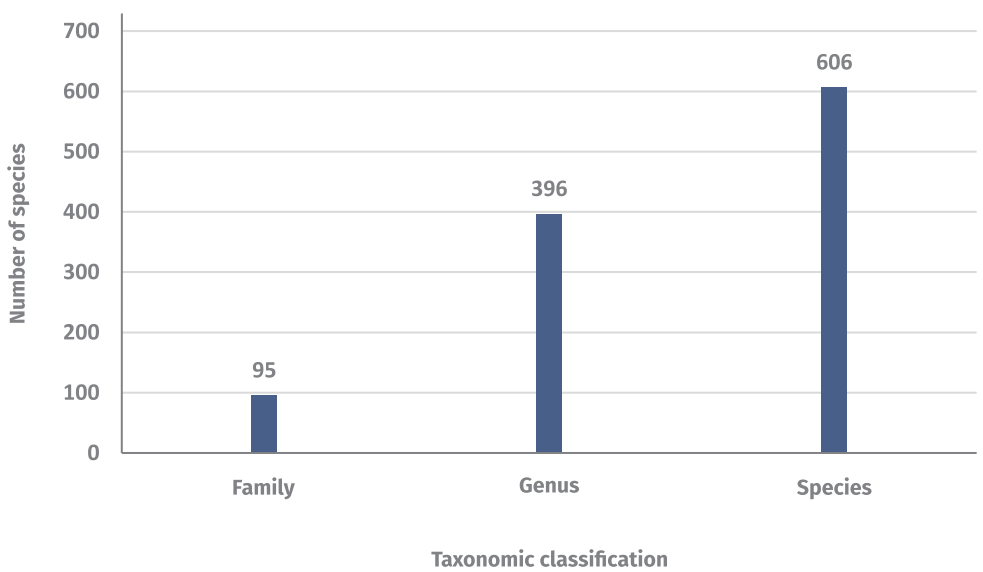


Figure 1.7 Taxonomic classification of plants recorded during the survey in select rivers of Bihar

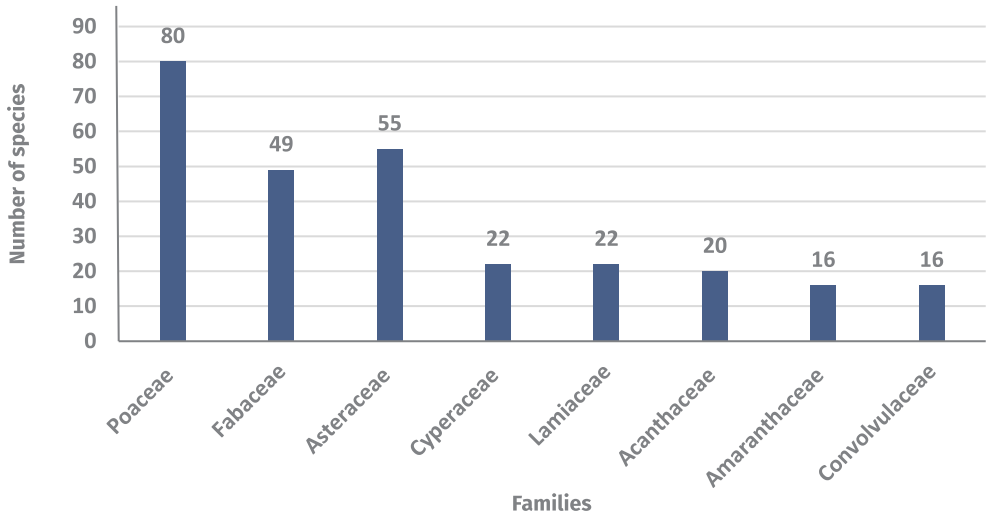


Figure 1.8 Families with maximum no. of species

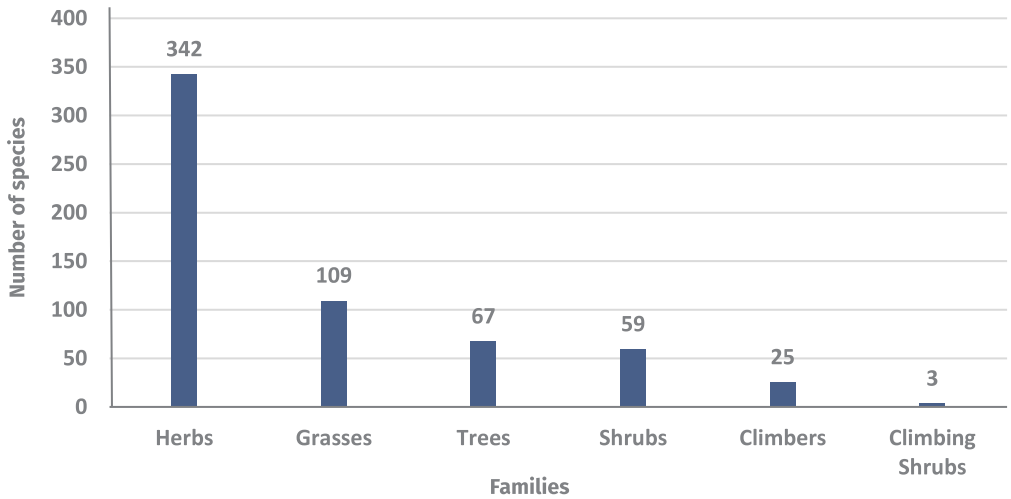


Figure 1.9 Habit-wise classification of species

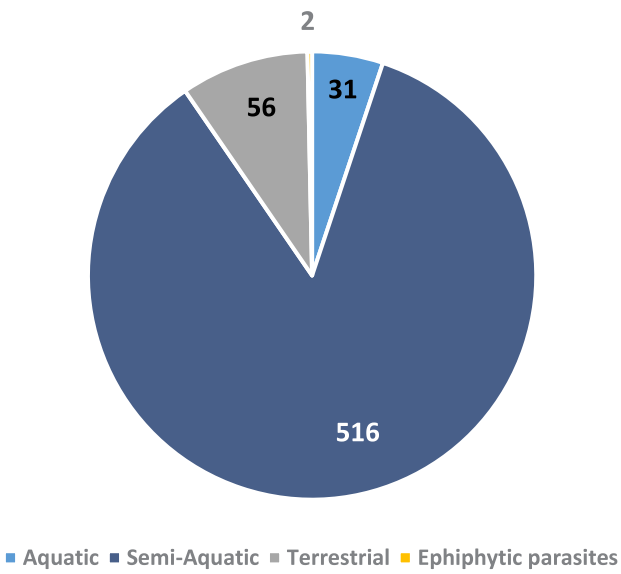


Figure 1.10 Habit-wise classification of species

2.

ECO-TOXICOLOGICAL ASSESSMENT

2.1 Background and Objectives

Chemical pollution is identified as one of the major contributors towards the decline in water quality and biodiversity fitness of Ganga River basin. Aquatic species are particularly at higher risk because exposure to chemical toxicants can be life-long and through multiple routes, thus bioaccumulation is frequent. Apex predators, characterized by their low population densities, slow population growth rates, extended lifespans, low metabolic capacity, and high lipid reserves, are exceptionally susceptible to chemical pollution resulting from various human activities, encompassing both direct and indirect impacts. Considering, that the entire Ganga Basin is also home to rich and diverse fauna and several endangered species like otters, crocodiles, turtles, fishes and the Gangetic dolphin, the threat to biodiversity and ecological risks posed by the contaminants needs special attention

Bihar covers a total geographical area of approximately 94163 km^2, with a net cultivated area of 56030 km^2 and a gross cultivated area of 79460 km^2 (Dept. of Agriculture, Bihar). The Bihar State Pollution Control Board has identified 57 Grossly Polluting Industries in the Ganga basin within the state. Major industries along the banks of the Ganga River in Bihar include Barh Super Thermal Power Station, NTPC in Patna district; Kahalgaon Super Thermal Power Station (KhSTPS), NTPC in Bhagalpur district; Barauni Oil Refinery, IOC Ltd. in Begusarai district; Barauni Thermal Power Station (BTPS) in Begusarai; and Indian Tobacco Company Ltd. in Munger district. Additionally, 42 drains with a flow greater than 1 MLD, contributing a total discharge of 778 MLD into the Ganga River, have been identified in Bihar. The state occupies a geophysical area of 94,163 km^2 has a population of 10.41 crore (10,40,99,452) (Census of India, 2011).

2.2 Methodology

An approximately 200 km stretch of the Gandak River, 150 km of the Kosi River, 8 km of the Ghaghara River, 150 km of the Sone River, and 300 km of the Ganga River were surveyed for water quality and contaminant concentrations in the river's surface water. The survey was conducted during the pre-monsoon (March-April) and post-monsoon (December-January) months in the year 2021, and in

the pre-monsoon months in 2023 (Feb-April). The survey points are given in (Figure 2.1).

The main water-quality parameters that have to be considered for surface water quality management, in general, include pH, dissolved solids, dissolved oxygen, nitrates, and conductivity, etc. For the present study, all of the above parameters have been evaluated by using digital kit ProDSS and YSI. The surface water samples from each site were transported to the instrumentation laboratory and the contaminant quantification was performed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS), and Gas Chromatography-Tandem Mass Spectrometry (GC-MS/MS). Major contaminant classes, including hormones (Steroid estrogens, 4) and Organochlorine Pesticides (OCPs=23), plastic additives (Phthalic Acid Esters PAEs and Bisphenol A, 7), heavy metals (8) and household and personal care products (2) are quantified in the present study. Ecological risk assessments were conducted to identify pollution hot-spots by evaluating the risks posed to three different trophic levels. The following section provides the status of water quality in the rivers of the Ganga River basin flowing through Bihar.

2.3 Result

Status of Water Quality

Gandak River

The Gandak River, also known as the Narayani River in Nepal, originates from the Nepal Himalayas near the Tibet border. It flows through the plains of Nepal and then enters the Indian state of Bihar near the Valmiki Tiger Reserve. In Bihar, the river traverses a length of approximately 260 km before merging with the Ganges River near Patna. An important habitat for numerous species of birds, turtles, crocodilians and Gangetic Dolphins, the Gandak River suffers from severe pollution due to industrial and agricultural runoff. The river is prone to floods, and excessive siltation increases the risk of flooding, affecting mobilization of land-derived and sediment-bound contaminants in its ecosystem. The Gandak River is an important waterway for irrigation, drinking water, and transportation in the regions it flows through.

The key water quality parameters reveal that the dissolved oxygen (DO) levels in the Gandak river range from approximately 8.07 mg/l to 10.93 mg/l. DO levels were found to be below the recommended threshold (≤ 5 mg/L) for aquatic life at 4% of the sites in Bihar. The pH values range from around 7.41 to 8.18, within the permissible limit (6.5-8.5) for aquatic life criteria. Total Dissolved Solids (TDS) range from approximately 194.40 mg/l to 224.60 mg/l, within recommended threshold (500 mg/L). Nitrate levels range from about 0.03 mg/l to 2.70 mg/l, within the permissible limit (10 mg/L). Conductivity ranges from approximately 259.70 µS/cm to 303.53 µS/cm within the aquatic life criteria limit of 500 µS/cm in the Gandak river stretch in Bihar. Threats identified in river across Bihar are presented in Figure 2.2 & 2.3. The average concentration of BPA ranged from 10.53-93.98 ng/L, from 0.35-6.17ng/L for ΣHPCPS. The ΣPAEs ranged from 2613.29-3639.35ng/L, ΣSteroids ranged from 0-8.23 ng/L, while ΣOCPs ranged from 0-1.94 ng/L. In this study, the observed concentrations of heavy metals in the Gandak River stretch in Bihar are as follows: Cr: 0.85-1.49 µg/L, Ni: 0.5-1.4µg/L, Cu: 1.31-2.99µg/L, Zn: 1.21-5.20µg/L, As: 2.35-2.68µg/L, Cd: 0.01-0.02µg/L, Hg: 0.001-0.003µg/L, and Pb 0.41-1.42µg/L.

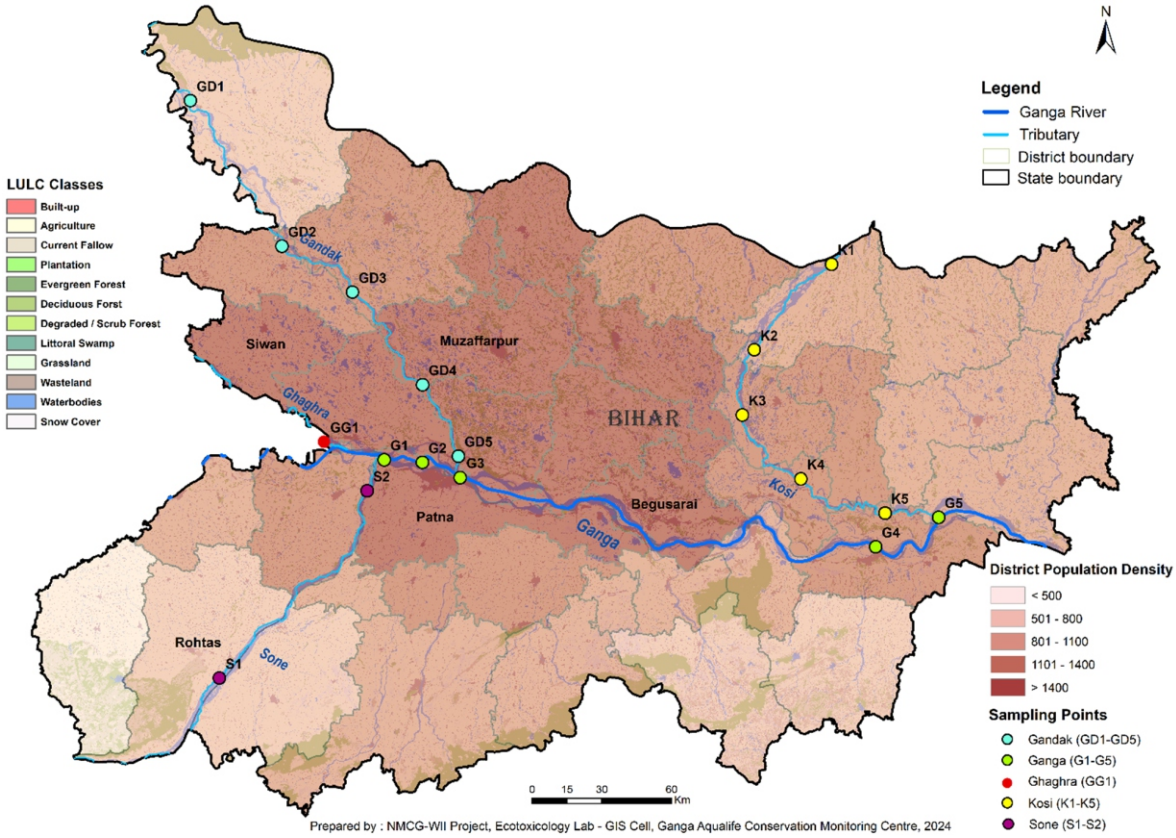


Figure 2.1 Sampling points covered in select rivers of Ganga River Basin across Bihar

Kosi River

The Kosi River originates in the Himalayas of Nepal, from the confluence of the Sun Kosi, Arun, and Tamur rivers. It enters India in the state of Bihar near Bhimnagar. In Bihar, the river flows for approximately 260 km before joining the Ganges near Kursela. The river and its floodplains support various species of fish, birds, and mammals, including endangered species like the Gangetic dolphin. The river's wetlands are crucial for migratory birds, offering feeding and breeding grounds. The Kosi River is vital for agriculture and livelihoods in the region but poses significant challenges due to its dynamic and unpredictable nature.

The recent survey indicates that the range of DO in the Kosi River varies from 9.20 mg/L to 11.63 mg/l. DO levels were found to be favourable for aquatic life survival at all the sampling sites. The TDS ranged from around 99 mg/l to 143.67 mg/L. The nitrate value ranged from 0.21 mg/L to 0.65 mg/L. Nitrate values were within the permissible limit in all the sampling sites of Kosi River. In our study, the range of conductivity extended from around, 141.77 µS/cm to 195.27 µS/cm. The range of natural pH extended from 7.73 to 8.64. The pH value exceeded the permissible range in 25% of the sites in Kosi River.

BPA concentration ranged from 71.08-153.72 ng/L, ΣHPCPs ranged from 0.99-11.29 ng/L, ΣSteroids ranged from 0.82-13.42 ng/L, ΣPAEs ranged from 3356.34-7427.97 ng/L, and ΣOCPs ranged from ΣDL-1.97ng/L.

In this study, the observed concentrations of potential toxic metals in the Kosi River stretch in Bihar are as follows: Cr: 0.95-9.10 µg/L, Ni: 0.75-2.61µg/L, Cu: 1.26-3.87µg/L, Zn: 2.44-6.73µg/L, As: 0.96-2.28µg/L, Cd: 0.009-0.02µg/L, Hg: 0.002-0.008µg/L, and Pb: 0.35-1.08 µg/L.

Son River

The Son River, a tributary of the Ganga, originates near Amarkantak in Madhya Pradesh. It flows northeast through Madhya Pradesh and Uttar Pradesh before entering Bihar near Rohtas district. In Bihar, the river runs for approximately 202 km, passing through key areas like Patna district, before joining the Ganga near Maner. The Son River is crucial for irrigation, water supply, and hydroelectric power generation in the region. The river faces significant pollution from industrial discharge and agro chemicals. Deforestation in the surrounding areas results in increased soil erosion and sediment load, heightening the risk of flooding and reducing agricultural productivity. In this study, the value of DO varies from 5.98 mg/L (D/S Indrapuri dam) to 8.80 mg/L (Koilwar) in the Son River. DO values were recorded to have deteriorated at 33% of the sites in Bihar. The recorded values of TDS ranged from around, 151.92 mg/L (D/S Indrapuri dam) to 167.03

mg/L (Koilwar). TDS value recorded at all sites were within the permissible limit of 500 mg/L. The nitrate value ranged from around, 0.74 mg/L (D/S Indrapuri dam) to 3.07 mg/L (Koilwar). The nitrate values were within the permissible limit at in all the sampling sites on the Son River. The conductivity value was recorded at 224.07 µS/cm and were within the permissible limit. The range of pH extended from around, 7.83 to 7.95 and was within the permissible range.

In Son River, BPA ranged from 5.61-38.34 ng/L, ΣHPCPs ranged from 1.11-3.44 ng/L, Σsteroids ranged from 0-30.29ng/L, ΣPAEs ranged from 318.99-2035.98 ng/L, and ΣOCPs ranged from 0.03-0.14 ng/L. The observed concentrations of heavy metals in the Son River stretch in Bihar are as follows: Cr: 1.06-1.27 µg/L, Ni: 0.47-1.02µg/L, Cu: 1.25-1.77µg/L, Zn: 3.25-3.94µg/L, As: 0.42- 0.75µg/L, Cd: 0.008-0.10µg/L, Hg: 0.001-0.002µg/L, and Pb: 0.52-2.43µg/L.

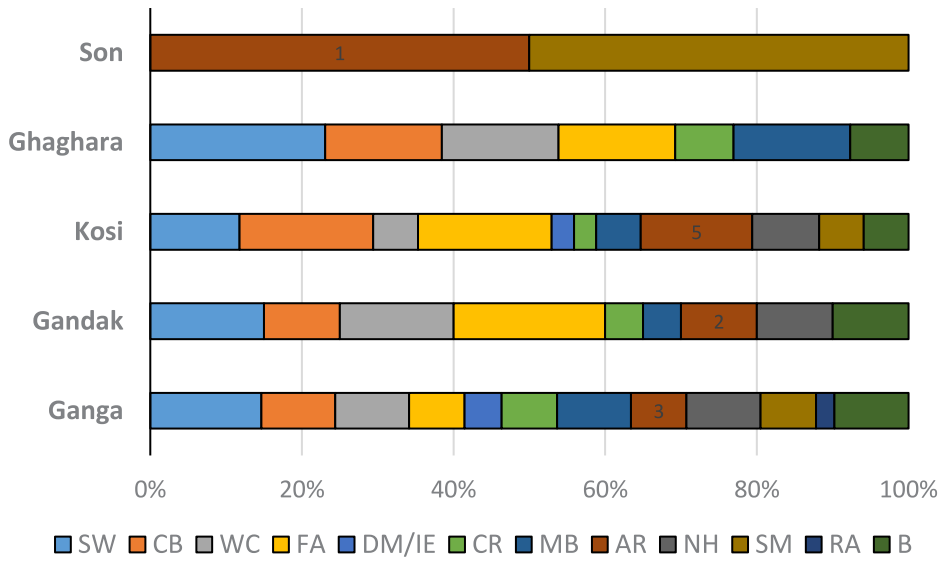


Figure 2.2 Percentage stretch of the rivers within Bihar under various category of threats

FA- fishing activities, **CB-** community bathing; **CR-** cremation and post cremation activity (e.g. disposing of ashes etc.); **DM-** domestic effluents (point and non-point); **AR-** agricultural runoff, **RA-** recreational activities; **WC**: washing clothes; **NH-** National Highway; **B-** bridge; **SW-** solid waste; **IE-** industrial effluent; **SM-** sand mining

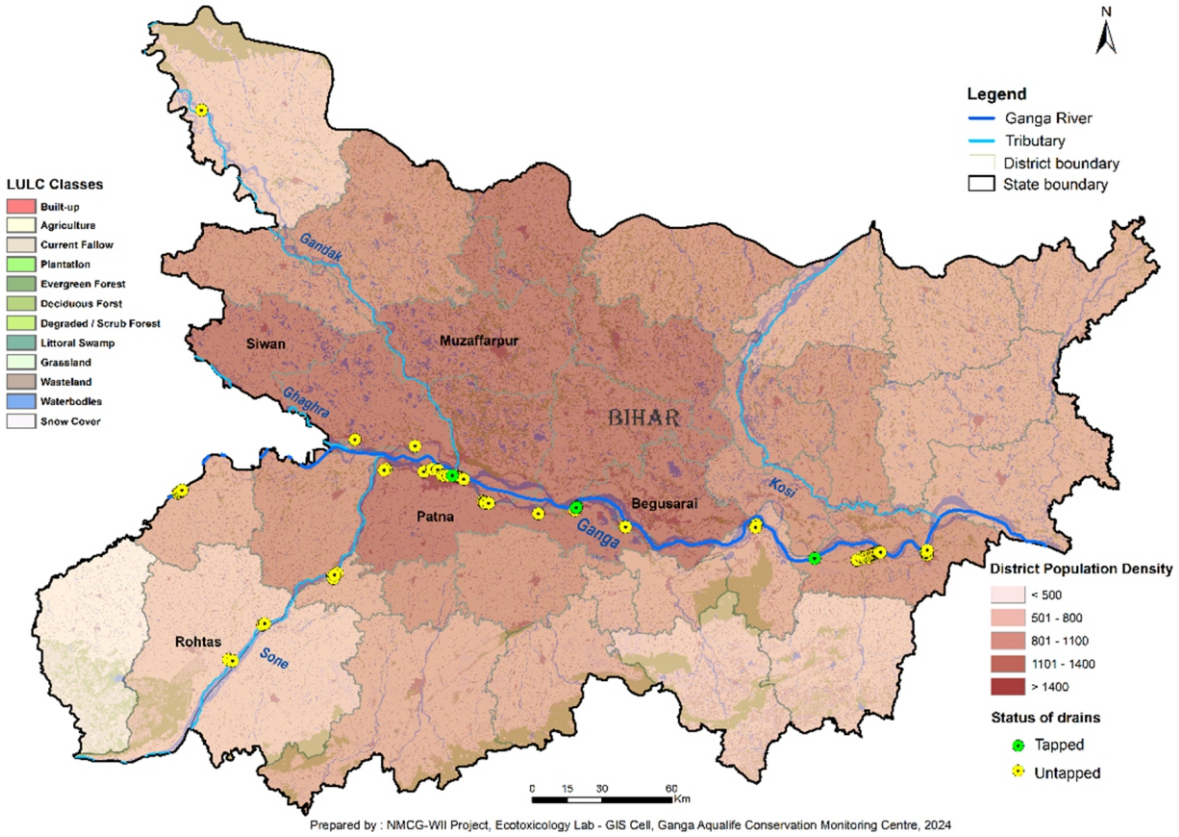


Figure 2.3 Point-sources identified in select rivers of Bihar

Ghaghra River

The Ghaghra River, also known as the Karnali River in its upper reaches, originates in the Tibetan Plateau, near Lake Manasarovar. It flows southeast through Nepal and enters India in Uttar Pradesh. In Bihar, the Ghaghra enters near Chhapra in Saran district and flows for approximately 80 km before joining the Ganga near Doriganj. Ghaghra supports high biodiversity including threatened species of fish, Gangetic dolphins and otters. The river is essential for irrigation, agriculture, and water supply in the regions it traverses, supporting local economies and communities.

The river has a predominantly agricultural landscape in Bihar, supporting human settlements along its banks as well. As a result, the river is impacted by agrochemicals, domestic effluents and solid waste in the state.

The survey indicates that the range of DO in the Ghaghra River varies from approximately 7.98 mg/L (Revelganj ghat) to 9.87 mg/L (Darauli). DO levels were found to be favourable for sustaining aquatic life at all the sampling sites. The range of TDS extends from around 232.40 mg/l (Revelganj ghat) to 250.25 mg/l (Darauli). The TDS levels at all sites were within the permissible range of 500 mg/l conducive for the survival of aquatic life. The range of nitrate extends from around 4.68 mg/l (Darauli) to 5.88 mg/l (Revelganj ghat). The nitrate levels at all sites were recorded within the permissible limit of 10 mg/L conducive for sustaining aquatic life. The conductivity range extended from 323.60 µS/cm (Revelganj ghat) to 349 µS/cm (Darauli) were within the permissible limit for sustaining aquatic life. In the recent study, the range of natural pH extended from 8.25 (Darauli) to 8.27 (Revelganj). The pH values were observed to be within the permissible range conducive for sustaining aquatic life.

In Ghaghra river, BPA concentration ranged from Σ130.795-167.96 ng/L, ΣHPCPs ranged from 12.695-16.265 ng/L, ΣSteroids ranged from 2.3-2.33 ng/L, ΣPAEs ranged from 4918.17-5918.34 ng/L, and ΣOCPs ranged from 2.04-2.10 ng/L. In the current study, the concentration ranges of potential toxic metals in the Ghaghra River stretch in Bihar are as follows: Cr: 0.82-2.18µg/L, Ni: 0.67-2.17µg/L, Cu: 2.01-4.46µg/L, Zn 3.70-7.29µg/L, As: 1.95-2.28µg/L, Cd: 0.02-0.04µg/L, Hg: 0.004-0.007µg/L and Pb: 0.86-2.71µg/L.

Ganga River

The Ganga River enters Bihar near Chausa in Buxar district and traverses the state for approximately 445 kilometers, passing through key cities like Patna and Bhagalpur. It supports diverse wildlife, the Gangetic dolphin, otters, various fishes and numerous bird

species. The Ganga River in Bihar is threatened by extreme pollution from industrial effluents, sewage, and agricultural runoff. Deforestation along its banks has led to severe soil erosion, while inadequate infrastructure and climate change intensify the frequency of devastating floods. The Ganga is crucial for Bihar's agriculture, transportation, culture, providing water for irrigation, supporting biodiversity and holding immense religious significance for millions.

The recent survey reveals that the range of DO extended from around 7.50 mg/l (Confluence with Gandak) to 10.66 mg/l (Arrah-Chhapra) in the Ganga River. DO levels were found to be favorable for sustaining aquatic life at all the sampling sites. The range of TDS extended from around 240.33 mg/l (Downstream confluence with Kosi River) to 341.25 mg/l (Sitabdiara). The TDS levels at all sites were within the permissible range of 500 mg/l, conducive for the survival of aquatic life. In the recent study, the nitrate value ranged from around 0.78 mg/l (D/S confluence with Kosi River) to 8.43 mg/l (Sitabdiara). Nitrate values were within the permissible limit at all the sampling sites of the Ganga River. The recent survey indicates that the range of conductivity extends from around 296.93 µS/cm (D/S confluence with Kosi River) to 495.70 µS/cm (Sitabdiara). The Conductivity values were within the permissible limit for sustaining aquatic life. In the recent study, the range of natural pH extended from around 7.96 (Patna) to 8.97 (Sitabdiara). pH value at all sites were recorded within the permissible limit for sustaining aquatic life.

In Ganga River, BPA concentration ranged from 4.5902 -105.64 ng/L, HPCPs ranged from 0.255-9.48 ng/L, Steroids ranged from BDL-2.4 ng/L, PAEs ranged from 1014.096-5446.3777 ng/L, OCPs ranged from 0.87735-19.1793 ng/L.

In this study, the observed concentrations of potential toxic metals (ng/L) in the Ganga River stretch in Bihar are as follows: Cr: 0.29-1.08µg/L, Ni: 0.43-1.13µg/L, Cu: 1.29-2.39µg/L, Zn:<DL-0.06µg/L, As: 2.29-3.27µg/L, Cd:<DL-0.30µg/L, Hg:<DL-0.001µg/L and Pb: 0.05-2.95µg/L.

2.4 Risk Assessment and Hotspot Identification

A number of chemical contaminants reach rivers through point sources such as domestic and industrial effluents, as well as non-point sources, such as agricultural and urban runoff. This section presents the risks posed to select rivers in Bihar from diverse chemical pollutants including OCPs, plasticizers, heavy metals, household and personal care products, and natural and synthetic hormones etc.

The map (Figure 2.4 and Table 2.1) highlights critical areas where focused management efforts are needed to mitigate ecological risks. The ecological risk levels are marked with red (high risk), yellow (moderate risk), and green (low risk) dots, whereas population density is indicated in three shades, with darker shades representing higher densities. The LULC classes represents various land use types such as built-up areas, agriculture, forests, grasslands and water bodies, whereas high biodiversity zones are highlighted in cyan.

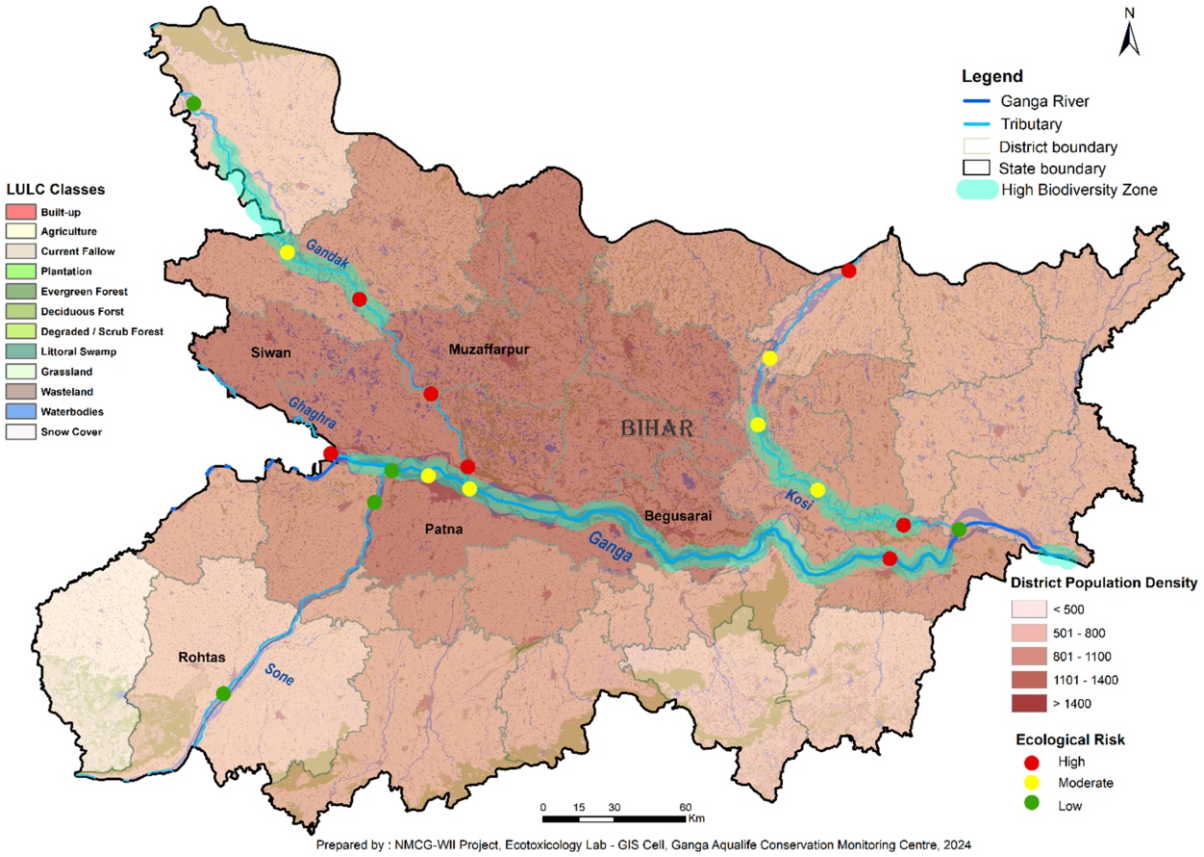


Figure 2.4 Pollution hotspots in select rivers of Bihar

Table 2.1 Pollution hotspots in select rivers of the Ganga River basin in Bihar

River	Risk zone (% stretch of River)	Stretch	District	Anthropogenic threats
Kosi	High Risk Zone (40%)	Piprahigot - Kursela Bridge	Supaul Katihar	FA, CB, AR, SM, SW, B, NH
	Moderate Risk Zone (60%)	Nemua-Agrahan	Supaul Saharsa Munger	FA, SW, NH, CR, MB, B, AR, SM
Gandak	High Risk Zone (60%)	Dumaria Ghat-Sonepur-Hajipur Bridge	Gopalganj Chapra Vaishali	FA, WC, CB, AR, B, NH, SW, CR
	Moderate Risk Zone (20%)	Gopalganj	Gopalganj	FA, WC, CB, B
Ghaghra	High Risk Zone (60%)	Darauli-Revalganj	Siwan Saran	FA, WC, CB, SW, CR, B, NH, DM, IE, MB
Ganga	High Risk Zone (36%)	U/S Kosi Confluence	Bhagalpur	FA, NH, B, AR, CR, SW, CB
	Moderate Risk Zone (32%)	U/S Gandak Confluence-Gandak Confluence	Patna, Vaishali	FA, AR, B, NH, SW, CR, MB, RA

3.

CAPACITY BUILDING INITIATIVE

3.1 Background

Wildlife Institute of India (WII), has been at the forefront to protect and conserve the biodiversity of the Ganga River Basin. As one of India's most significant ecological resources, the Ganga River is home to a rich array of aquatic species. Over the years, the efforts of NMCG-WII have extended across multiple states, including Uttarakhand, Himachal Pradesh, Uttar Pradesh, Bihar, and West Bengal, to enhance the conservation and protection of this vital ecosystem. WII has focused on not only direct conservation actions but also educational outreach and capacity-building programmes to ensure a more sustainable future for the river and its biodiversity.

This chapter brings together a comprehensive overview of initiatives in Bihar from January 2020 to August 2024, with an emphasis on grassroots awareness and capacity-building activities that directly involve local stakeholders. Numerous school-based sensitization programs have been conducted, empowering students to take an active role in environmental guardianship and fostering a growing network of "Bal Ganga Praharis." These young advocates have been central to the mission, participating in hands-on activities, river walks, and interactive sessions designed to build an early and lasting connection to river conservation.

The efforts in Bihar have also included extensive capacity-building initiatives with state and national training sessions aimed at strengthening the skills of local stakeholders, educators, government personnel, and community leaders. These training sessions have provided essential knowledge on biodiversity conservation techniques, practical skills for managing environmental challenges, and strategies for sustainable coexistence with the river's ecosystem. Through structured workshops and interactive sessions, participants have gained a comprehensive understanding of how to address environmental

impacts on the Ganga and sustain its natural resources.

Collectively, these initiatives represent a significant contribution to the Ganga's conservation by cultivating an informed, proactive community of citizens who understand their role in the river's preservation. The work carried out over this period reflects a multifaceted approach to conservation that not only prioritizes environmental protection but also emphasizes education, community involvement, and resilience building.

3.2 Spearhead Trainings

The Spearhead Training initiative has been pivotal in enhancing the capacity of various stakeholders in biodiversity conservation and sustainable practices within the Ganga River basin. Over the course of eight national-level trainings, the initiative has successfully engaged a wide range of participants, including Ganga Praharis, Nehru Yuva Kendra Sangathan (NYKS) officials, university professors, National Service Scheme (NSS) volunteers, and other key influencers. These training programmes were meticulously designed to address crucial aspects of biodiversity conservation, particularly focusing on the Ganga River Basin's unique ecosystem, which is home to a wide variety of species that are vital to maintaining ecological balance.

The programme aimed at empowering participants with practical knowledge and skills required to conserve biodiversity in the Ganga Basin while promoting sustainable practices in their respective fields. Each training session not only focused on the theoretical understanding of conservation practices but also included hands-on activities, field visits, and interactive discussions to ensure the participants could apply these learnings in real-world scenarios. The training sessions covered critical topics like wetland conservation, monitoring of Ganga's biodiversity, species management, and habitat restoration, providing participants with a holistic view of environmental conservation in the context of the Ganga River.

Overall eight national-level training workshops were conducted targeting five stakeholder groups viz., Fisheries Department, NYKS, NSS, Ganga Praharis and school teachers (Table 3.1). A total of 180 participated in the workshops, held between 2022 and 2024. These workshops aimed to align biodiversity conservation with sustainable livelihoods, teaching participants about the challenges faced by aquatic species in the Ganga River and how local communities can help mitigate these threats. The National-level training workshop for school teachers focused on integrating river conservation into education programmes, equipping educators to incorporate conservation lessons into curricula and fostering long-term conservation mindset among younger generations.

Swachhta Pakhwada

Table 3.1 Spearhead trainings held at various location

Stakeholder groups	Total number of participants from Bihar
Ganga Prahari	23
Nehru Yuva Kendra Sangathan (NYKS)	05
Professors	03
National Service Scheme (NSS)	25
Fisheries Department	03
School teacher	121
Total	180

3.3 Training with stakeholders

A state level training programme were conducted to engage Ganga Praharis, media personnel from print, television, and digital journalism, as well as local, national, and international NGOs. A total of 51 participated in this workshop held at Bettiah, West Champaran in Bihar (Table 3.2).

The training incorporated interactive sessions, team-building exercises, and in-depth discussions covering various aspects of aquatic conservation and ecosystem services. Participants explored the critical role of rivers like the Gandak in maintaining biodiversity and providing resources that support both human and wildlife populations. The program also emphasized practical outreach activities, equipping stakeholders with the skills to promote conservation awareness within their communities.

Glimpses of teachers training

Table 3.2 Spearhead training held at Bettiah, West Champaran in Bihar

Stakeholder groups	Organisation/Media houses name	Number of participants
Non-governmental organisations	Childline	1
	Jan Vikash	2
	Nav-jivan Social Welfare Society	2
	Swaraj Adhayan Evam Prayogatmak	2
	Pratham	1
	Goonj	2
	Alok Foundation	2
	WWF-India	1
Media houses	Prabhat Khabar	1
	Sabhasad	1
	News18 Bihar	1
	ETV	1

Stakeholder groups	Organisation/Media houses name	Number of participants
	Dainik Bhaskar	1
	Zee Media	1
	Dainik Jagran	1
	Punjab Kesari	1
	TV9 Bharatvarsh	1
	Brodia	2
Ganga Prahari		26
Total		51

3.4 Bal Ganga Prahari Programme

The Bal Ganga Prahari Programme is an initiative aimed at raising awareness and fostering a sense of responsibility among young students regarding the conservation of the Ganga River and its biodiversity. By engaging school children, the program seeks to instil a deep understanding of the ecological importance of the Ganga River and its tributaries, highlighting their critical role in supporting diverse species and the livelihoods of millions of people.

The Bal Ganga Prahari Programme has reached 35,427 students through different initiatives conducted across 62 schools in 13 districts of Bihar. These awareness programs focus on incorporating an understanding of river conservation and the critical role of biodiversity in maintaining healthy ecosystems. Students have been introduced to the rich biodiversity of the Ganga River through interactive sessions that explore its importance in supporting both wildlife and human communities. Through workshops, presentations, and hands-on activities, they learn about the Ganga's unique species and the threats they face, such as pollution, habitat degradation, and climate change.

To create a meaningful learning experience, the program uses various engaging approaches such as role-play exercises, river biodiversity-themed games, and creative arts activities where students design posters or models representing the Ganga's ecosystem. Field visits to local water bodies and mini-exploration projects on nearby flora and fauna are also arranged to help students connect directly with nature, cultivating an emotional and intellectual understanding of conservation needs.

This initiative is designed not only to impart theoretical knowledge but to empower students to take action in their own lives. The program emphasizes the importance of sustainable practices that protect the river's health, aiming to create a new generation of young conservationists with a deep-rooted commitment to safeguarding the Ganga and its habitats. Through the Bal Ganga Prahari Programme, these students are encouraged to become advocates for conservation in their communities, fostering an environmental ethic that contributes to the long-term protection of the Ganga River.

Dolphin Day celebration

Glimpses of teachers training

Swachhta Pakhwada

Table 3.3 District-wise distribution of students and teachers educated under the Bal Ganga Prahari Programme in Bihar:

District	Number of schools	Number of students sensitized	Number of teachers
Samastipur	2	700	23
Vaishali	8	5,350	132
Muzaffarpur	2	3,550	30
Madhubani	1	620	14
Begusarai	1	635	17
Patna	4	3,023	77
Bhagalpur	21	10,392	260
Aurangabad	1	170	06
Khagaria	2	375	11
West Champaran	14	8,533	391
East Champaran	1	450	24
Bettiah	2	300	10
Supaul	3		
Total	62	35,427	1,040

4.

COMMUNITY BASED CONSERVATION

A total of 975 Ganga Praharis have been inducted in Bihar state. A Ganga Praharis cadre comprising of 389 individuals (60 females, 329 males) was established in Bihar during Phase I. This has seamlessly transitioned into a cadre of 586 Ganga Praharis (302 females, 284 males) during Phase II (Table 4.1). These Ganga Praharis represent various socio-economic strata of different regions of mainstem Ganga and its tributaries, Ghaghra, Gandak, Kosi, Son and Mahananda, and three sub-tributaries i.e. Burhi Gandak, Chandan and Kiul. These committed Ganga Praharis are judiciously dispersed among 24 districts in Bihar.

Table 4.1 Ganga Prahari distribution along mainstem Ganga and select tributaries and sub-tributaries in Bihar

Rivers	Female	Male	Total
Bagmati		1	1
Burhi Gandak	1	3	4
Chanan	2	4	6
Dabra		1	1
Daha		1	1
Gandak	64	67	131
Ganga	239	423	662
Ghaghra		3	3
Kiul		13	13
Kosi	56	64	120
Mahananda		1	1
Noon		29	29
Total	362	613	975

To mobilize stakeholders, meticulously 1,024 activities were conducted across 29 districts of Bihar along 10 rivers. These activities mainly included awareness programmes, cleanliness drives, plantation initiatives, sensitization workshops, consultative meetings, livelihood training sessions, cultural activities and ecological surveys. The activities drew in about 23,006 participants from various stakeholder groups, such as the local community, Ganga Praharis, Forest Department, district administration, NGOs, line agencies.

Table 4.2 Conservation activities conducted in Bihar to sensitize and mobilize the stakeholders

Type of activities	Number of activities	Number of participants
Awareness and sensitization	191	12,420
Cleanliness drives	6	177
Consultative meetings	513	3,372
Cultural activities	2	66
Ecological monitoring	1	47
Livelihood activities	154	3,036
Livelihood training	25	828
Orientation/mobilization/training workshops	14	495
Plantation	4	386
Socio-economic survey	66	447
Special occasions and days celebration	8	218
Others	40	1,686
Total	1,024	23,006

Awareness and sensitization programmes

Awareness and sensitization programmes

Socio-economic survey

Consultative meetings

Consultative meetings

Consultative meetings

Cleanliness drive

Cleanliness drive

Activities under Mission LiFE

Activities under Mission LiFE

Plantation drives

In Bihar, different livelihood training programmes were conducted (n=25), each serving as a specialist arena for skill development. A total of 656 Ganga Praharis (Table 4.3) received trainings in a range of fields, including sewing and stitching, creating bamboo products, creating organic soap, and developing nurseries. Additionally, in line with the Arth Ganga mission, Ganga Prahari's active involvement in Jalaj activities was crucial in creating new opportunities, aimed at fostering independence and self-sufficiency.

Table 4.3 Livelihood skill development trainings in Bihar

Type of trainings	Number of trainings	Number of persons trained
Bamboo products making	2	29
Candle making	1	20
Herbal soap making	4	105
Incense Stick, ladoo and candle making	1	25
Mat and basket weaving	1	20
Nursery development	1	27
Sewing and stitching	15	430
Total	25	656

Herbal soap making training

Sewing and stitching training

Sewing and stitching training

Nursery development training

Candle making training

Bamboo products making training

A total of 269 household surveys have been conducted across 6 districts along Kosi and Gandak rivers to assess the socio-economic status of the local communities and assess their attitude, knowledge, awareness and livelihood dependence on river resources.

Trained and motivated Ganga conducted 626 self-initiated conservation activities, of which 541 were conducted (Table 4.4) without any assistance or support (financial or technical) from NMCG-WII Project. These activities encompassed initiatives such as awareness and community mobilisation, tree plantation, livelihood development, assistance in ecological monitoring and ecological surveys, and microplan data collection, rescue, and rehabilitation.

Table 4.4 Activities initiated by Ganga Praharis (GPs)

Type of activities	Activities conducted by GPs with technical or financial support from NMCG-WII project		Activities conducted by GPs without any assistance from NMCG-WII project	
	Number of activities	Number of participants	Number of activities	Number of participants
Awards & achievements			4	11
Awareness and community mobilisation	47	2,553	145	9,935
Cleanliness drive/Swachhata hi Sewa	10	232	47	854
Consultative meetings	2	4	7	121
Covid awareness	2	53	29	3,781
Cultural activity			3	226
Ecological monitoring	3	20	99	493
Livelihood activities	1	17	2	21
Participation in activities organized by other organizations			17	485
Plantation	7	59	74	1,865
Rescue & rehabilitation	5	18	71	379
Special occasions & days celebration	5	241	10	808
Others	3	62	33	4,401
Total	**85**	**3,259**	**541**	**23,380**

Socio-economic surveys conducted by Ganga Praharis

Cleanliness drive organized by Ganga Praharis

LiFE exhibition organised by Ganga Praharis

Awareness rally with students organized by Ganga Praharis

Yoga Day celebration by Ganga Prahari

Nadi Utsav celebration by Ganga Prahari

Dolphin Day celebration by Ganga Prahari

Species rescue by Ganga Prahari

Microplans for three villages viz., Siswa in Khagaria district, Khawaspur in Bhagalpur district and Madanpur in West Champaran district, were prepared. Issues pertaining to ecological and socio-economic aspects were identified. Specific activities related to issues identified are being conducted in microplan villages.

Microplan consultation

Social mapping for microplan

Two groups of Ganga Praharis have been been registered under the Societies Registration Act, 1860, i.e. Srishti: Ganga Prahari Environment and Welfare Society and Ganga Prahari Nature Conservation Society (GPNCS). Apart from this, two self help groups (SHGs) of trained women Ganga Praharis have been created, who are actively working for rescue of animals in distress, awareness and alternate livelihood development in their respective sites. These groups and societies are conducting conservation activities in their respective sites.

Ganga Prahari group registered as Society under the Societies Registration Act, 1860

Awareness programme by GPNCS Society

संस्थाओं के निबन्धन का प्रमाण–पत्र

(ऐक्ट 21, 1860)

№ S22307

संख्या S000184 वर्ष 2022-2023

मैं इसके द्वारा प्रमाणित करता हूँ कि SRISHTI : GANGA PRAHARI ENVIRONMENT AND WELFARE SOCIETY

Address - Mohalla- Pustakalaya Gali(Near Durga Mandir) , S.M. College Road, Bhagalpur-812001 BHAGALPUR BIHAR 812001

सोसाईटीज रजिस्ट्रेशन ऐक्ट 21, 1860 के अधीन आज यथावत् निबंधित हुआ/हुई ।

आज तारीख 16 मास Aug वर्ष 2022 को पटना में मेरे हस्ताक्षर के साथ दिया गया।

महानिरीक्षक, निबंधन, बिहार, पटना।

Society registration certificate

Among the 656 Ganga Praharis, who received livelihood skill development trainings, more than 150 individuals have started their own small business or self-employed ventures, and are earning ₹3000-4000 per month. Also, 10 Ganga Praharis who received training on becoming bird guides are actively working with the State Forest Department. Six Ganga Praharis have joined Wildlife Institute of India as research scholars.

To inform and sensitize the stakeholders and to align conservation goals with various national and international programmes, activities (n=23) such as awareness rallies, yoga sessions, talks etc., were conducted during which more than 1,200 people participated (Table 4.5).

Table 4.5 Celebration of special occasions and days in Bihar

Occasion	Number of activities	Number of participants
Dolphin Day	4	140
International Yoga Day	8	277
Road Safety Week	1	555
Wildlife Week	5	193
World Ozone Day	1	48
World River Day	4	54
Total	23	1,267

Independence Day celebration

Nadi Utsav celebration

Participatory mapping of ecosystem services by local communities was carried out in 18 villages across nine districts in Bihar, namely Begusarai (n=2), Bhagalpur (n=3), East Champaran (n=3), Jamui (n=1), Khagaria (n=1), Samastipur (n=1), Supaul (n=3), Vaishali (n=1) and West Champaran (n=3), along Ganga, Budhi Gandak, Kosi, Gandak and Nagi (Table 4.6). Overall, 238 people participated in the focus group discussions, of which 181 were male and 57 were female. The purpose of the study is to assess the perceived dependency on the ecosystem services provided by rivers (such as the biotic and abiotic resources, cultural and religious services, and dependence of agriculture, livestock and other village level economic constituents upon the riverine resources) at the grassroots and the perceived change in the supply of these ecosystem services over the years, and the consequent change in livelihood. Participants were also asked about any disservices provided by the river.

Table 4.6 Participatory Mapping of Ecosystem Services in Bihar

District	Number of villages	River
Begusarai	2	Ganga, Budhi Gandak
Bhagalpur	3	Ganga, Kosi
East Champaran	3	Gandak

District	Number of Villages	River
Jamui	1	Nagi
Khagaria	1	Kosi
Samastipur	1	Ganga
Supaul	3	Kosi
Vaishali	1	Budhi Gandak
West Champaran	3	Gandak

To sustain the livelihood development efforts and create market for Ganga Prahari products and services as well as to link them to existing markets, five Jalaj viz., Jalaj Shardul (West Champaran), Jalaj Amala (Bhagalpur), Jalaj Shallika, Jalaj Saras (Begusarai) and Jalaj Ramchiraiya (Katihar) were established. Each Jalaj model has been developed in accordance with socio-economic conditions, agricultural and other local produce available, market and demands. Jalaj are in the form of souvenir shop, nature interpretation and awareness centre, livelihood centre, Jalaj safari and homestay. Another Jalaj awareness centre *cum* souvenir shop of local Tikuli Art, Jalaj Ashoka, has been proposed in Patna and plans for inauguration are underway.

Jalaj Amala: a souvenir shop *cum* sale point, Bhagalpur, Bihar

Jalaj Shallika: Dolphin Safari, Simaria Ghat, Begusarai, Bihar

4.2 Jalmala Samvaad

Jalmala Samvaad is an interpretative initiative in schools for disseminating information about rivers and its biodiversity. These informative corners focus on the journey of the river from its origin to destination. It also provides information about the rich biodiversity in the Ganga River basin and how students and teachers can contribute towards the conservation initiatives. In 2023, six Jalmala Samvaad were established in three districts of Bihar, namely West Champaran, Vaishali and Muzzafarpur. A total of 14 schools were targeted along Gandak River and 5,167 students and 50 teachers were sensitized through workshops (Table 4.7).

Table 4.7 Details of Jalmala Samvaad established and activities carried out in Bihar

Activity	Total number
Jalmala Samvaad established	6
Schools targeted	14
Students sensitized	5,167
Teachers sensitized	50

5.

MANAGEMENT FRAMEWORK

Table 5.1 Management framework for pollution abatement

Strategies/Actions	Objectively verifiable indicators (OVI)	Means of verification (MOV)
Objective 1: Reduce pollution level in rivers		
1.1 Establish adequate functional infrastructure for treatment of industrial effluents • Membrane filtration, nanofiltration • Biochar • Ion exchange • Constructed wetlands	Percentage of industries with functional treatment facilities	Reports of SPCBs and Municipalities Regular water quality monitoring and risk assessment
1.2 Establish adequate functional infrastructure for treatment of municipal waste water discharge.	Percent of households connected to the STPs Level of discharge of untreated waste.	Reports of SPCBs and Municipalities Eco-toxicological surveys, regular water quality monitoring and risk assessment

The management framework, is provided in Table 5.1 to achieve a good ecological status of selected rivers of the Ganga River basin (GRB) in the state of Bihar through integrated and sustainable approaches. This framework formulates objectives for pollution management and abatement in GRB rivers, with specific measures identified to ensure a comprehensive and effective strategy for river health improvement.

Assumptions	Agencies responsible	Supporting Organizations
Compliance with Zero Liquid Discharge Rules, Water Prevention and Control of Pollution Act, 1974, and of the Environment Protection Rules of 1986	Textile, Brass, Petrochemical, Pharmaceutical and Agrochemical industries, distilleries and tanneries in each catchment NGT	Companies involved in developing and disseminating emerging technologies for wastewater treatment Industrial Development Authorities
Availability of adequate funds Strict implementation of guidelines/protocols under Water (Prevention and Control of Pollution) Act, 1974, Environment (Protection) Act, 1986,	MoEFCC, Municipal agencies/ Ministry of Jal Shakti, Central/ State Pollution Control Board (CPCB/SPCB) NGT	Companies involved in developing and disseminating emerging technologies for wastewater treatment

Strategies/Actions		Objectively verifiable indicators (OVI)	Means of verification (MOV)
Objective 1: Reduce pollution level in rivers			
1.3	Identification, tapping, and monitoring of high priority drains in rivers	Number of priority drains identified based on pollutant load and flow Interception and diversion of priority drains to STPs/ETPs/WWTPs	Municipality Records Water quality reports
1.4	Ensure effective functioning of above infrastructure using supportive laws and promoting good practices-	Agency in place for evaluation of effective functioning Number of training and workshops undertaken for sensitization of different stakeholders such municipalities, industrial sectors, PWD System in place for reuse of reclaimed wastewater/sludge	Regular Audits/Monitoring Reports for status priority pollutants in wastewater/sludge Regular data on quantity of reclaimed wastewater/sludge Number of industries and farmers using the reclaimed wastewater and sludge
1.5	Reduce the use of pesticides in river bank agriculture through adoption of green agriculture practices (organic farming, certification, hydroponics)	Number of farmers adopting green agriculture practices Extent of area under green agriculture practices	Agriculture department records Survey of farmers involved green agriculture.
1.6	Holistic ecological risk assessment to evaluate the ecological effect of Emerging Contaminants (ECs) & Endocrine disrupting compounds (EDCs)	Aquatic life standards for priority contaminants/ river water quality parameters developed Ecosystem health indices developed Competent organization/body for regular monitoring constituted	Number of scientific and technical reports/publications Scientific reports to support the policies for effective mitigation plans

Assumptions	Agencies responsible	Supporting Organizations
National Green Tribunal Act, 2010, Municipal Solid Waste (Management and Handling) Rules, 2000 Plastic Waste Management (Amendment) Rules, 2021, Extended Producer Responsibility (EPR), and other legislation		
Govt. commitment to divert identified priority drains to STPs/ETPs/WWTPs Legislation including Guidelines on Water Quality Monitoring , 2017 is functional	Ministry of Jal Shakti, MoEFCC, CPCB/SPCB, in collaboration with multiple competent research institutions	Bihar State Pollution Control Board Patna University Nalanda University Indian Institute of Technology (IIT) Patna
Regular evaluation for STPs/ ETPs/ WWTPs for efficacy/ performance by multiple competent organization Policy upgradation & implementation Acceptability to use the reclaimed wastewater and sludge	Ministry of Jal Shakti, MoEFCC, CPCB/SPCB, in collaboration with multiple competent research organizations	Bihar (SPCB) Department of Environment, Forest, and Climate Change, Government of Bihar Bihar State Biodiversity Board State Environmental Impact Assessment Authority (SEIAA), Bihar State Disaster Management Authority (SDMA), Bihar Centre for Environment and Energy Development (CEED)
Govt. bodies vigilance on tracking/ controlled use of pesticides Govt. commitment to provide subsidies on organic/ Ecofriendly Pesticides & fertilizers Willingness of the farmers to accept/adopt ecofriendly and modern agricultural practices	Ministry of Agriculture & Farmers Welfare, (Central and State), Directorate Of Plant Protection, Quarantine & Storage, Forest Department, Ministry of Panchayati Raj, Local Administrative dept., MoEFCC	Krishi Vigyan Kendras State Agriculture Universities
Adequately trained personnel available Government mandate to include ECs/EDCs in National monitoring Programme Government commitment	MoEFCC, Central, State institutions, universities and involvement	Bihar (SPCB) Wildlife Institute of India, Dehradun Patna University Nalanda University Indian Institute of Technology (IIT) Patna

Strategies/Actions		Objectively verifiable indicators (OVI)	Means of verification (MOV)
Objective 1: Reduce pollution level in rivers			
1.7	Develop eco-friendly public transport	Number of intra- and inter-city buses operating Number of electric buses/rickshaws/trains operating	Emission reports Pollution control reports for public vehicles
Objective 2: Address knowledge gaps through systematic research and monitoring			
2.1	Establish a network of institutions dedicated to conducting research and monitoring programs.	Number of institutions/ universities in the network	Records of network of institutions Number of research papers published under collaborations
2.2	Conduct systemic research and monitoring ofEmerging Contaminants (ECs) & Endocrine disrupting compounds (EDCs) in the Ganga River Basin	Number of scientific reports/papers published	Research reports/ records
2.3	Development of data repositories	Regular compilation of data from reports and research papers into a common repository	Regular updates and cross-verification from data sources
2.4	Ensuring data availability	Number of popular articles/ news reports published Number of open access scientific publications Number of citations per publication	Institutional records and repositories

Assumptions	Agencies responsible	Supporting Organizations
to establish, upgrade and support such facilities		
Availability of adequate funds for investment in vehicles and infrastructure Incentives for switching to eco-friendly transportation provided	MoEFCC CPCB/SPCB State Transport Department	Patna University Nalanda University Indian Institute of Technology (IIT) Patna State technological universities
Willingness of Institutions to collaborate. Funds are mobilized by the Government for such purposes Rules and legislation support frequent monitoring over larger sampling sites, for example Expansion of National Water Monitoring Programme (NWMP) 2019	Central, State institution, universities and NGOs effort and involvement	Wildlife Institute of India, Dehradun Indian Instiute of Toxicological Research Patna University Nalanda University Indian Institute of Technology (IIT) Patna State Agriculture Universities National, International and local NGOs
Funds are available Willingness of Institutions to collaborate	Central, State institutions, universities and NGOs effort and involvement	Wildlife Institute of India, Dehradun Indian Instiute of Toxicological Research Patna University Nalanda University Indian Institute of Technology (IIT) Patna State Agriculture Universities National, International and local NGOs
Coordination between different stakeholders Adequately trained, dedicated personnel	Central, State institutions, universities	Central Government State Government Set up of dedicated bodies Central and State Universities
Legislation facilitating data sharing and availability Adequate funds for publishing open access peer-reviewed research Involvement of mass media and popular media		DST Respective research institutions and universities

Strategies/Actions		Objectively verifiable indicators (OVI)	Means of verification (MOV)
Objective 3: Develop supportive institutional mechanisms for regular and long-term monitoring, management and developing solutions			
3.1	Establish a multitier institutional mechanism for programme implementation at National, state, district and local level.	Effective functioning of different institutions at different levels	Government notifications and order for establishing the committee. Implementation reports
3.2	Establish an authority for management of related issues in the country	Order and notification from Central Govt. authority	Baseline records of CEC's distribution Recommendation from the constituted committee of Ministry/ Dept./Institution
	Involving local communities in decision-making and management activities.	Regular monitoring of pollutants and contaminants. Assessments of flora and fauna diversity along riverbanks. Monitoring river flow to ensure sustainability.	Regular reports from monitoring stations. Periodic ecological surveys and studies. Input from local communities on water quality and ecosystem health.
Objective 4: Engage and empower the local communities and other stakeholders for promoting sustainable resource use in the rivers and associated water bodies			
4.1	Put in place a system for regulated mining practices in the river ecosystem, through supportive policy, legal and administrative framework.	Stretches of high mining activities identified and mapped. Area under regulated mining Number of violations	Mining and offence records of concerned districts
4.2	Develop and Incentivise sustainable, chemical-free agriculture and aquaculture practices among local farmers		

Assumptions	Agencies responsible	Supporting Organizations
Continuation of Policy support at Centre and state level	Multi departmental effort and involvement	Village panchayats Wildlife Institute of India, Dehradun Rural Development Board Cooperatives and self-help groups
Adequate human and financial support is available for its functioning.	MoEFCC, Ministry of jal Shakti, Central, State institution, State Forest Departments	Central Government Bihar Government CPCB, BPCB Bihar Forest Department
Continued political will and funding for river management initiatives. Availability of skilled professionals for monitoring and implementing plans. Willingness of communities to actively participate in conservation efforts.	MoEFCC, Ministry of Jal Shakti Bihar Jal Nigam: Implementation of water treatment and pollution control measures. State Pollution Control Board: Monitoring and enforcing pollution regulations. Department of Irrigation: Implementing riverfront development plans and flood management. Local Municipal Corporations: Ensuring proper waste management and sanitation practices along riverbanks. NGOs and Community Organizations: Engaging in awareness campaigns and community-driven conservation efforts.	Local fisherfolk Local farmers Local residents Municipal bodies
Continued political support Continued support from concerned departments	MoEFCC, Ministry of Jal Shakti, Ministry of Mines	National Mineral Development Corporation (NMDC) Bihar State Mineral Development Corporation Limited (JSMDC)
Streamlined extension activities Incentives and subsidies for switching to sustainable practices	Ministry of Agriculture & Farmers Welfare, (Central and State), Directorate of Plant Protection, Quarantine & Storage	ICAR State Agriculture Universities Krishi Vigyan Kendras Research Institutions

Strategies/Actions		Objectively verifiable indicators (OVI)	Means of verification (MOV)
Objective 4: Engage and empower the local communities and other stakeholders for promoting sustainable resource use in the rivers and associated water bodies			
	and fish farmers		
4.3	Organize a series of awareness, sensitization and capacity building programme for local communities.	Number of programmes conducted Number of stakeholders sensitized. Support of local community	Official records Community surveys
4.4	Involve local communities and other stakeholders in protection and management of river ecosystem.	Number of local institutions/ communities participating in river protection/ management programmes	Official records Community surveys

Assumptions	Agencies responsible	Supporting Organizations
	Krishi Vigyan Kendras Ministry of Micro, Small & Medium Enterprises (M/o MSME)	
Willingness of local communities to participate Continued support from concerned local institutions	MoEFCC, Ministry of Jal Shakti, State Biodiversity board, State Forest Department, WWF	Wildlife Institute of India, Dehradun Village panchayats
Motivated local communities and other stakeholders are available in the region	Ministry of Panchayati Raj, Local Administrative dept., Ministry of Rural development	Village panchayats Local fishermen Local farmers Schools Municipal bodies Local NGOs

IN NEWS

समारोह पूर्वक मनाया गया विश्व मगरमच्छ दिवस मनाया गया

दैनिक भास्कर भागलपुर 21-05-2024

गंगा में मिले प्लास्टिक को भेजा गया देहरादून

गंगा किनारे प्लास्टिक को इकट्ठा किया गया

नवगछिया। भारतीय वन्य जीव संस्थान देहरादून के तत्वाधान में एनएमसीजी-जलज टीम ने प्लास्टिक मुक्त भविष्य की ओर बढ़ते हुए, बिहार राज्य के भागलपुर जिला अंतर्गत (इस्माइलपुर गंगा नदी के किनारे) में एक स्वच्छता अभियान चलाया। इसमें गंगा प्रहरियों और स्थानीय समुदाय के लोगों को प्लास्टिक कचरा एकत्र करने की प्रक्रिया में शामिल किया गया। प्रत्येक गंगा प्रहरी एवं स्थानीय समुदाय को बताया गया कि नमकीन, बिस्कुट, आइसक्रीम, चिप्स आदि के विभिन्न कंपनियों के प्लास्टिक रैपर, जिन्हें मल्टी लेयर प्लास्टिक कहा जाता है, उसे ही एकत्र करने का अनुरोध किया गया। सभी गंगा प्रहरियों और स्थानीय समुदाय के लोगों ने गंगा नदी के किनारे प्लास्टिक को इकट्ठा किया। जलज परियोजना के सहायक समन्वय राहुल कुमार राज ने बताया कि एक किलोग्राम प्लास्टिक को देहरादून डाक के द्वारा भेजेंगे।

दान शिविर का आयोजन

नवगछिया. इस्माइलपुर प्रखंड में आयोजित श्रमदान शिविर का उद्घाटन जिला पार्षद विपिन कुमार मंडल ने दीप प्रज्वलित कर किया. मौके पर पौध रोपण कर पर्यावरण के प्रति लोगों को जागरूक किया. शिविर में 40 प्रतिभागियों ने भाग लिया. मौके पर स्वयं सेवा, स्व सहायता, श्रम की गरिमा जैसे विषयों पर वक्ताओं ने संबोधित किया. कार्यक्रम में राहुल राज, उमेश कुमार, पिंटू यादव, पंकज कुमार, अभिषेक गुप्ता मौजूद थे.

भागलपुर बना प्रवासी पक्षियों का बसेरा, हर साल पहुंच रहे 174 प्रजाति के पक्षी

गांगेय डॉल्फिन जलज सफारी का हुआ शुभारंभ

अपनी जिज्ञासा को कभी सीमित नहीं करें : डीएफओ

डॉल्फिन दिवस पर हुए कार्यक्रम में उपस्थित भारतीय वन्य जीव संस्थान के सदस्य ● जागरण

जासं, भागलपुर : सुंदरवन में सोमवार को डॉल्फिन दिवस का आयोजन डीएफओ एस. सुधाकर की अध्यक्षता में हुई। इस मौके पर तिलकामांझी भागलपुर विश्वविद्यालय के जंतु विज्ञान विभाग के प्राध्यापक डॉ. डीएन चौधरी ने प्रोजेक्टर के माध्यम से डॉल्फिन के बारे में विस्तार पूर्वक जानकारी दी।

उन्होंने कहा कि वर्तमान में डॉल्फिन की संख्या करीब 200 से 250 के करीब रह गई है। डॉल्फिन मछली नहीं, बल्कि स्तनपाई जीव है। डीएफओ एस. सुधाकर ने कहा कि डॉल्फिन संरक्षण को लेकर जागरूकता फैलाने के उद्देश्य से यह आयोजन किया जा रहा है। डीएफओ ने कार्यशाला में मौजूद डॉल्फिन मित्र, गंगा प्रहरी एवं टीएमबीयू के छात्र-छात्राओं से सवाल जवाब भी किया। उन्होंने छात्रों से कहा कि वे अपनी जिज्ञासा को कभी सीमित नहीं करें। उन्होंने कहा कि डॉल्फिन मित्र, गंगा प्रहरी के अलावा विभिन्न शैक्षणिक संस्थानों के 500 छात्र-छात्राओं को इस मुहिम से जोड़ने के लिए विक्रमशिला गांगेटिक सेंचुरी इको क्लब बनाया गया है। क्लब के तहत पर्यावरण प्रेमी छात्र-छात्राओं को इस गांगेटिक डॉल्फिन सेंचुरी का भ्रमण क अधिकारियों-कर्मियों एवं डॉ. डीए चौधरी के नेतृत्व में करवाया ज है। इस मौके पर मंदार नेचर क्लब अरविंद मिश्रा ने प्रोजेक्टर के माध्यम से कई जानकारी दी।

दैनिक भास्कर भागलपुर 21-06-2023

योग दिवस की पूर्व संध्या पर इस्माइलपुर में निकाली रैली

भास्कर न्यूज | नवगछिया/बिहपुर

भारतीय वन्यजीव संस्थान देहरादून के तत्वाधान में इस्माइलपुर में गंगा प्रहरी राहुल कुमार राज के नेतृत्व में विश्व योग दिवस की पूर्व संध्या पर रैली निकाली गई। वहीं घाट सहित विभिन्न जगहों पर योगाभ्यास किया गया। राहुल कुमार राज ने बताया कि नियमित योग करने से स्वस्थ जीवन शैली तथा बेहतर जीव जीने में सहायता मिलता है। योग वह क्रिया जिसके अन्तर्गत शरीर के विभिन्न भागों को साथ लाकर शरीर, मस्तिष्क और आत्मा सन्तुलित करने का कार्य किया जाता है। योग से तनाव भी कम होता है। तनाव का होना एक आम बात है जिससे शरीर और प्रतिकूल प्रभाव पड़ता है।कार्यक्रम में पंक यादव, डुबेश रॉय, मिथिलेश कुमार कुमार, संदीप कुमार, दीपक कुमार, राज उपस्थित थे। वहीं क्रीड़ा भारती के बिहपुर के सोनवर्षा गर्ल्स हाईस्कूल बुधवार को योग प्रशिक्षण शिविर होगा। इसमें सभी आयुवर्ग के ल क्रीड़ा भारती के संयोजक निलेश कि योग शविर को लेकर तैयारी प

दैनिक भास्कर समस्तीपुर भास्कर 20-05-2024

प्लास्टिक मुक्त नदी को लेकर चलाया अभियान

गंगा नदी के किनारे की गई साफ-सफाई

सफाई के बाद प्लास्टिक को वर्गीकृत करते लोग।

भास्कर न्यूज | गोहनपुर

प्रखंड क्षेत्र के धरनी पट्टी पूर्वी गंगा नदी के बाबा बालनाथ घाट पर रविवार को भारतीय वन्य जीव संस्थान देहरादून के तत्वावधान में लिए थैली को सं देहरादून भेजकर सोशल फाउंडेशन द्वारा रिस पेट्रोलियम पदार्थ सुनिश्चित करना भारतीय वन्य जी असिस्टेंट कोऑ कुमार सिंह, बि गोपाल सिंह, शिवम, मोहित, शिवम, सौरभ, सुधांशु, सुभाष आदि मौजूद थे।

दैनिक भास्कर हाजीपुर 19-06-2024

प्रशिक्षण लिए महिलाओं को मिला प्रमाण पत्र

जंदाहा। भारतीय वन्यजीव संस्थान देहरादून भारत सरकार द्वारा नमामि गंगे अंतर्गत महिलाओं हेतु बिझरौली पंचायत भवन पर तीन महीने चले सिलाई प्रशिक्षण के समापन के मौके पर कुल 35 महिलाओं के बीच प्रशिक्षण प्राप्त प्रमाण पत्र का वितरण किया गया।प्रशिक्षण प्राप्त महिलाओं एवं लड़कियों में प्रियंका कुमारी , दिव्या, साक्षी, शांभवी रंजन, काव्या रानी, दीपा चौधरी , सीमा देवी आदि को प्रमाण पत्र दिया गया। मालूम हो कि बिझरौली से पहले तीन महीने का प्रशिक्षण लोमा पंचायत के महिलाओं को भी दिया गया था । मौके पर भारतीय वन्यजीव संस्थान देहरादून

प्रभात खबर

Latest News

प्लास्टिक मुक्त बनाने को ले गंगा घाट पर सफाई

पटना सिटी. गंगा के निर्मल व स्वच्छ बनाने के साथ प्लास्टिक मुक्त बनाने के लिए गंगा घाट पर सफाई चलाया गया. भारतीय वन्यजीव संस्थान से जुड़े महिला गंगा प्रहरियों की ओर से कंगन घाट पर चलाये गये सफाई अभियान में प्लास्टिक को गंगा नदी से मुक्त करने का संकल्प लिया गया. आयोजन का नेतृत्व जलज सहायक समन्वयक मयंक ओझा के नेतृत्व में चला इसमें लोगों ने गंगा सहयोग

Meet the women of Bihar reshaping society, one job at a time

Turning goat milk into eco-friendly soaps

B K Mishra | TNN

Hundreds of tribal women have turned themselves into entrepreneurs in Bagaha-2, West Champaran district, and are supporting their families by producing bathing soaps using goat milk. Of late, the soaps — rich in essential vitamins, minerals and fatty acids — have attracted health-conscious citizens.

Suman Devi, a leader of one of the entrepreneurial groups, said every member is making decent money ever since they started manufacturing bathing soaps. "A profit of at least Rs 200-300 every day is almost guaranteed. The sales are gradually picking up as the demand for this soap is increasing by the day," Suman said, adding that her group consists of 30 women from the Tharu community in Kadmahiya village in Bagaha-2 block.

Rita Devi, another member of the group, asserted that goat milk soap has brought an economic revolution for tribal women of the village. "Now, more and more Tharu women, even from the neighbouring villages, have started manufacturing the soap in their homes and provide financial support to their families," Sarita added.

Soap manufacturing has emerged as a popular cottage industry in this area as women from most homes are engaged in this 'profitable' venture. The process of manufacturing is simple. Firstly, a base of glycerin and 'li' (a sort of adhesive) is prepared, and goat's milk is added to the base. Then, the base is kept in moulds for at least three hours, during which it develops into a soap. No chemical is used, and only some flowers are added for fragrance.

Suman's group has divided work among 30 women. Some members rear goats, others prepare the base for soaps and the remaining are engaged in packaging and marketing the finished products. The women are being trained by 'Namami Gange' under the National Mission for Clean Ganga (NMCG) and Wildlife Institute of India (WII) 'Jalaj' programme.

Sunita Devi, a member of Suman's group, said, "The women are termed 'Ganga Praharis' (a group dedicated to the conservation of Ganga river and its biodiversity). This eco-friendly soap, weighing 100 gms, costs Rs 60, and is gaining rapid popularity. People from other states are also purchasing the soap."

"Goat milk has several health benefits, including immune-modulatory effects, allergy management and anti inflammatory effect," said Dr Dineshwar Prasad, former principal of Govt Ayurvedic College and Hospital, Patna.

INTERNATIONAL WOMEN'S DAY March 8, 2024

Reaping dividends from the field

Faryal.Rumi@timesgroup.com

Who could have thought the humble potato would give rural women from Bihar a new identity and make them financially independent? Armed with the zero-tillage method of farming, some 732 women of Nalanda, Patna, Rohtas and Vaishali districts are reaping dividends from the field.

"I get between Rs 8,000 from one cultivation. Our fi tion has also improved," Devi (38) of Kalri village in N trict's Biharsharif, who loves of a 'lady farmer'.

Under the zero-tillage meth directly sown without the need or plough the soil. This was in in 2022 with support from Inter Potato Centre, Peru. It was imple by NGO Jeevika initially in Nalan Patna district.

"I manage everything on my own best part of this technology is that quires very less fertiliser, minimum tering, no ploughing and no effort to the potatoes out as they grow above soil," Sangeeta said.

Sushila Devi (38) of Nagwa village Maner, Patna, said her crop output ha increased 7-8 times. "After taking trainin in growing potatoes through the no-till age process, I started farming last Novem ber. I produced up to 57 kg of potatoes Earlier, the total production was only 7-8kg on the same land," Sushila said.

शिकारियों की जांच के लिए बनाई जाएगी कमेटी

संजय सिंह ● भागलपुर

जागरण प्रभाव

● कमेटी में शामिल होंगे भागलपुर मंथुरा व सहरसा के वनकर्मी

● घट रहे प्रवासी पक्षी, शिकार के लिए हो रहा कीटनाशक का इस्तेमाल

भागलपुर के नए प्रभागीय वनाधिकारी (डीएफओ) श्वेता कुमारी ने कहा है कि मधेपुरा में शिकारियों के खिलाफ कार्रवाई के लिए वनकर्मियों की एक कमेटी गठित की जाएगी। कमेटी की रिपोर्ट आते ही हर हाल में दोषियों के खिलाफ कार्रवाई होगी। इस वर्ष प्रवासी पक्षियों की संख्या में कमी देखी जा रही है। कमी का कारण शिकार के साथ-साथ पेस्टीसाइड का अभाव भी है। प्रवासी पक्षियों के शिकार के लिए कीटनाशक दवाओं का भी इस्तेमाल किया जा रहा है।

मधेपुरा और भागलपुर की सीमा पर हुए शिकार को लेकर पिछले 13 दिनों से सीमा क्लियर के कारण शिकारियों के खिलाफ प्राथमिकी दर्ज नहीं की जा सकी है। अब तक दोनों जिले के वनकर्मियों के बीच पत्राचार ही हो रहा है। इधर, एक शिकारी प्राथमिकी दर्ज न होने को लेकर वन विभाग के अधिकारियों पर दबाव बनाए हुए हैं। पक्षी प्रेमी ज्ञानचंद्र झा का कहना है कि इस वर्ष प्रवासी पक्षियों की संख्या में कमी आई है। कई जगहों पर धान, मकई व गेहूं में फेनेडाल कीटनाशक टक को मिलाकर प्रवासी पक्षियों को चारे के रूप में दिया जाता है। इस चारे को खाते ही पक्षी बेहोश हो जाते हैं या अर्द्धमूर्छित हो जाते हैं। इन पक्षियों को पकड़कर बाजारों में ऊंची कीमत पर बेचा जाता है। इसके अलावा समाज के कुछ दबंग लोग पशु-पक्षियों का शिकार भी करते हैं। उन्होंने बताया कि बाढ़ का पानी अन्य जगहों पर नहीं फैले इसके लिए कोसी, गंगा सहित अन्य नदियों के किनारे गाइड बांध बना दिया गया है। इस कारण अब कई जगहों पर अस्थायी झील का निर्माण नहीं होता। परिणामस्वरूप इन जगहों पर पक्षी नहीं आते हैं। पक्षियों के घटने का यह भी एक प्रमुख कारण है। यहां से पकड़े गए पक्षियों को दिल्ली, पटना, कोलकाता, मुंबई आदि भेजा जाता है। खगड़िया से लेकर कटिहार और मुंगेर से लेकर साहिबगंज के बीच बड़े-बड़े प्लास्टिक जाल के माध्यम से भी सिकारी इन प्रवासी पक्षियों को फंसाते हैं और अवैध तरीके से इसका व्यापार भी करते हैं। वन विभाग के अधिकारी सबकुछ जानते हुए भी मौन धारण किए हुए रहते हैं।

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ANNEXURE

Annexure - I

Waterbirds recorded in Bihar

S. No.	Order	Family	Species name
1	Ciconiiformes	Ciconiidae	Asian openbill
2	Anseriformes	Anatidae	Bar-headed goose
3	Passeriformes	Hirundinidae	Barn swallow
4	Ciconiiformes	Ciconiidae	Black stork
5	Pelecaniformes	Ardeidae	Black-crowned night heron
6	Charadriiformes	Laridae	Black-headed gull
7	Pelecaniformes	Threskiornithidae	Black-headed ibis
8	Ciconiiformes	Ciconiidae	Black-necked stork
9	Charadriiformes	Recurvirostridae	Black-winged stilt
10	Charadriiformes	Laridae	Brown-headed gull
11	Passeriformes	Motacillidae	Citrine wagtail
12	Gruiformes	Gruidae	Common crane
13	Charadriiformes	Scolopacidae	Common greenshank
14	Anseriformes	Anatidae	Common merganser
15	Anseriformes	Anatidae	Common pochard
16	Charadriiformes	Scolopacidae	Common redshank
17	Charadriiformes	Scolopacidae	Common sandpiper
18	Anseriformes	Anatidae	Common shelduck
19	Anseriformes	Anatidae	Common teal
20	Pelecaniformes	Ardeidae	Cattle egret
21	Charadriiformes	Scolopacidae	Eurasian curlew
22	Pelecaniformes	Threskiornithidae	Eurasian spoonbill
23	Anseriformes	Anatidae	Eurasian wigeon
24	Anseriformes	Anatidae	Falcated duck
25	Anseriformes	Anatidae	Ferruginous duck
26	Anseriformes	Anatidae	Gadwall
27	Anseriformes	Anatidae	Garganey
28	Suliformes	Phalacrocoracidae	Great cormorant
29	Podicipediformes	Podicipedidae	Great-crested grebe

Scientific name	Feeding guilds	IUCN status	IWPA status	Residential status
Anastomus oscitans	R/LM	LC	Sch-II	C
Anser indicus	WM	LC	Sch-II	H
Hirundo rustica	R/WM	LC	Sch-II	I
Ciconia nigra	WM	LC	Sch-II	C
Nycticorax nycticorax	R/LM	LC	Sch-II	C
Chroicocephalus ridibundus	WM	LC	Sch-II	C
Threskiornis melanocephalus	R/LM	NT	Sch-II	C
Ephippiorhynchus asiaticus	R/LM	NT	Sch-II	C
Himantopus himantopus	R/LM	LC	Sch-II	C/H
Chroicocephalus brunnicephalus	WM	LC	Sch-II	C
Motacilla citreola	R/WM	LC	Sch-II	C
Grus grus	WM	LC	Sch-I	H/C
Tringa nebularia	WM	LC	Sch-I	C
Mergus merganser	WM	LC	Sch-II	C
Aythya ferina	WM	VU	Sch-I	H/C
Tringa totanus	R/WM	LC	Sch-II	C
Actitis hypoleucos	R/WM	LC	Sch-II	C
Tadorna tadorna	WM	LC	Sch-II	C/H
Anas crecca	WM	LC	Sch-II	H
Bubulcus ibis	R	NR	Sch-II	I/C
Numenius arquata	WM	NT	Sch-II	C
Platalea leucorodia	R	LC	Sch-I	C
Mareca penelope	WM	LC	Sch-II	H/C
Mareca falcata	WM	NT	Sch-II	H
Aythya nyroca	WM	NT	Sch-II	O
Mareca strepera	WM	LC	Sch-II	H/C
Spatula querquedula	WM	LC	Sch-II	H/C
Phalacrocorax carbo	R/LM	LC	Sch-II	C
Podiceps cristatus	R/WM	LC	Sch-II	C/H

S. No.	Order	Family	Species name
30	Pelecaniformes	Ardeidae	Great egret
31	Charadriiformes	Rostratulidae	Greater painted-snipe
32	Ciconiiformes	Ciconiidae	Greater adjutant
33	Charadriiformes	Scolopacidae	Green sandpiper
34	Pelecaniformes	Ardeidae	Grey heron
35	Charadriiformes	Charadriidae	Grey plover
36	Accipitriformes	Accipitridae	Grey-headed fish-eagle
37	Charadriiformes	Charadriidae	Grey-headed lapwing
38	Anseriformes	Anatidae	Greylag goose
39	Passeriformes	Hirundinidae	Grey-throated martin
40	Suliformes	Phalacrocoracidae	Indian cormorant
41	Pelecaniformes	Ardeidae	Indian pond heron
42	Charadriiformes	Laridae	Indian skimmer
43	Anseriformes	Anatidae	Indian spot-billed duck
44	Charadriiformes	Burhinidae	Indian thick-knee
45	Pelecaniformes	Ardeidae	Intermediate egret
46	Charadriiformes	Scolopacidae	Jack snipe
47	Charadriiformes	Charadriidae	Kentish plover
48	Anseriformes	Anatidae	Knob-billed duck
49	Ciconiiformes	Ciconiidae	Lesser adjutant
50	Anseriformes	Anatidae	Lesser whistling-duck
51	Suliformes	Phalacrocoracidae	Little cormorant
52	Pelecaniformes	Ardeidae	Little egret
53	Podicipediformes	Podicipedidae	Little grebe
54	Charadriiformes	Charadriidae	Little ringed plover
55	Charadriiformes	Scolopacidae	Little stint
56	Charadriiformes	Laridae	Little tern
57	Anseriformes	Anatidae	Mallard
58	Charadriiformes	Scolopacidae	Marsh sandpiper
59	Charadriiformes	Charadriidae	Northern lapwing
60	Anseriformes	Anatidae	Northern pintail
61	Anseriformes	Anatidae	Northern shoveler
62	Suliformes	Anhingidae	Oriental darter
63	Charadriiformes	Glareolidae	Oriental pratincole
64	Accipitriformes	Pandionidae	Osprey

Scientific name	Feeding guilds	IUCN status	IWPA status	Residential status
Ardea alba	R/LM	LC	Sch-II	C
Rostratula benghalensis	R/LM	LC	Sch-II	C
Leptoptilos dubius	R/LM	EN	Sch-I	C
Tringa ochropus	R/WM	LC	Sch-II	C
Ardea cinerea	R/WM	LC	Sch-II	C
Pluvialis squatarola	WM	LC	Sch-II	C
Icthyophaga ichthyaetus	R	NT	Sch-I	P/C
Vanellus cinereus	WM	LC	Sch-II	C
Anse ranser	WM	LC	Sch-II	H
Riparia chinensis	I	LC	Sch-II	R/ LM
Phalacrocorax fuscicollis	R/LM	LC	Sch-II	P/C
Cygnus columbianus	R	LC	Sch-II	C
Rynchops albicollis	R/LM	EN	Sch-I	P/C
Anas poecilorhyncha	R	LC	Sch-II	O
Burhinus indicus	R	LC	Sch-II	C
Ardea intermedia	R/LM	LC	Sch-II	C
Lymnocryptes minimus	WM	LC	Sch-II	C/H
Anarhynchus alexandrinus	R	LC	Sch-II	I
Sarkidiornis melanotos	WM	LC	Sch-II	H/C
Leptoptilos javanicus	R/LM	VU	Sch-I	C
Dendrocygna javanica	LM	LC	Sch-II	H/C
Microcarbo niger	R/LM	LC	Sch-II	C
Egretta garzetta	R/LM	LC	Sch-II	C
Tachybaptus ruficollis	R/LM	LC	Sch-II	C
Charadrius dubius	R/WM	LC	Sch-II	C
Calidris minuta	WM	LC	Sch-II	C/H
Sternula albifrons	R/WM	LC	Sch-II	C
Anas platyrhynchos	WM	LC	Sch-II	H/C
Tringa stagnatilis	WM	LC	Sch-II	C
Vanellus vanellus	WM	NT	Sch-II	C
Anas acuta	WM	LC	Sch-II	H/C
Spatula clypeata	WM	LC	Sch-II	C/H
Anhinga melanogaster	R/LM	NT	Sch-II	C
Glareola maldivarum	R/LM	LC	Sch-II	I
Pandion haliaetus	R	LC	Sch-I	P/C

S. No.	Order	Family	Species name
65	Ciconiiformes	Ciconiidae	Painted stork
66	Charadriiformes	Laridae	Pallas's gull
67	Falconiformes	Falconidae	Peregrine falcon
68	Charadriiformes	Recurvirostridae	Pied avocet
69	Coraciiformes	Alcedinidae	Pied kingfisher
70	Anseriformes	Anatidae	Red-crested pochard
71	Pelecaniformes	Threskiornithidae	Red-naped ibis
72	Podicipediformes	Podicipedidae	Red-necked grebe
73	Charadriiformes	Charadriidae	Red-wattled lapwing
74	Charadriiformes	Charadriidae	River lapwing
75	Anseriformes	Anatidae	Ruddy shelduck
76	Charadriiformes	Scolopacidae	Ruff
77	Gruiformes	Gruidae	Sarus crane
78	Charadriiformes	Glareolidae	Small pratincole
79	Charadriiformes	Scolopacidae	Spotted redshank
80	Accipitriformes	Accipitridae	Steppe eagle
81	Pelecaniformes	Ardeidae	Striated heron
82	Charadriiformes	Scolopacidae	Temminck's stint
83	Charadriiformes	Charadriidae	Tibetan sand-plover
84	Anseriformes	Anatidae	Tufted duck
85	Passeriformes	Motacillidae	Western yellow wagtail
86	Passeriformes	Motacillidae	White wagtail
87	Gruiformes	Rallidae	White-breasted waterhen
88	Passeriformes	Motacillidae	White-browed wagtail
89	Coraciiformes	Alcedinidae	White-throated kingfisher
90	Charadriiformes	Scolopacidae	Wood sandpiper
91	Ciconiiformes	Ciconiidae	Woolly-necked stork
92	Charadriiformes	Charadriidae	Yellow-wattled lapwing

EN- Endangered, **VU-** Vulnerable, **NT-** Near Threatened

Scientific name	Feeding guilds	IUCN status	IWPA status	Residential status
Mycteria leucocephala	R/LM	LC	Sch-II	C
Ichthyaetus ichthyaetus	WM	LC	Sch-II	C
Falco peregrinus	R/WM	LC	Sch-I	C
Recurvirostra avosetta	R/WM	LC	Sch-II	C
Ceryle rudis	R	LC	Sch-II	C
Netta rufina	WM	LC	Sch-II	H/C
Pseudibis papillosa	R	LC	Sch-II	C
Podiceps grisegena	C	LC	Sch-II	WM
Vanellus indicus	R/LM	LC	Sch-II	C
Vanellus duvaucelii	R/LM	NT	Sch-II	C
Tadorna ferruginea	R	LC	Sch-II	O
Calidris pugnax	WM/PM	LC	Sch-II	C/H
Grus antigone	R/LM	VU	Sch-I	H/C
Glareola lactea	R/LM	LC	Sch-II	I
Tringa erythropus	WM	LC	Sch-II	C
Aquila nipalensis	WM	EN	Sch-I	C
Butorides striata	R	LC	Sch-II	C
Calidris temminckii	WM	LC	Sch-II	C/H
Anarhynchu satrifrons	WM	LC	Sch-II	I
Aythya fuligula	WM	LC	Sch-II	C/H
Motacilla flava	R	LC	Sch-II	C
Motacilla alba	WM	LC	Sch-II	C
Amaurornis phoenicurus	WM	LC	Sch-II	O
Motacilla maderaspatensis	R	LC	Sch-II	I
Halcyon smyrnensis	R	LC	Sch-II	C
Tringa glareola	WM	LC	Sch-II	C
Ciconia episcopus	R	VU	Sch-II	C
Vanellus malabaricus	R/LM	LC	Sch-II	C

Annexure - II

Amphibian species recorded in select rivers of Bihar

Family	Common name/ (Scientific name)	IUCN status	This study rivers sighting				Records	
			Ganga	Kosi	Son	Mahananda	This study	Previous records
Bufonidae	Asian common toad (*Duttaphrynus melanostictus*)	LC	+	+	+	+	+	1,2,3
	Indus valley toad (*Duttaphrynus stomaticus*)	LC	+	+	_	+	+	1,2,3
Dicroglossidae	Common skittering frog (*Euphlyctis cyanophlyctis*)	LC	+	+	+	+	+	1,2,3
	Odisha frog (*Fejervarya orissaensis*)	LC	+	_	_	_	+	4
	Pierre's cricket frog (*Fejervarya pierrei*)	LC	+	_	_	_	+	4
	Boie's wart frog (*Fejervarya limnocharis*)	LC	_	_	_	_	_	2,3
	Jerdon's bullfrog (*Hoplobatrachus crassus*)	LC	+	_	+	_	+	1,2,3
	Indian bullfrog (*Hoplobatrachus tigerinus*)	LC	+	+	+	+	+	1,2,3
	Common cricket frog (*Minervarya agricola*)	LC	+	+	+	+	+	4
	Maskey's burrowing frog (*Sphaerotheca maskeyi*)	LC	+	_	_	_	_	4
	Indian burrowing frog (*Sphaerotheca breviceps*)	LC	_	+	+	_	+	1,2,3
	Ronald's burrowing frog (*Sphaerotheca rolandae*)	LC	_	_	_	_	_	3,4
	Terai tree frog (*Minervarya teraiensis*)	LC	_	_	_	+	+	4
	Java frog (*Occidozyga lima*)	LC	_	_	_	_	_	3

Family	Common name/ (Scientific name)	IUCN status	This study rivers sighting				Records	
			Ganga	Kosi	Son	Mahananda	This study	Previous records
Microhylidae	Malaysian narrowmouth toad (*Kaloula pulchra*)	LC	_	_	_	_	_	3
	Assamese balloon frog (*Upredon assamensis*)	LC	_	_	_	_	_	3
	Indian balloon frog (*Uperodon globulosus*)	LC	+	_	_	_	+	4
	Marbled globular frog (*Uperodon Systoma*)	LC	_	_	_	_	_	2,3
	Srilankan bullfrog, (*Uperodon taprobanicus*)	LC	_	_	_	_	_	3
	Narrow mouthed frog, (*Microhyla nilphmariensis*)	LC	+	+	+	+	+	4
	Ant frog (*Microhyla ornata*)	LC	_	_	_	_	_	1,3
	Guangdong rice frog (*Microhyla rubra*)	LC	_	_	_	_	_	3
Ranidae	Common green frog (*Hylarana erythraea*)	LC	_	_	_	_	_	3
Rhacophoridae	Bengal whipping frog (*Polypedates taeniatus*)	LC	_	+	_	+	+	4
	Indian tree frog (*Polypedates maculatus*)	LC	_	_	_	+	+	1,2,3
	Java whipping frog (*Polypedates leucomystax*)	LC	_	_	_	_	_	3

Previous literature record comparing with this study sighting, Least Concern **(LC)**; This study species presence in river **(+)**; No record from River **(0);** Presence **(+)**; Absence **(-)**; Pankaj, N., 2020 **(1)**; Pankaj, N and Nath, B., 2021 **(2)**, Husain, A and Hasan, W., 2021 **(3)**, No previous record **(4)**.

Annexure - III

Details of target contaminants

Class	Compound
Plastic Additives - BPA	Bisphenol-A
Plastic Additives - Phthalic Acid Esters (PAEs)	Dimethyl phthalate Diethyl phthalate Di-n-butyl phthalate Butyl benzyl phthalate Bis(2-ethylhexyl) phthalate Di-n-octyl phthalate
Household and Personal Care Products (HPCPs)	Triclosan Triclocarban
Steroid Hormones	Diethylstilbestrol Estrone Estradiol Estriol 17α-ethynylestradiol
Pesticides	alpha HCH gamma HCH BHC-Alpha BHC-beta BHC-delta DDT-p,p' DDE-p,p' DDD-p,p' Aldrin Dieldrin Endrin Endrin Aldehyde Endrin Ketone Heptachlor Heptachlor Epoxide trans-Chlordane cis-Chlordane Methoxychlor Endosulfan -I Endosulfan - II Endosulfan sulfate
Heavy Metals	Chromium Copper Cadmiun Nickel Lead Arsenic Zinc Mercury

Annexure - IV

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Conservation planning for Gangetic dolphin (*Platanista gangetica*) in smaller rivers of the Ganga River Basin, India

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ABSTRACT

The complex and dynamic networks of river system, vital for the maintenance of biodiversity and ecosystem services, are under pressure due to human-induced water stress disrupting ecological processes. Recognition of the importance of rivers as source of life though has led to efforts towards protecting large rivers, nevertheless the conservation and management of smaller rivers remained mostly neglected, creating significant gaps in ecological restoration initiatives. In the present study, we assess the distribution and population status of Gangetic dolphin (*Platanista gangetica*) in the small rivers in the Ganga River Basin for integrating it into the basin wide river conservation strategy. We observed that the Gangetic dolphin inhabited most tributaries and sub-tributaries of the Ganga River, with a naïve occupancy rate of $\Psi = 0.68 \pm 0.04$ (mean ± SE) having 606 ± 142.77 (mean ± SE) individuals and accounts for 15% of the total Gangetic dolphin population in the Basin. The results of *N*-mixture and MaxEnt models demonstrate that channel depth, presence of meanders and water discharge were key predictors of distribution in these rivers, and the proximity to confluences were identified as a critical predictor. About 54%

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(620 km) of 1150 km of the surveyed river stretches exhibited suitability for dolphins in the Basin, indicated by a probability distribution score of ≥0.50. Combining this data with the available information, we delineated a total of 2850 km stretch covering entire Ganga River System suitable for Gangetic dolphins within the Basin. Notably, the 620 km of suitable stretches identified in smaller rivers represent 22% of the overall suitable stretches across the entire basin. These stretches were translated to conservation priority stretches for systematic conservation planning involving various stakeholders for improved river conservation in the Basin.

1. Introduction

The network of river systems, sustained by the interplay of biotic and abiotic components, functions as biodiversity hotspots and offer essential services for human needs (Carpenter et al., 2011; Grill et al., 2019; Meybeck, 2003; Ripl, 2003). The spatial and hierarchical structure, as well as the longitudinal connectivity of the river system, hold together the most diverse composition of flora and fauna globally (Collen et al., 2014; Dudgeon, 2000; Reid et al., 2019). In this complex network, each hierarchical order of streams plays a pivotal role, indispensably contributing to the ecological processes that heavily rely on biodiversity (Bouska et al., 2023; Pracheil et al., 2013). As per the classic stream order or Hack's stream order, existence of large rivers is greatly dependent on the vital contributions of their tributaries and sub-tributaries (Rodriguez-Iturbe and Rinaldo, 1997) and these are crucial for strengthening the hydrological network of the river basins (Nel et al., 2007). The small rivers are often characterized by a mosaic of diverse habitats, which support rich biodiversity, serve as migration routes, sources of nutrients, contributors to climate resilience, and significant refuges for macrofauna (Davis et al., 2013; Gido et al., 2016). The small rivers facilitate connectivity, creating a network that allows for the movement of aquatic species essential for maintaining metapopulations. This, in turn, enables the creation of a metapopulation structure, ensuring genetic exchange and preventing isolation of populations, enhancing the resilience of aquatic species to environmental changes and disturbances (Allendorf et al., 2012; Tonkin et al., 2018). Unfortunately, the fundamental attributes that maintain the integrity of riverine networks are increasingly undermined by human-induced stressors such as the construction of dams, reservoirs, canals, and irrigation systems. The evident decline in freshwater biodiversity underscores the urgent need for conservation actions to halt biodiversity loss and deteriorating ecological processes in these vulnerable ecosystems (Dudgeon et al., 2006; Grill et al., 2019; Vörösmarty et al., 2010).

Until recently, the predominant focus of conservation and restoration efforts has been on large rivers, often overlooking the importance of small rivers (Palmer and Ruhi, 2019). The vital contributions of these lesser known small rivers to the health and resilience of larger river systems are increasingly being recognized in the literature, demanding a shift towards more comprehensive and inclusive conservation strategies that adopt basin-wide approach and prioritize the interconnected nature of riverine ecosystems (Dudgeon et al., 2006; Saunders et al., 2002; Thorp et al., 2010).

The Ganga River, one of the most biodiverse subtropical rivers of India, is currently confronting unprecedented threats from various human-induced stresses (Hussain et al., 2020; Kumar, 2017). The tributaries and sub-tributaries of the Ganga River, hereafter called as small rivers, are pivotal in enriching the hydrological processes and ecological health of the entire Ganga River Basin (henceforth GRB) (Singh and Singh, 2020). The biodiversity of these small rivers is declining rapidly and the paucity of robust ecological information has impeded river conservation efforts (Dudgeon, 2000; Hughes, 2017). This dearth of information poses a significant challenge in understanding the intricate dynamics of these ecosystems, thereby hindering the development of effective conservation strategies. In such a scenario, the utilization of the widely-recognized umbrella-species approach can be fundamental in shaping the future conservation strategies for these lesser known small rivers (Branton and Richardson, 2011; Roberge and Angelstam, 2004). The umbrella-species concept operates on the premise that providing adequate space for species with more extensive spatial needs will also serve as protection for an entire assemblage of species with more modest spatial requirements (Wilcox, 1984; Andelman and Fagan, 2000; Roberge et al., 2008). Hence, large-bodied organisms, often vertebrates, particularly large mammalian carnivores, have been favored as potential umbrella species (Carroll et al., 2001; Roberge and Angelstam, 2004). Consequently, the umbrella species approach can play a crucial role in delineating protected areas, assuming that conserving these species will confer adequate protection to coexisting species (Roberge et al., 2008; Roberge and Angelstam, 2004; Sergio et al., 2008). Indeed, this approach aligns with the goal of 'bending the curve of freshwater biodiversity loss' and is instrumental in garnering public support, thereby increasing the likelihood of conservation actions (Kalinkat et al., 2017; Tickner et al., 2020).

Gangetic dolphin (*Platanista gangetica*, Lebeck, 1801), is an obligatory river cetacean endemic to the Indian subcontinent (Kelkar et al., 2018, 2022; Anderson, 1879). It plays a crucial role in stabilizing ecosystems, regulating energy flows and maintaining the prey base (Behera et al., 2014; Gomez-Salazar et al., 2012; Turvey et al., 2012). While the GRB hosts numerous long-ranging large aquatic vertebrates, such as gharial, mugger, otters, and freshwater turtles, the presence of dolphin throughout the basin, along with its specific hydro-geomorphological requirements, renders it an exemplary candidate as an umbrella species. Utilizing the Gangetic dolphin in this role provides valuable insights into the extent of human pressures and aids in prioritizing conservation efforts within the basin (Hussain et al., 2013; Roff, 2013; Sinha and Kannan, 2014). In recent years, the distribution range of the Gangetic dolphin in various rivers has dwindled, particularly in the upstream stretches (Das et al., 2022, Sinha and Kannan, 2014). The species is now believed to be extirpated from the Son, Ken, Betwa, and Sind rivers, the middle and upper stretch of the Sharda River, and the upper stretch of the Yamuna River (Sinha and Sharma, 2003, Behera et al., 2014). Additionally, several tributaries north of the Ganga River, including the Babai, Bagmati, and Sharda rivers, lack updated information on the status of the Gangetic dolphin (Kelkar et al., 2022), while Rapti

River was surveyed a decade back (WWF-UPFD, 2015). Hence, a comprehensive study is essential to assess the current population status, distribution, and perceived threats, with the goal of integrating this information into basin-wide river conservation strategies.

In this study, we assessed the distribution, population status, and habitat suitability of Gangetic dolphin in small rivers within GRB. Through the study we addressed following research questions, (i) What is the extent of current distribution range? (ii) What is the population status and occupancy? (iii). What are the spatial and environmental factors influencing the distribution and abundance of dolphins in small rivers, and how can this information be utilized to prioritize conservation efforts in these rivers?

2. Methodology

2.1. Study area

The study was carried out in the tributaries and sub-tributaries of the Ganga River. We carried out boat-based visual encounter surveys in ten rivers, covering a total linear stretch of 1290 km, *viz* Girwa (20 km), Kauriyala (15 km), Babai (75 km), Sharda (220 km), Rapti (500 km), Bagmati (60 km), Mahananda (230 km), Ken (40 km), Betwa (90 km), and Sind (40 km) (Fig. 1 **and** Table S1). The survey of the upstream of the Bagmati River was omitted due to navigability concerns. Of the rivers surveyed, Bagmati, Babai, Girwa, Kauriyala, Mahananda, Rapti, and Sharda are northbound Himalayan rivers, partially snow-fed. Whereas the Ken, Betwa, and Sind are rain-fed and have their origins in the Deccan Peninsula (Singh, 2017). The surveys were carried out during the post-monsoon seasons (November -February) of 2022 and 2023 using an inflatable rubber boat fitted with 25 hp Yamaha engine.

2.2. Data collection

We employed a boat-based visual encounter method to record Gangetic dolphin sightings (Smith and Reeves, 2000; Qureshi et al., 2021). All surveys were conducted using inflatable boats, with two independent observers stationed at the front and rear ends of the boat to simultaneously record Gangetic dolphin sightings. The observers did not maintain visual contact and were instructed to adhere to the same survey protocol described in Das et al. (2022). The boat was kept at an average speed of 6–8 km/hr to minimize the likelihood of missing any surfacing event of the Gangetic dolphin (Smith et al., 2006; Das et al., 2022). The least concurrent sighting records obtained by two independent observers were then fitted into -the occupancy framework.

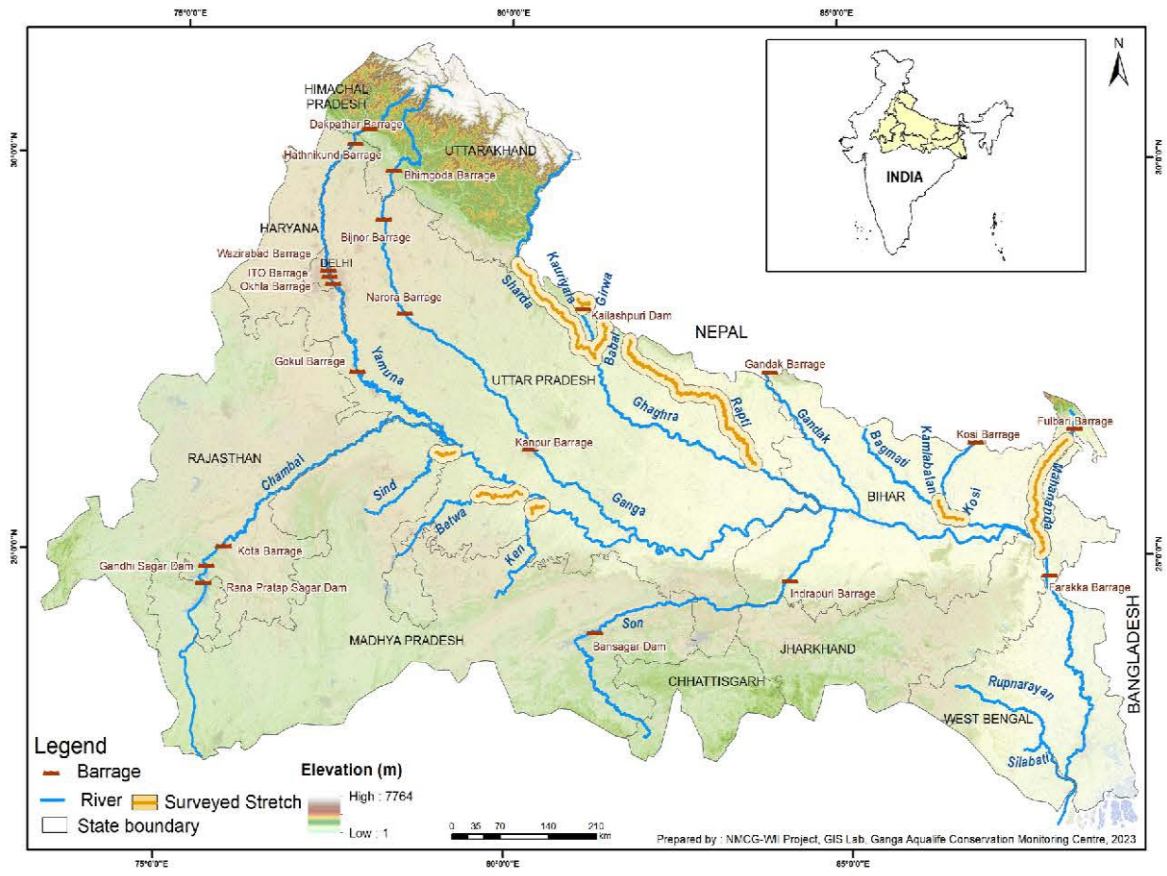

Fig. 1. Location map of the rivers surveyed for recording Gangetic dolphin (*Platanista gangetica*) presence in the Ganga River Basin, India.

In addition to Gangetic dolphin occurrence records across these rivers, we also collected data on (i) hydro-morphological variables (n=5) *viz.* slope, discharge, channel width, channel depth, presence of meanders, (ii) physiochemical parameters (n=5) *viz.* water temperature, dissolved oxygen (DO), pH, salinity, Total Dissolved Solids (TDS) and (iii) human induced stressors (n=5) *viz.* ferry intensity and fishing intensity (number of active nets), sand mining intensity, water extraction pumps and human presence. To mitigate the impact of shallow and unnavigable river sections, the boat-based direct count method utilized the thalweg, or the deepest section of the river channel, to estimate dolphin abundance (Smith and Reeves, 2000; Smith et al., 2006; Braulik et al., 2012; Richman et al., 2014). Leveraging these hydro-geomorphological features and adhering to the assumptions outlined by Charbonnel et al. (2014), we standardized our spatial units to 5 km, in accordance with the methodology proposed by Das et al. (2022). The 1290 km linear stretch was segmented into 258 Biodiversity Evaluation Units (BEUs) (Table S1), and data were collected at 1 km intervals within each BEU. Subsequently, the collected data were averaged and incorporated into the occupancy and N-mixture framework, following the study design outlined in Das et al. (2022). The length of the sampling site i.e. 25 km (five spatial replicates of 5 km segment/BEUs) was selected to meet the assumptions critical for the hierarchical-N mixture model and is based on the following criteria. First, we utilized the mean home range of *Platanista minor* (Toosy et al., 2009) as a surrogate to select the length of the sampling sites for this study, as *Platanista gangetica* and *Platanista minor* both share identical physiological and biological attributes (Smith and Braulik, 2009). Therefore, based on the information, we assumed a maximum daily movement of approximately 25 km for the Gangetic dolphin, considering the intermittent shallow and deep pools in the river stretches. Secondly, the length of the sampling site chosen to meet the closure assumption Royle, (2004), detect the presence of a species, and the requirement for more than three spatial replicates, as recommended by Hines et al. (2010). As the aim of the present study was to assess the abundance and distribution of Gangetic dolphins in the lesser-known rivers of the Ganga Basin, surveys were conducted in narrow channel habitats from November 2022 to February 2023 (low water season). We implemented single observer method, which builds upon the foundation of multiple observers stationed in a single boat, following a thalweg path in the river, are ideal for detecting dolphin sightings (Smith and Reeves, 2000; Paudel et al., 2015; Qureshi et al., 2021). The single observer method always remains a cost-effective survey option for monitoring (Richman et al., 2014). However, unlike the double-observer method, it cannot account for detectability (McConville et al., 2009). To address this, we compared the findings from our study with a correction factor derived utilizing the mean detection probability from double-observer methods (Das et al., 2022).

2.3. Data analysis

2.3.1. River habitat assessment

For habitat assessment, the average values of each variable were computed for a total of 258 Biological Evaluation Units (BEUs). While the presumption was that various rivers possess unique attributes because of their distinct origins and passage through different biogeographical provinces, we employed one-way ANOVA (Analysis of Variance) to assess whether there were significant variations between these BEUs and across rivers.

2.3.2. Encounter rate (ER) and site occupancy

We calculated the Gangetic dolphin encounter rate (sightings per km of linear stretch) for each spatial unit and employed ANOVA to examine variations in encounter rates across the rivers. Gangetic dolphin presence and absence data was pooled from each spatial unit to fit into the occupancy framework (MacKenzie et al., 2002, 2017). We utilized data from repeated visual encounter surveys to fulfill the requirements of single-season occupancy analyses. Key assumptions in single-season occupancy analysis include: (1) closure, assuming the population is demographically closed during surveys, (2) site independence, assuming species detection at one site is independent of detections at others (Fiske and Chandler, 2011), (3) no-false positives, requiring correct species identification and disregarding doubtful detections, and (4) constant probability of occupancy and detection, wherein the default model assumes uniform probability of occupancy and detection across all sites or adjusts for site and observation-level covariates (Mackenzie, 2006). The site occupancy of Gangetic dolphin in the surveyed river was estimated using the *occu ()* function in the "*unmarked*" package (version 1.3.2) in R version 4.3.0, with R Studio version 2023.04.21 (Fiske and Chandler, 2011; RStudio Team, 2022). First, we assessed factors e.g., time spent on each spatial unit (effort), time of the day during survey (time) and channel width influencing the likelihood of detecting Gangetic dolphin (p), while keeping the probability of their presence (Ψ) constant following MacKenzie et al. (2017). Continuous variables were z-standardized, and categorical variables (Table S2) were dummy-coded in order to prevent numerical optimization of the likelihood following Hines, (2006) and Sunarto et al. (2012). To ensure the reliability of our results, we checked for potential multicollinearity among variables using the Pearson correlation test (Graham, 2003). Variables with a Pearson correlation coefficient higher than 0.70 were excluded from the analysis.

2.3.3. Abundance estimation

2.3.3.1. Gangetic dolphin abundance estimation using N-mixture model. We used Binomial *N*-mixture models to estimate the dolphin abundance and factors influencing their distribution (Royle, 2004; Kéry and Royle, 2020; Kéry, 2018). The N-mixture model accounts for imperfect detection and evaluates the likelihood of an event occurring as well as the likelihood of detecting a species (Mackenzie, 2006; MacKenzie et al., 2002; Rota et al., 2009). These models are known to yield more reliable abundance estimates of rare and cryptic species compared to traditional direct counting (MacKenzie and Bailey, 2004; Rota et al., 2009). This method has been successfully used to assess Gangetic dolphin abundance in major rivers of the Ganga basin and the Karnali River in Nepal (Das et al., 2022;

Paudel et al., 2015). We used dolphin sighting records per spatial unit as baseline data and employed the N-mixture model using the '*pcount*' function available in the "*unmarked*" package in R version 4.3.0, with R Studio version 2023.04.21 (Fiske and Chandler, 2011; R Development Core Team, 2023; RStudio Team, 2022). We administered the spatial counts data into the Negative Binomial distributions as it effectively models abundance, taking into account occupied survey sites with fewer true zeros in the dataset (Barão-Nóbrega et al., 2022). Given the patchy distribution of dolphin during the low water season, Negative Binomial distributions align well with over-dispersion data (Knape et al., 2018; Kéry and Royle, 2020). The upper bound value for K (abundance estimates) were determined through multiple trials iterations (Fiske and Chandler, 2011; Knape et al., 2018; Kéry and Royle, 2020). Site covariates such as channel width, meander, fishing intensity, water discharge, individual river characteristics, and anthropogenic influences are hypothesized to influence the relative abundance (λ) of dolphin and detection covariates (Table S2) influencing detection probability (p), when dolphins are present at a site. These covariates were chosen based on existing knowledge and relevant literature (Das et al., 2022; Paudel et al., 2015). A comprehensive set of 32 N-mixture models, encompassing various combinations of univariate and multivariate factors, were created to evaluate the abundance and detection probability of dolphins, under the Negative Binomial distribution. MacKenzie and Bailey goodness-of-fit test was performed to evaluate model performance (MacKenzie and Bailey, 2004). Models were ranked based on Akaike Information Criterion (AIC) scores and AICc weights were taken into consideration while determining overall covariate significance (Akaike, 1974; Burnham and Anderson, 2004). A final model set was generated from the top-ranked univariate models that included combinations of site use and detection covariates with $\Delta AICc \leq 2$, indicating substantial empirical support. Significant covariate influence was determined if the 95% confidence interval of the beta coefficient ($\beta \pm 1.96 \times SE$) did not overlap zero, with the sign of the coefficient indicating the impact's direction (Searle et al., 2020). The probability of Gangetic dolphin relative abundance (λ) was estimated for each site by averaging the predicted values from the most parameterized top-ranked models within the final model set, using the '*MuMin*' package in R(Bartoń, 2013; R Development Core Team, 2023). We performed a goodness-of-fit test for the highest-ranked model with the maximum parameters (Searle et al., 2020).

2.3.3.2. Gangetic dolphin abundance estimation using correction factor (D_{cf}). Correction Factors (D_{cf}) compensate for missed individuals during visual encounter surveys (Bashir et al., 2010; Richman et al., 2014; Vu et al., 2018). Therefore, we determined the relative abundance of Gangetic dolphin using mean correction factors (D_{cf}) obtained from previously published studies conducted in rivers across the Indian subcontinent (Das et al., 2022). These studies encompassed a range of river types, including narrow and wide channels with varying widths, depths, and lengths. The derived indices were then compared with population estimates derived from *N*-mixture models. The corrected population estimates of Gangetic dolphin were obtained by multiplying the correction factor (D_{cf}) by the total number of sightings recorded in a given river.

2.3.4. Conservation Priority Stretch (CPS)

To predict the potential distribution and delineate priority stretches, we employed maximum entropy (MaxEnt) models. The MaxEnt is one of the effective modelling algorithms, which take environmental variables and species presence-only data to predict and model species distribution. It is also capable of predicting future distributions under the influence of global climate change (Clements et al., 2012; Elith et al., 2006; Phillips et al., 2006).

For MaxEnt modeling, we utilized a total of 176 dolphin presence locations across seven rivers (no Gangetic dolphin presence was recorded in three rivers). To generate the species distribution model, we selected 33 variables comprising bioclimatic (n=19), hydro-morphological (n=4), physiochemical parameters (n=5), and human induced stressors (n=5) (Das et al., 2022; Jain and Singh, 2020; Rai et al., 2023). The climatic variables were resampled at 5 km^2 resolution, obtained from WorldClim version 2 with a spatial resolution of 2.5 arc minutes (approximately 4.5 km^2) to ensure uniformity (Fick and Hijmans, 2017). All pairs of variables were assessed for correlation, and variables displaying a Pearson correlation coefficient of $\geq$0.70 were removed if they were found to have minimal ecological significance (Zuur et al., 2010). Finally, a subset of 12 uncorrelated ecologically meaningful variables was used to generate dolphin distribution in the seven rivers using MaxEnt software (version 3.4.4) (Table S2). Model over-complexity and overfitting, were adjusted by optimizing user-modifiable factors, *viz.*, regularization multipliers and the feature classes (Elith et al., 2010). We examined a variety of model combinations, initially individual feature classes (e.g. Linear (L), Quadratic (Q), Product (P), Threshold (T), and Hinge (H) with varying regularization values at 0.5, 1.0, 1.5, and 2.0. For example, within the linear feature class, four different models were assessed L-0.5, L-1.0, L-1.5, and L-2.0 (Table S3). The best fit models were assessed using AIC approaches computed in ENMTools 1.4.4 software (Warren et al., 2010). The prediction probabilities were transformed into a raster layer to generate a probability distribution map using ArcGIS 10.6 (https://www.esri.com/). Subsequently, the probability distribution was categorized in three classes viz. >0.70, 0.61–0.70 and 0.51–0.60. These classes were then translated to priority stretches following Das et al. (2022) as CPS1->0.70, (High Conservation Priority Stretches), CPS2 −0.61–0.70 (Moderate Conservation Priority Stretches), and CPS3 −0.51–0.60 (Low Conservation Priority Stretches).

3. Results

3.1. River habitat assessment

The surveyed rivers exhibited diverse hydro-morphological characteristics and physicochemical properties along their lengths. The average channel depth across studies rivers was 3.03 m ± 2.71 (mean ± SD), with individual rivers varying significantly between a depth of 1.78 m ± 0.91 in Sind River and 5.25 m ± 4.37 in Bagmati River (ANOVA, $F = 15.55$, $p < 0.001$). Notably, the Mahananda,

Rapti, and Bagmati rivers exhibited depth variations, primarily due to the presence of deeper pools compared to the other studied rivers (Figure S1). The mean river width was 253.13 m ± 177.27, with widths ranging from 83 m ± 24 in Sind River to 525 m ± 281 in Sharda River. A significant difference in mean channel width was observed across the studied rivers (ANOVA, F = 147.26, p <0.001) (Figure S1). Additionally, the presence of meanders varied significantly among the rivers. Physicochemical properties also displayed substantial variations among the studied rivers (Table S2).

We observed significant variations in various human induced stressors across the studied rivers. The fishing intensity, measured as the average number of active nets per BEU (mean= 8.81, range= 0–131), varied significantly (ANOVA, F = 23.94, p <0.001). The Mahananda River had the highest fishing intensity (38.64 0–131 nets/BEU), while the Sind River had the lowest (0.14, 0–3 nets/BEU). No fishing activity was observed in the Girwa and Kauriyala rivers, as these rivers flow through the Katerniaghat Wildlife Sanctuary a Protected Area declared under the Indian Wild Life (Protection) Act, 1972. The mean number of ferry crossings (1.95, 0–34 ferry/per BEU) also varied significantly (ANOVA, F = 22.04, p <0.001) among the rivers. Sand mining intensity, including activities involving boats, tractors, and earthmovers, differed significantly across the rivers (ANOVA, F = 6.439, p <0.001), with the highest intensity in the Betwa River (5.52, 0–58 activities/BEU) and the lowest in the Babai River (0.13, 0–2 activities/BEU). Notably, there were no signs of mining activities in the Girwa, Kauriyala, and Rapti rivers. Extraction of water through pumps among the rivers also exhibited significant variations (ANOVA, F = 34.675, p <0.001). The Bagmati River had the highest occurrence of water extraction pumps (6.75, 0–10pumps/BEU), while the Rapti River had the lowest (0.11, 0–3) (Table S2).

3.2. Encounter rate (ER) and site occupancy

A total of 359 sightings of Gangetic dolphins were documented within the 1120 km survey stretch across seven rivers, accounting for 41% of the total BEUs covered (Fig. 2 **A**). Maximum sightings were recorded from the Mahananda River (n=169, 47%) followed by sightings in the Rapti (n=89, 25%), Bagmati (n=68, 19%), Kauriyala (n=13, 4%), Girwa (n=9, 3%), Sharda (n=7, 2%), and the Babai River (n=4, 1%) (Table S4).

The average encounter rate of dolphin across rivers was 0.49 ± 0.15 (mean ± SE) sightings/linear km and ranged between 0.03 ±0.02 sightings/km in Sharda and 1.13 ± 0.04 sightings/km in Bagmati river. The highest encounter rate was observed in the Bagmati River (1.13 ± 0.04 sightings/km), followed by the Kauriyala (0.87 ± 0.47), Mahananda (0.73 ± 0.1), Girwa (0.45 ± 0.17), Rapti (0.18

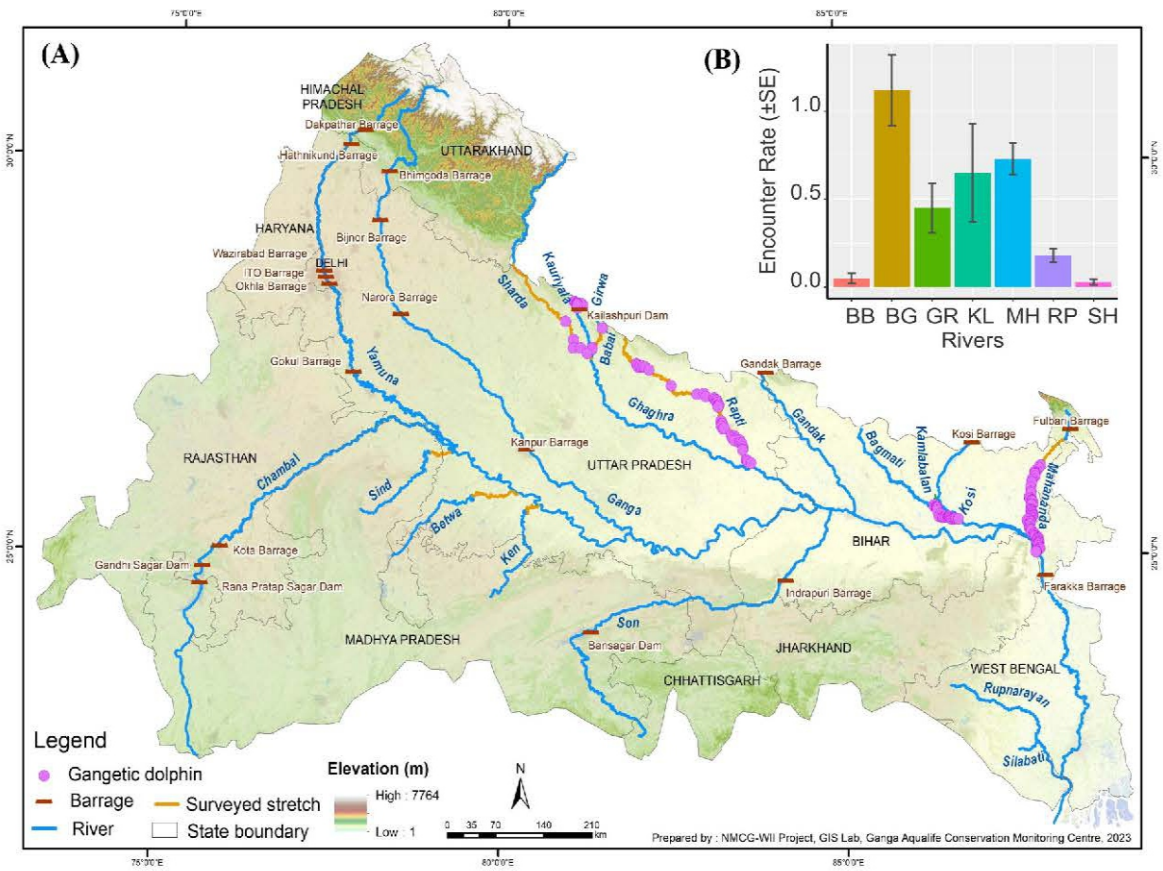

Fig. 2. **(A)** Sighting locations of Gangetic dolphin and **(B)** Gangetic dolphin encounter rate (sightings/linear kilometer) recorded in seven small rivers of the Ganga River Basin, India. (BB Babai; BG Bagmati; GR Girwa; KL Kauriyala; MH Mahananda; RP Rapti; SH Sharda).

± 0.04), Babai (0.05 ± 0.04), and Sharda (0.03 ± 0.02) rivers (Fig. 2 **B**). A significant variation in encounter rates was observed across the surveyed rivers (ANOVA, F = 25.20, p <0.001). Gangetic dolphins were detected in 31 sampling units, resulting in a naïve occupancy of 0.68 ± 0.07 (95% CI = 0.54 − 0.81). The mean probability of detecting Gangetic dolphin was estimated at (P) 0.61 ± 0.04, and the average likelihood of these dolphins occupying a site was $\Psi = 0.68 \pm 0.04$.

3.3. Abundance estimation

3.3.1. Gangetic dolphin abundance estimation using N-mixture model

The total estimated population of dolphin across the examined rivers was 606 ± 142.77 (mean ± SE) dolphins (CI = 381 – 923) (Table 1). Among the rivers, the Mahananda River encompassed 43.56% of the estimated total population, at 264 ± 47.07 individuals (CI = 180–363) and lowest in the Babai River, at 8 ± 7.08 individuals (CI = 4–18) constituting only 1.32% of the total estimated population. The Rapti, with an estimated abundance of 146 ± 45.79 individuals (CI = 79–256) constitutes the second largest population, contributing to 24.09% of the total estimated population. The Bagmati River had an estimated population of 120 ± 22.13 individuals, accounting for 19.80% of the total estimated population. The Kauriyala River was estimated to have 36 ± 8.48 individuals, Girwa River had 19 ± 5.22 individuals, and Sharda River held 13 ± 7.08 individuals using the *N*-mixture model. The Babai River exhibited the lowest abundance estimate, with 8 ± 7.08 individuals, constituting only 1.32% of the total estimated population across all the rivers analyzed **(**Table 1**)**.

3.3.2. Gangetic dolphin abundance estimation using correction factor (D_{cf}).

The mean derived correction factor (D_{cf} =1.52) and the abundance estimated using correction factor was 546 ± 37.05 individuals (CI = 473–619) (Table 1). The abundance estimate was highest in Mahananda River (47.06%) with 257 ± 11.15 individuals (CI = 235–279). Similar to the estimates obtained through the N-mixture model, the Rapti River displayed the second-largest Gangetic dolphin population of 135 ± 11.67 individuals (CI = 112–158). Following this, the Bagmati River had an estimated 103 ± 8.10 individuals (CI = 87–119), while the Kauriyala accounted for 20 ± 2.26 individuals (CI = 16–24). The Girwa River accounted for 14 ± 1.09 individuals (CI = 12–16), followed by Sharda with an estimate of 11 ± 1.69 individuals (CI = 8–14). The lowest abundance estimate was for the Babai River, with 6 ± 1.09 individuals (CI = 4–8) using the correction factor (D_{cf}).

3.3.3. Factors affecting Gangetic dolphin abundance (λ)

The optimal model for estimating abundance (λ) included factors such as channel depth, meanders, and individual rivers, while for detection (p) it included river width and effort **(**Table S6**)**. Based on model-averaged parameter estimates (cumulative weight of $\Sigma w = 1.00$), factors such as channel depth, meanders and individual rivers were identified as the most reliable predictors of dolphin abundance (Table S6). While the parameter 'river' was present in the final model set, their individual impact varied. Among these rivers, Bagmati and Mahananda had a notably positive influence on dolphin abundance, whereas the Sharda exhibited a negative influence (Table S6). Moreover, the width of the river was determined to have a notably adverse impact on the detection probability (cumulative weight of $\Sigma w = 1.00$), while the level of effort displayed a positive correlation with the detection probability of Gangetic dolphins in the Ganga Basin (Figs. S3 and S4).

3.4. Identification of Conservation Priority Stretches (CPS)

The Species distribution model (SDM) yielded an impressive Area Under Curve (AUC = 0.97, SD 0.008) **(**Figure S2**)**. The prediction model identified seven bioclimatic variables - Annual Mean Temperature (Bio 1), Isothermality (Bio 3), Temperature Seasonality (Bio 4), Precipitation of the Wettest Month (Bio 13), Precipitation Seasonality (Bio 15), Precipitation of the Driest Quarter (Bio 17), and Precipitation of the Warmest Quarter (Bio 18) as key factors influencing the distribution of Gangetic dolphin. Other hydrological and human induced stressors such as channel depth, channel width, water discharge, fishing, and sand mining contributed significantly in determining the species distribution **(**Figure S2**)**. The predicted potential distribution of dolphin indicated that water discharge contributed the most (30.6%), followed by Temperature Seasonality (16%) and Annual Mean Temperature (12.5%) in the Basin

Table 1
The length of the river surveyed, number of sightings, abundance estimates derived using the N-mixture model and Correction factor (D_{cf}) of Gangetic dolphin across seven small rivers in the Ganga River Basin, India.

River	Surveyed length (km)	Concurrent least sightings	Population estimates (λ), Mean ± SE (CI 95%)	Population estimates (D_{cf}) Mean ± SE (CI 95%)
Babai	75	4	8 ± 3.8 (4–18)	6 ± 1.09 (4–8)
Bagmati	60	68	120 ± 22.13 (81–168)	103 ± 8.10 (87–119)
Girwa	20	9	19 ± 5.22 (10–30)	14 ± 1.09 (12–16)
Kauriyala	15	13	36 ± 8.48 (21–55)	20 ± 2.26 (16–24)
Mahananda	230	169	264 ± 47.07 (180–363)	257 ± 11.15 (235–279)
Rapti	500	89	146 ± 45.79 (79–256)	135 ± 11.67 (112–158)
Sharda	220	7	13 ± 7.08 (7–33)	11 ± 1.69 (8–14)
Grand total	**1120**	**359**	**606 ± 142.77 (381–923)**	**546 ± 37.05 (473–619)**

(Table S5).

The MaxEnt models predicted a probability distribution of Gangetic dolphin that encompassed a total stretch of 1150 km, including both historical and current ranges. Out of the entire projected distribution, approximately 54% (620 km) of river stretches were identified as suitable for dolphins (based on probability distribution score ≥0.50) (Table 2). Priority stretches were delineated and categorized based on the Gangetic dolphin's potential distribution map. About 37.39% (430 km) of the river stretches were designated as High Conservation Priority Stretches, followed by 9.57% (100 km) of river stretches as Moderate Conservation Priority Stretches, and 6.96% (70 km) of river stretches as Low Conservation Priority Stretches. Most of the CPS1 stretches were concentrated in the lower sections of the Rapti, Bagmati, and Mahananda rivers (Figs. 3 and 4), while the remaining CPS1 were located in the confluences of tributaries. Among the rivers with suitable habitat, the Mahananda River had the largest contiguous, suitable river segment spanning 170 km, accounting for 14.78% of the total predicted stretch.

4. Discussion

The dynamic hydrological and morphological characteristics of rivers and their physicochemical attributes contribute to high habitat heterogeneity, which plays a central role in determining the species occurrences (Ward, 1998). Unfortunately, most rivers in the GRB are now highly regulated, thus homogenous and offer limited biodiversity conservation potential (Pradhan et al., 2023). The growing human population in the Basin is predicted to further magnify human-induced stressors, such as agriculture, fishing, and mining during the dry season, making these rivers sub-optimal and less conducive for biodiversity conservation (Haidvogl, 2018; Schmutz and Sendzimir, 2018; Das et al., 2022). Unlike terrestrial ecosystems, the riverine system are more vulnerable and poised with challenges arising from conflicting resource use, direct human dependency and land use conflicts (Ledger et al., 2023). These effects are more conspicuous and cascading in small river systems (Dudgeon, 2000). In such circumstances, delineating areas of conservation significance in these small rivers holds potential for protecting and restoring local ecosystems and maintaining the integrity and health of entire river basins. The umbrella-species concept, advocating that conservation strategies crafted for one species can positively impact co-occurring species, has gained prominence as a framework for conservation planning (Branton and Richardson, 2011). Faced with constraints such as limited funding, knowledge, and time for action, conservation efforts often seek efficient strategies for biodiversity maintenance. The umbrella species concept, recently attracting increased attention, proposes using species requirements as a foundation for conservation planning. This concept serves as a tool for determining the minimum size of conservation areas, selecting sites for inclusion in protected area networks, and establishing minimum standards for the composition, structure, and processes of ecosystems (Roberge and Angelstam, 2004).

The study presents an insight into the distribution and abundance of the Gangetic dolphin and utilizes its presence location to identify conservation priority stretches in the lesser-known tributaries and sub-tributaries of the GRB. In the present study, we found that the Gangetic dolphin distribution, shows a reduction in its range, especially in the peninsular rivers, with the last recorded presence noted in 1998 (Sinha et al., 2000; Sinha and Kannan, 2014). On the basis of the present study and literature, we conclude that the Gangetic dolphin may have locally extirpated from Ken, Betwa and Sind rivers (Behera et al., 2014; Sinha et al., 2000). The encounter rate and distribution of Gangetic dolphins have decreased in the Girwa, and Rapti rivers (Table 3) (Behera et al., 2014; WWF-UPFD, 2015), whereas in Mahananda River encounter rate remains unchanged (Kelkar and Dey, 2021). Gangetic dolphin sightings were more frequent in the lower sections of the rivers, particularly near the confluences (Bashir et al., 2012; Choudhary et al., 2012).

The variations in encounter rates and distribution, especially local extirpation of dolphin from Ken, Betwa and Sind rivers, may be linked to substantial river development projects that resulted in flow alteration (Sinha and Kannan, 2014). Previous surveys were mainly restricted to small stretches where dolphin sightings were common, which could have skewed the results (Das et al., 2022, Paudel et al., 2015). Further, habitat loss related to increasing water demands, creation of physical barriers (Braulik et al., 2014; Aggarwal et al., 2020; Sonkar and Gaurav, 2020; Paudel and Koprowski, 2020), deliberate killing for oil (Kolipakam et al., 2020) and mortality in the fishing gears (Kelkar et al., 2010) may have contributed to these changes. The clustered presence and frequent sightings of dolphins in the downstream sections of rivers could be linked to the presence of optimum habitat such as adequate river depth, discharge, and the presence of meandering habitats which are preferred by dolphins. Variations in the sighting frequency of

Table 2
Delineation of the Conservation Priority Stretches (CPS) in the small rivers of the Ganga River Basin, India.

River	Length (km)	Predicted length (km)	CPS1 (km)	CPS2 (km)	CPS3 (km)
Girwa	20	20	5 (0.43%)	5 (0.43%)	0
Kauriyala	20	15	10 (0.87%)	0	0
Babai	85	75	10 (0.87%)	0	0
Sharda	455	220	30 (2.61%)	25 (2.17%)	0
Rapti	510	510	175 (15.22%)	70 (6.09%)	55 (4.78%)
Bagmati	395	60	50 (4.35%)	0	5 (0.43%)
Mahananda	285	250	150 (13.04%)	10 (0.87%)	20 (1.74%)
Grand total	1685	1150	430 (37.39)	110 (9.57%)	80 (6.96%)

The abbreviations used are as follows: 'CPS1' stands for High Conservation Priority Stretches, 'CPS2' represent Moderate Conservation Priority Stretches and 'CPS3' represents Low Conservation Priority Stretches.

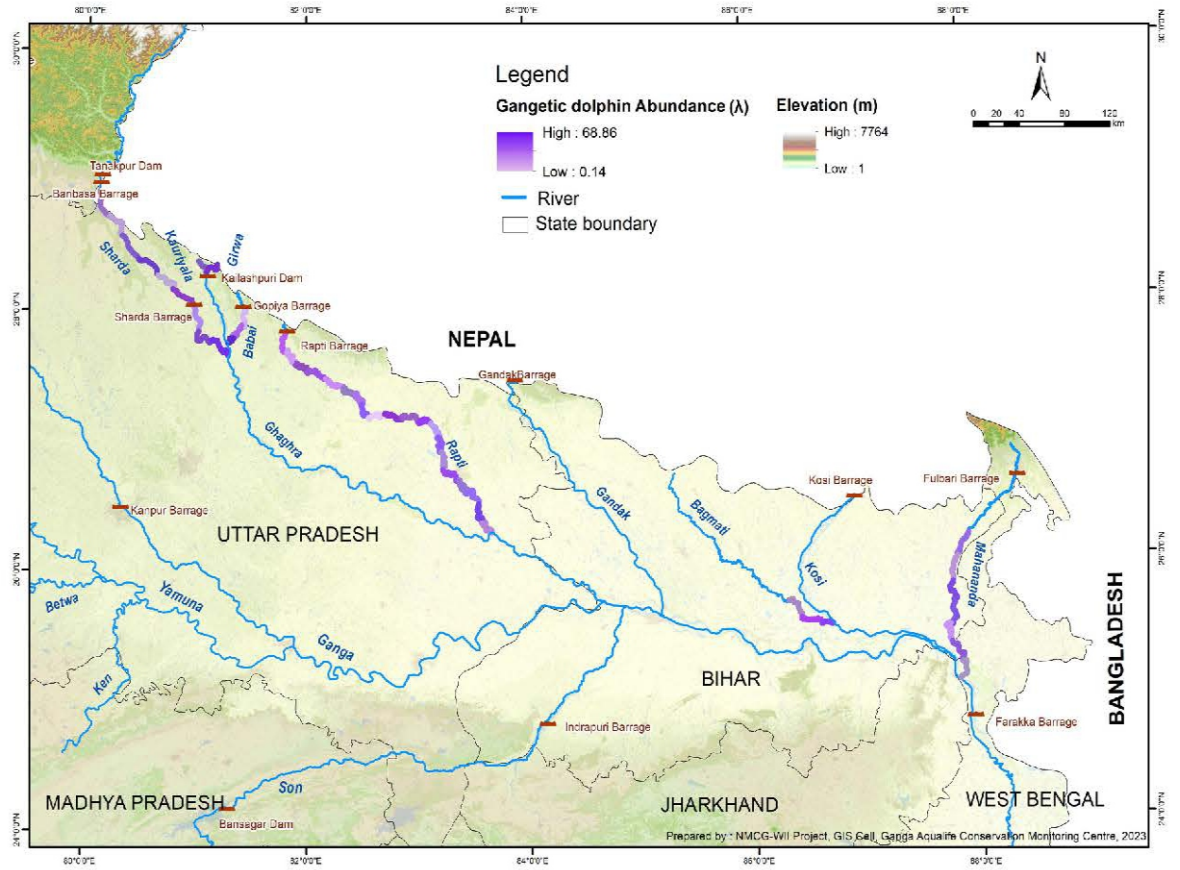

Fig. 3. Model-averaged estimates of Gangetic dolphin relative abundance (λ) (with 95% confidence intervals). Map was generated utilizing the highest-ranked model determined by AICc ranking.

Gangetic dolphin were noted along the studied stretch, with certain sections indicating an upsurge while others exhibited a decline (Behera et al., 2014; Choudhary et al., 2012; Das et al., 2022). In order to comprehend the plausible causes of these apparent increases, changes in barrage operations during the November 2022 survey may be a contributing factor. Sharda and Babai rivers, being alluvial, exhibit inherent dynamism in response to variations in water and sediment inputs during the monsoons (Midha and Mathur, 2014). During November, when there is less demand for irrigation water, the release of water from the lower Sharda Barrage located in Lakhimpur-Kheri to the main channel (Midha and Mathur, 2014) would have deepened the channel profile, potentially influencing dolphin estimates, as observed in our results. Similarly, in the Babai River, the Gopiya barrage's excessive discharge into the downstream river led to increased flows and channel depth during the survey period (Bhattarai, 2009). The river's inherent hydrological dynamics play a pivotal role in shaping the distribution of Gangetic dolphins, and alterations in hydrological processes are likely to impact dolphins spatial and temporal distribution (Braulik et al., 2014; Sonkar and Gaurav, 2020; Rai et al., 2023; Sharma et al., 2022).

The study provides a comprehensive assessment of the Gangetic dolphin populations in surveyed rivers, offering vital insights into the distribution and abundance of this iconic aquatic mammal in the region. The overall abundance estimates of the dolphin across these rivers revealed that small rivers hold 15% of dolphin population of the entire GRB (Table S8). Notably, the Mahananda and Rapti rivers contain 10% of the Gangetic dolphin population of the basin, and thus emerge as a vital dolphin stronghold. The Bagmati River also contributed significantly to dolphin population. Additionally, rivers like Kauriyala, Girwa, and Sharda displayed varying dolphin presence, underlining the need for tailored conservation strategies. Our findings highlight a significant difference in fishing intensity between the Mahananda and Babai rivers. Mahananda exhibited a higher fishing intensity at 38.64 ± 38.01 (mean ± SD) compared to Babai at 1.27 ± 1.79. Besides channel depth and the presence of meanders, fishing intensity emerges as another critical factor indicating the presence of an optimal prey base in the Mahananda River, influencing dolphin persistence.

Based on the results of the N-mixture model, channel depth and meanders emerged as significant variables influencing the relative abundance of dolphins. The average channel depth across the studied rivers was 3.03 m ± 2.71 (mean ± SD), while the Rapti and Bagmati rivers measured 3.36 m ± 2.85 and 5.25 m ± 4.37, respectively, significantly higher than the mean depth of all studied rivers. Moreover, the mean count of meanders per BEU across rivers was 1.11 ± 0.93, while the Rapti and Bagmati rivers had counts of 1.53 ± 0.95 and 0.83 ± 0.94, respectively. We would assume that this variation in depth and the presence of meanders in the Rapti and Bagmati rivers may have inflated the abundance estimates. However, during the peak dry period (March-May) when water discharge becomes limiting, fishing intensity may substantially affect dolphin persistence (Kelkar et al., 2010; Paudel and Koprowski, 2020;

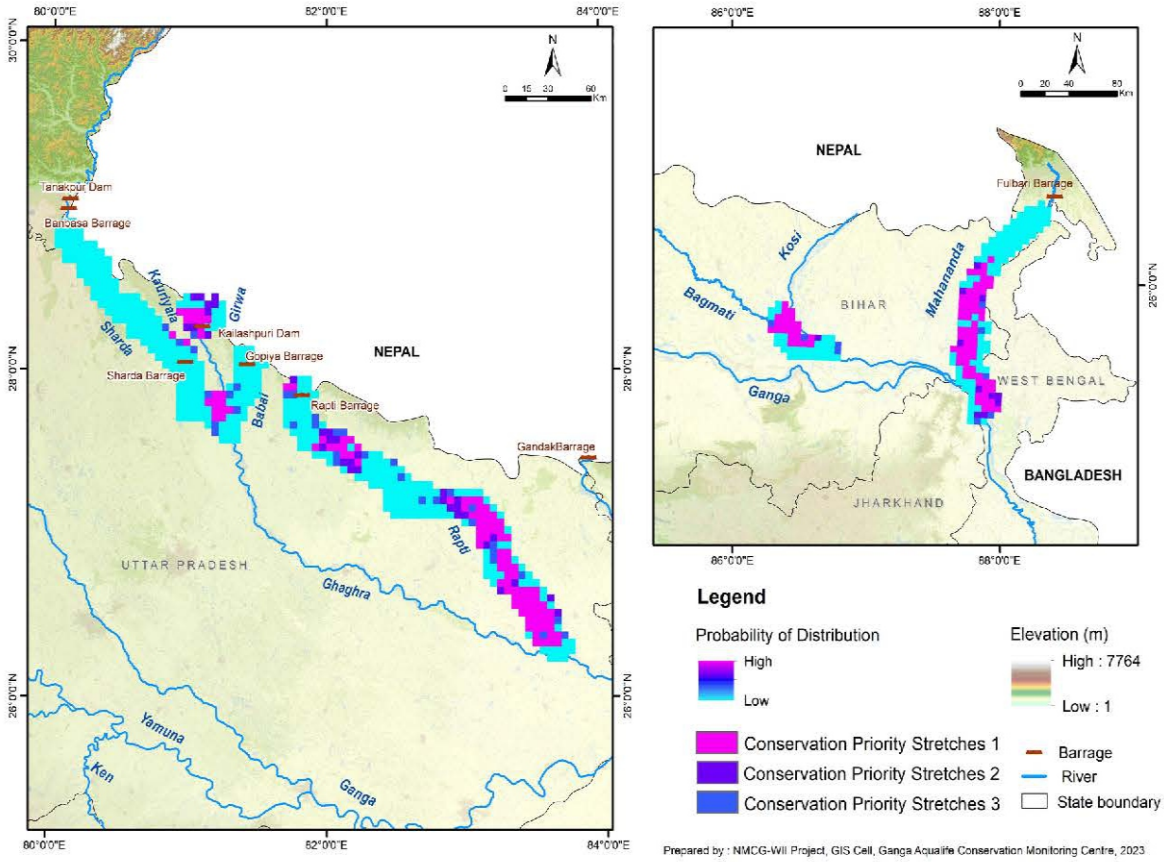

Fig. 4. Map showing Conservation Priority Stretches in the small rivers of the Ganga River Basin, India.

Samad et al., 2022).

Additionally, the lower stretch of the Bagmati River receives adequate discharge from the Kamla River and a distributary of the Kosi River to sustain dolphin population, as evident from the increasing depth as well as the high congregation of dolphins in the lower stretch of the Bagmati River. River systems exhibit inherent dynamism in response to variations in water and sediment inputs, with each element of their hydro-geomorphology playing a vital role in governing species distribution (Nestler et al., 2012). Given that the studied rivers originate from different sources and traverse through varied biogeographic regions and land-use classes are likely to influence species distribution beyond depth and width would contribute to dolphin occurrence. This is well-supported by our findings that the factor 'river' emerged as one of the contributing factors to dolphin abundance in the final model, indicating the complexity of riverine ecosystems and their influence on species distribution patterns. Our results underscore the importance of maintaining adequate dry season discharge and mitigating fishing activity in rivers such as Mahananda, Bagmati, and Rapti to sustain dolphin population and reduce competition from fishing activities. Additionally, the present study was conducted exclusively between November and February months, encompassing only the dry season. The impact of seasonal variations on the abundance of dolphins needs to be studied and considered when formulating conservation strategies. By incorporating data from different seasons, we can gain a more comprehensive understanding of the dynamics of dolphin populations and their habitats. Such consideration would offer valuable insights into formulating effective conservation strategies for Gangetic dolphins and their habitats.

The abundance estimate obtained using the N-mixture model and correction factors (D_{cf}) were comparable and hence provide support for the usability of these for abundance estimate of aquatic species. Nonetheless, the distribution and abundance of Gangetic dolphin were influenced by the availability of fish resources and the presence of deep pools in particular segments, despite the apparent uniformity in hydrological characteristics of these rivers (Bashir et al., 2010; Rai et al., 2023; Samad et al., 2022). Dolphin residing in small river stretches face heightened vulnerability due to their specific requirements within the environment, such as adequate water flow, which enables them to traverse deep pools, and hydraulic shelter to protect them from swift currents (Smith and Reeves, 2000; Smith et al., 2009). Our findings align with the observation that the predominance of Gangetic dolphins in rivers of moderate size within low-lying areas corresponds to their preference for habitats characterized by moderate annual average flow and greater depths. Although, the D_{cf} approach produced better Confidence Intervals (CIs) compared to the N-mixture models. In the absence of river-specific D_{cf} values, we utilized overall D_{cf} values derived from published literature conducted in various rivers with varying channel widths and depths. It is important to note that using an average across rivers may present a limitation, as detection rates may vary among rivers, potentially leading to biases in estimates. Therefore, we opted to apply the N-mixture model in this study,

Table 3
Past and present Encounter Rate of Gangetic dolphin in the Ganga River Basin, India.

River	River Segment	Survey length (Km)	Encounter rate	Year	Reference	Present study
						Encounter rate (SE)
Ganga	Haridwar barrage to Bijnor barrage	100	0	1996	Sinha et al. (2000)	0
	Bijnor Barrage to Narora Barrage	175	0.34	2010	Bashir et al. (2012)	0.33 ± 0.06
	Narora to Kanpur	300	0.01	2010	Behera et al. (2014)	0.05 ± 0.02
	Kanpur to Prayagraj	240	0.39	2012	Behera et al. (2014)	0.43 ± 0.09
	Prayagraj to Buxar	400	0.48	1997	Sinha et al. (2000)	1.7 ± 0.26
	Buxar to Manihari ghat	500	1.62	2006	Sinha et al. (2010a)	1.03 ± 0.14
	Manihari ghat to Farakka	90	1.64	1998	Sinha, (1999)	0.54 ± 0.12
	Farakka Feeder Canal	38.2	0.55	1996	Sinha et al. (2000)	0.06 ± 0.04
	Jangipur to Triveni Ghat	300	0.37	1995	Sinha, (1997)	0.10 ± 0.02
	Triveni ghat to Sagar Island	190	0.51	2008	Sharma, (2010)	0.38 ± 0.09*
Yamuna	Bareh-Prayagraj	400	0.07	2012	Behera et al. (2014)	0.12 ± 0.06
Chambal	Rajghat-Pachhnada	235	0.36	2012	Behera et al. (2014)	0.37 ± 0.12
Ken	Sindhan kalan village - Yamuna confluence	30	0	2012	Behera et al. (2014)	No sightings
Betwa	Orai - Yamuna confluence	84	0	2012	Behera et al. (2014)	No sightings
Sind	Yamuna confluence to 110 km upstream	110	0.04	1998	Sinha et al. (2000)	No sightings
Girwa	Pathrena-Girijapuri barrage	18	2.17	2012	Behera et al. (2014)	0.45 ± 0.17
Kauriyala	India Nepal border- Girijapuri barrage	15			NA	0.87 ± 0.47
Babai	Gopiya barrage-Ghaghra confluence	75			NA	0.05 ± 0.04
Sharda	Sharda barrage-Palia	100	0	2001	Sinha and Sharma, (2003b)	0.03 ± 0.02
Ghaghra	Girijapuri barrage-Chhapra	630	0.52	2012	Behera et al. (2014)	0.54 ± 0.08
Rapti	Ghaghara confluence to 30 km upstream	30	0.26	2012	Behera et al. (2014)	0.18 ± 0.04
Son	Bichhi-Doriganj	130	0.08	1998	Sinha et al. (2000)	No sightings
Gandak	Valmiki Nagar-Ganga confluence	295	0.77	2010	Choudhary et al. (2012)	0.36 ± 0.05
Bagmati	Jagmohra- Badlaghat				NA	1.13 ± 0.24
Kosi	Kosi Barrage-Kursela	235	0.42	2001	Sinha and Sharma, (2003)	0.76 ± 0.13
Mahananda	Balubari ghat- Jankiramtala	250	0.76	2021	Kelkar and Dey, (2021)	0.73 ± 0.1
Rupnarayan	Bander-Gadiara	80	0.42	2006	WWF Nepal, (2006)	0.68 ± 0.17

as it considers imperfect detection and allows for the straightforward identification of explanatory variables affecting abundance (λ) and detection (p). Additionally, it provides independent estimates for each site, which are comparable to the D_{cf} approach derived from capture-mark-recapture methods (Courtois et al., 2016; Ficetola et al., 2018; Royle, 2004). Despite other sampling methods being available, such as capture–recapture and distance sampling, the minimal data collection effort and cost-effectiveness of the N-mixture model make it a preferred choice for the present study (Dennis et al., 2015).

These lesser-known rivers are home to more than 15% of the Gangetic dolphin population, supporting previous findings that these small rivers function as refuges for macrofauna, support habitat diversity and species assemblage (Bouska et al., 2023; Pracheil et al., 2013). This proffers the importance of protecting these rivers for biodiversity conservation and functioning of the ecological processes. Furthermore, the species distribution model provided valuable insights into the distribution of dolphins across the Ganga Basin. Bioclimatic, hydrological and human-induced stressors emerged as significant determinants of Gangetic dolphin distribution. The predicted probability distribution encompassed a substantial stretch of 1150 km, representing both historical and current ranges of the species. Notably, approximately 54% (620 km) of the river stretches, accounting for 22% of the priority stretches in the Ganga Basin, were deemed suitable for dolphins, underscoring the significance of these stretches for dolphin persistence (Table S9). Bioclimatic variables that significantly influence the distribution of Gangetic dolphins, such as Annual Mean Temperature, Isothermality, and Temperature Seasonality, were found to play pivotal roles. This underscores the importance of considering climatic factors in understanding the habitat preferences and distribution patterns of the species, particularly during water-scarce periods. Interestingly, similar to the findings of previous studies (Choudhury et al., 2019; Sinha and Kannan, 2014), we also observed a high suitability near the confluence areas. Tributary confluences are significant, not just due to their ability to modify environmental conditions and trigger a biological response upon merging with the main channel (Benda et al., 2004; Fernandes et al., 2004; Rice et al., 2008), but they also represent areas of inherent ecological importance, concentrating specific biophysical processes and ecosystem services (Kiffney et al., 2006; Rice et al., 2008). The high suitability of the confluence areas underscores the significance of these regions in the conservation of the Gangetic dolphin. (Choudhary et al., 2012; Das et al., 2022; Kelkar, 2008). The suitability, translated into potential conservation priority stretches, represents a valuable resource for managers and policymakers, by allowing for concentrated efforts aimed at preserving the biodiversity and ecological integrity of the riverine ecosystem.

Identification of the priority river stretches is one of the most important tenets of the systematic conservation planning, which is followed by monitoring of spatial and temporal biodiversity changes, implementing stringent measures to reduce pollution, enforcing sustainable fisheries management practices, implementing measures to safeguard and restore riverine habitats, engaging local

communities and stakeholders participation, awareness programs to enhance understanding about the importance of biodiversity conservation, consideration of socio-economic aspects and potential conflicts between conservation goals and human activities and ensuring alignment with existing conservation laws and policies, along with implementation of new protective measures (Hermoso et al., 2012; Bond et al., 2014; Linke et al., 2019). Addressing these points makes systematic conservation planning a more effective and inclusive process, contributing significantly to the long-term protection of biodiversity and ecosystems. Conservation prioritization of the rivers in the GRB will aid in allocating resources and efforts where they are most needed and where they will have the greatest impact. Such an approach will ensure that conservation efforts are efficient and targeted, addressing the most critical areas first and gradually extending protection to other priority stretches as resources permit. Overall, our approach focuses on preserving the integrity of the priority stretches, as was also recommended in our prior study (Das et al., 2022), which will contribute to the overarching goal of a basin-wide conservation strategy.

5. Conclusions

In the Indian context, the riverine species particularly crocodylians started getting attention in early-1970s (Sharma et al., 2021). However, the conservation of riverscapes and other aquatic species received little attention. The previous efforts to document the aquatic species were limited to the globally known larger rivers such as Ganga, Brahmaputra, and Indus (Dudgeon, 2000). The flagship initiative, 'National Mission for Clean Ganga' by the Ministry of Jal Shakti, Government of India, represents a pioneering effort to develop an integrated basin-wide river restoration strategy through maintaining river habitat and aquatic biodiversity. Yet, the lesser-known smaller rivers, despite their key role in the ecological process received no or very little attention (Richter et al., 1997). The present study provides evidence of smaller rivers as refuges for Gangetic dolphin, thereby supporting the theory that these smaller rivers contributing to the resilience of larger rivers. This contribution is apparent through the presence of a habitat mosaic, diverse species assemblages, and the provision of freshwater inputs. The findings are crucial as a baseline for India's ongoing range-wide population estimation exercise in India and serve as a precedent for future assessments and studies in the region. The establishment of this baseline for the Kauriyala, Babai, and Bagmati rivers sets a precedent. It encourages further research, monitoring efforts, and proactive conservation initiatives in coordination with the State Department of Environment, Forests, and Climate Change and the National Mission for Clean Ganga (NMCG) to safeguard the river's biodiversity, in line with the systematic conservation planning. Community support needs to be harnessed to ensure successful conservation, especially in areas where dolphins are frequently encountered near villages. Linking local concerns about flood erosion, embankments, and livelihood security to biodiversity conservation programs can be a strategic approach to engage and garner support for river conservation efforts.

CRediT authorship contribution statement

Goura Chandra Das: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **Aftab Alam Usmani**: Data Curation. **Surya PrasadSharma**: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis. **Srijani Guha**: Visualization. **Sk Zeeshan Ali**: Visualization. **Shivani Barthwal**: Supervision, Writing – review & editing. **Arkojyoti Sarkar**: Data Curation. **Neeraj Mahar**: DataCuration. **Ajay Rawat**: Data Curation. **Gokulakrishnan. G**: Data Curation. **Javed Anwar**: Data curation. **Sandeep Kumar Behera**: Writing – review & editing, Supervision. **Ruchi Badola**: Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Syed Ainul Hussain**: Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgments

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2024.e02900.

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Prioritising river stretches using multi-modelling habitat suitability of Gangetic dolphin (*Platanista gangetica*) as a flagship species for aquatic biodiversity conservation in the Ganga River Basin, India

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ABSTRACT

Globally, the river ecosystems are threatened due to human-driven exploitation and indiscriminate resource use. The rate of species loss is a magnitude higher in these ecosystems, hence, identifying conservation priority areas as refugia, using the flagship-cum-indicator species approach can aid in long-term conservation of multiple species and ensure uninterrupted functioning of ecological processes. For effective conservation planning, we derived the site occupancy and abundance of Gangetic dolphin (*Platanista gangetica*) as a flagship species in the Ganga River Basin, and modelled their distribution *vis-à-vis* river conditions for identifying Conservation Priority Stretches (CPS). The study incorporates the first-ever basin-wide (4635 km river) Gangetic dolphin (GD) sightings to estimate range decline, abundance, and identify CPS of select rivers in the Basin. A total of 2151 sightings of surfacing dolphins with mean encounter rate of 0.55 ± 0.09 sightings/km of the river was observed from the surveyed stretch. The GD encounter rate varied significantly across the surveyed rivers (Analysis of Variance, F 3.08, $p < 0.001$). We estimated 24.37 % decline in the dolphin distribution range in the basin since 19th Century. The estimated population size of the dolphin in the Basin was 3330 individuals ± 620 individuals (Confidence Interval 95 % 2304–4668; Coefficient of Variance 18.61) which varied across the river. The site occupancy and abundance were best predicted by channel depth (β 0.82 ± 0.46), meanders (β 02.56 ± 0.87) and individual rivers, whereas channel width (β 0.11 ± 0.08) and survey efforts influenced detection probabilities. Further, we identified 610 km (12.2 %) of river stretches as high CPS in the Basin based on the prediction probability (≥0.70) of GD. Protection of these stretches is likely to ensure sustained reproduction of GD and provide refugia for other threatened species of the Ganga River and its tributaries, which is under increasing anthropogenic pressure.

1. Introduction

Freshwater ecosystems such as rivers, streams and associated wetlands are an integral component of the global water cycle, flow regulation, and effective functioning of associated ecosystems (Matthews, 2016; Grantham et al., 2019). The freshwater ecosystem comprises less than 1 % of the Earth's surface yet has the most diverse habitats, species, and biodiversity (Dudgeon et al., 2006). Besides, the freshwater ecosystems represent 9.5 % of all faunal species and harbour approximately 6 % of all described species and a third of all vertebrate species globally (Balian et al., 2007; Strayer and Dudgeon, 2010). These vital ecosystems are threatened by several human-induced factors, such as rapid infrastructure development, widespread habitat degradation, pollution, and hydrological alteration due to dams and barrages (Alizadeh et al., 2018; Alvarado et al., 2021; Kouadri et al., 2021). The upsurge in river infrastructure developments has disrupted longitudinal connectivity causing fragmentation leading to biodiversity loss and threatening ecosystem functioning (Dudgeon, 2000; Guo et al., 2019). Furthermore, the unprecedented impacts of these factors have potentially affected migration, breeding biology, habitat use pattern and has resulted in

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population isolation of many freshwater species (Strayer and Dudgeon, 2010; Boscari et al., 2022). Additionally, rivers are vulnerable to global climate change associated uncertainties of precipitation and temperature patterns, which would worsen rivers' hydrological conditions (Schneider et al., 2013). The impact of climate change is likely to have an irreversible cascading impact on thousands of freshwater species that are currently on the verge of extinction (Vörösmarty et al., 2010). Consequently climate change impacts have drastically modified trophic interactions and altered prey species distribution, limiting the top predators' physiological and biological requirements (Learmonth et al., 2006; Wynn et al., 2007).

River systems in Asia are considered among the most dynamic and threatened ecosystems (Dudgeon, 2000, 2002), as more than half of the global human population resides in 13 % of the world's land mass (Hannah et al., 1994). The rate of biodiversity loss is a magnitude higher in tropical rivers of Asia due to escalating human demands on the river ecosystems (Guo et al., 2019). The Ganga Basin (henceforth, GB) is the largest river basin in India, which supports ~650 million people and rich aquatic biodiversity, is experiencing increased human footfall leading to population declines and range reduction of riverine biota inhibiting vital ecological processes (Nautiyal, 2010). In a nutshell, despite the high ecological significance of the GB, socio-political demands, development and religious activities, and economic feasibility have become major obstacles in developing a comprehensive and systematic conservation plan for the basin. In the current epoch of Anthropocene, biodiversity conservation has become the world's most essential shared responsibility (Sun et al., 2022). The flagship species approach can be instrumental in invoking this shared responsibility. In recent years, the flagship species approach has gained much support and acceptance as a management tool for starting point to monitor biodiversity changes and developing conservation plans (Kim et al., 2021). The flagship species are relatively large, top predators, charismatic vertebrates that can significantly promote environmental awareness (Barua et al., 2011). Consequently, flagship species are explicitly perceived as 'umbrella' species in identifying protected areas, assuming their conservation will confer appropriate protection to other species (Piatt et al., 2007; Sergio et al., 2008).

The Gangetic dolphin (*Platanista gangetica*), (henceforth, GD) was first scientifically documented in the year 1801 by Heinrich Julius Lebeck (Lebeck, 1801; Kinze, 2000). Earlier the GD was considered a sub-species of the South Asian River dolphin. However, a recent phylogenetic study revealed GD as a distinct species from the Indus River dolphin (*Platanista minor*) (Braulik et al., 2021). The GD is a top predator that influences the food chain structure, thereby plays a critical role in maintaining the vital ecological processes of the river ecosystems and serve as a potential indicator for monitoring status of river health (Gomez-Salazar et al., 2012; Turvey et al., 2012; Sinha and Kannan, 2014). Its extirpation from river systems serves as a tool to measure the extent of human footprints exploiting riverine resources (Sinha et al., 2010; Sinha and Kannan, 2014; Behera et al., 2014). Once commonly distributed in major river systems between longitudes 77° E and 89° E in India, Nepal and Bangladesh (Anderson 1879, Smith, 1993; Mohan et al., 1997), the species is now restricted to disjunct stretches of the Ganga-Brahmaputra-Barak river system in India (Wakid, 2009; Behera et al., 2014; Sinha and Kannan, 2014; Choudhury et al., 2019), Karnali, Sapta Koshi and Narayani river systems in Nepal (Shrestha, 1989; Paudel et al., 2015) and Meghna, Karnaphuli and Sangu river systems in Bangladesh (Reeves et al. 2000; Smith et al. 2006). The GD is now isolated into small groups and is under severe threat due to a wide array of factors such as flow modification, habitat degradation, prey depletion, noise pollution, poaching and net entanglement (Dey et al., 2019; Paudel and Koprowski, 2020: Kolipakam et al., 2022). Owing to these threats, the GD experienced a ~30 % decline in its population (Paudel and Koprowski, 2020) and a range reduction between the late 19th and early 21st century (Mohan, 1989; Shostell and Ruiz-García, 2010; Sinha and Kannan, 2014).

The species in the past has attracted multiple conservation efforts; the Government of India has accorded utmost protection to the species by including it in Schedule I of the Wild Life (Protection) Act, 1972, since its inception in 1972 (Sinha and Kannan, 2014). The species has been listed in the Endangered category in the International Union for Conservation of Nature Red List of Threatened Species since 1996 (Kelkar et al., 2022). To prohibit international trade, the species was enlisted in Appendix I of the Convention on International Trade in Endangered Species (CITES) and in Appendix II of the Convention on Migratory Species (CMS). To further strengthen its conservation, the Government of India has declared GD as the National Aquatic Animal of India with a clear mandate of spreading awareness among local communities to protect and conserve GD and its habitats.

Despite these efforts, the information on current distribution, abundance and factors affecting GD is limited, and information on their distribution from previous studies are from specific short stretches and in different time scales (Behera et al., 2014; Sinha and Kannan, 2014; Chowdhury et al., 2016). Hence, there is little comprehensive information on the status of the GD from its range, which is crucial for the long-term conservation of this species. Moreover, information on the extent of suitable habitats for the GD in many parts of its range in India is lacking, which hinders conservation planning. Additionally, it is paramount to configure the impacts of climate change on the distribution of the GD (Paudel and Koprowski, 2020).

In the present study, we aimed to assess the occurrence, population status, and habitat suitability of GD in GB, India, to address the following research questions (a) what is the current distribution range of GD in the basin? (b) What is the current population status of the GD in the riverscape of the GB? (c) What is the extent of occupancy of the GD in the basin? (d) What factors influence site occupancy and abundance of GD across the basin? and (e) What is the extent of best suitable areas available in the basin for the conservation of GD as an indicator species, which ultimately may improve overall river conservation in GB.

The GD and other large vertebrates such as crocodiles are the large predators found in the GB and are potential flagship species. However, the basin wide distribution of GD and its greater hydrological requirements compared to other predators in the basin makes it an ideal choice as a flagship species. It provides ample data points required for increased efficacy and to draw reliable inferences. Large-scale visual encounter survey data was employed to assess the status of GD and their site use across riverscape in the GB. We used an occupancy framework to delineate the proportion of the riverscape used by GD and evaluate how suites of environmental and anthropogenic predictors influence their site use. We then derived the abundance of GD using N-mixture models and evaluated factors influencing the abundance. We also administered a flagship-cum-indicator species based systematic conservation planning approach to identify priority stretches for effective GD conservation. The identification of conservation priority stretches of the Ganga River and its tributaries is likely to enable the policymakers and managers to develop basin-wide conservation and restoration plans. This will be in line with India's international commitment to the United Nations Decade on Ecosystem Restoration.

2. Materials and methods

2.1. Study area

The present study was conducted in the Ganga River and its major tributaries *viz*. Yamuna, Chambal, Ghaghra, Son, Gandak, Kosi and Rupnarayan to record the sightings of the GD (Fig. 1). The GB alone drains an area of 8,61,404 sq. km (≥26 %) of India's geographical area (Dwivedi et al., 2018). The GB is surrounded by the great Himalayas in the north, the Chota Nagpur plateau and Vindhyas in the south, Aravalli range in the west, and the Brahmaputra Ridge in the east, which has given rise to climatic, topographical and hydrological variations (CWC, 2014). The hydrological regime also varies across seasons, with reduced

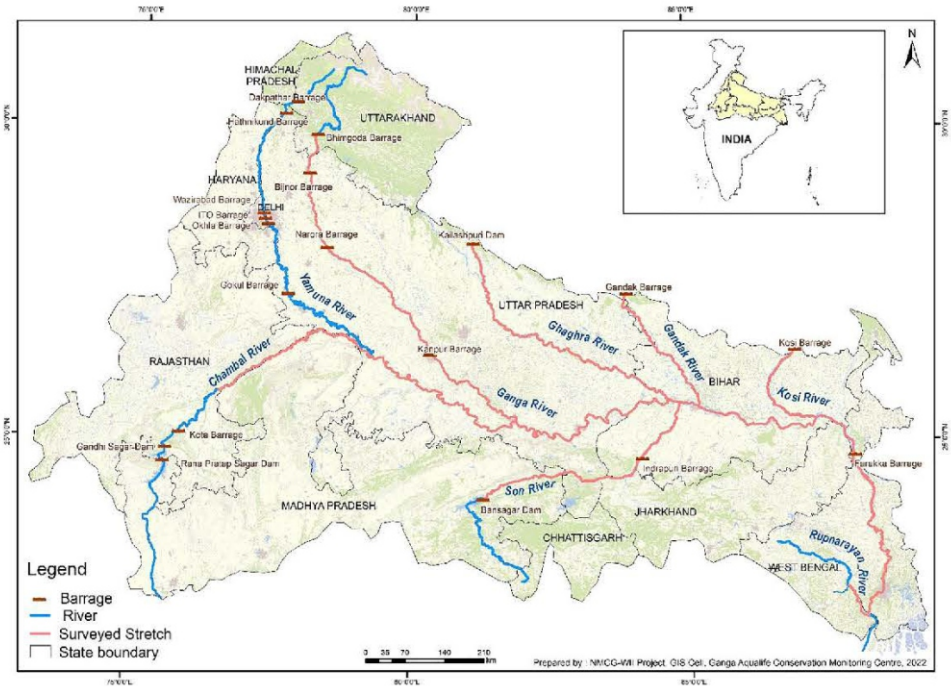

Fig. 1. Map of surveyed rivers for Gangetic dolphin in the Ganga Basin, India.

flow occuring between winter and summer and the highest river discharges recorded during the monsoon. The wide range of geomorphological and hydrological variations provides a mosaic habitat suitable for diverse flora and fauna (Hussain et al., 2020; Sonkar and Gaurav, 2020). The GB is one of the most densely populated regions of the world (>1400 individual/km^2). The high human density results in higher demand of water for agriculture, industry, electricity generation and navigation. Sand mining, unplanned developmental activities and point and non-point source discharge have further degraded the river habitat including water quality (Hussain et al., 2020; Dagar et al., 2021).

The GB is spread across 11 Indian states and lies within five distinct biogeographic zones, *viz*. Himalaya (North-West Himalaya 2A and West Himalaya 2B), Semi-Arid (Punjab Plains 4A and Gujarat Rajputana 4B), Deccan Peninsula (Central Highlands 6A and Chota Nagpur Plateau 6B), Gangetic Plain (Upper Gangetic Plain 7A and Lower Gangetic Plain 7B) and Coasts (East Coast 8B) (Rodgers and Panwar, 1988; CWC, 2014). The climate of the GB varies from alpine, temperate, to sub-tropical and tropical. The annual mean precipitation ranges from 500 mm to 2500 mm, and ~80 % of the precipitation occurs between June and September (Nandargi and Shelar, 2018).

In the GB, we studied eight major rivers through literature survey and field sampling (Supplementary Fig. S1). Of these, Ganga, Yamuna, Ghaghra, Gandak and Kosi are snow fed, whereas the Chambal, Son and Rupnarayan are rain fed. The smaller tributaries such as Girwa, Sharda, Rapti and Mahananda were not surveyed due to logistical constraints even though GD were reported from these rivers. Brief description of studied rivers has been provided in the supplementary information (Supplementary Table S1).

2.2. Data collection

We surveyed 4635 km of the rivers, *viz*. Ganga (2070 km), Yamuna (435 km), Ghaghra (615 km), Gandak (295 km), Kosi (235 km), Chambal (405 km), Son (500 km), and Rupnarayan (80 km) for their ecological condition *vis-à-vis* occurrence of GD using boat based visual encounter survey between 2020 and 2021 (Smith and Reeves, 2000; Sinha and Sharma, 2003a) (Fig. 1).

Each of the surveyed rivers were divided into 5 km segments referred to as Biodiversity Evaluation Unit (BEU) in ArcGIS 10.2 (ESRI, Redlands, USA). We collected information on five hydro-morphological and four anthropogenic variables at 1 km intervals, which were averaged for each BEU (Supplementary Table S2). The surveys were conducted during post-monsoon (November to February) season in daylight between 8:00 hrs to 12:00 hrs and 15:00 to 17:00 hrs using an inflatable rubber (25 hp)/country boat following thalweg (deeper part of the river) (Oliveira et al., 2017). The speed of the boatin was kept constant at 6–8 km/hr to avoid missing any sightings of surfacing GD. A team of four trained observers equipped with binoculars (NIKON 8 × 42), GPS (GARMIN e-Trex 30), depth sounder (HONDEX PS7), and range finder (HAWKE Endurance LRF-1000), were stationed at the front of the boat to obtain concurrent least counts of GD sightings and associated habitat variables following Smith et al., (2006). In each team, three observers were responsible for looking for surfacing GD, and the fourth observer for recording associated habitat variables at each sighting.

Habitat parameters such as channel width (m), efforts (duration of time spent in each BEU), time (time of the day), channel depth (m), water flow (m^3/sec.), river slope (degree), number of meanders (meanders/BEU), fishing intensity (active nets and boats/BEU), sand mining intensity (mining boats/BEU) as well as anthropogenic factors were recorded within each BEU (Supplementary Table S2).

2.3. Data analysis

2.3.1. Distribution and range decline

The decline in species' historical range and understanding the associated causes is central to species conservation and management. The decline is often measured through distribution or abundance changes (Gaston et al., 2000, Uzqueda et al., 2020). The use of reduction in distributional area is useful when there is no abundance data available but sufficient historical occurrence records exist (Shaffer et al.,

1998). To estimate the range decline in the GB, dolphin sighting records from recent surveys (2020 and 2021) and previous records of GD occurrences were obtained from the literature (Behera et al., 2014, Sinha and Kannan, 2014) and compared. Further, the local extinction was confirmed when it was not encountered/reported in a particular river for more than ten years' time frame (Mitra and Chowdhury, 2018). Potential hydro-morphological variables and encounter rate of GD (sightings/ km linear stretch), were evaluated for inter-river variation using Analysis of Variance (ANOVA) test (Supplementary Text S1).

2.3.2. Site occupancy and abundance

In ecological modelling, regression-based approaches such as Generalized Linear Model (Rushton et al., 2004) and Generalized Additive Models (Leathwick and Whitehead, 2001) are frequently used to evaluate species association with environmental and/or habitat variables (Guisan and Zimmermann, 2000; Rushton et al., 2004). However, these approaches do not estimate site-specific species occurrences. Unlike these approaches, models based on occupancy frameworks can produce unbiased estimates of occupancy (Ψ) and provide insights into the habitat use of a species simultaneously considering detection probabilities (p) (Mackenzie et al., 2002). The occupancy model also allows the inclusion of covariates to explain heterogeneity in both occupancy and detection probability (Mackenzie et al., 2006).

Selecting an appropriate method for population estimation is challenging, particularly for species having low detection probability, such as the GD. The occupancy models take into account detection and non-detection over multiple surveys of a sampling site to estimate detection probabilities (p) to derive unbiased estimates of occupancy (Ψ) (Mackenzie et al., 2002). Here, we used site occupancy models in maximum-likelihood frameworks to determine the probability of site use (MacKenzie et al., 2002), and the N-mixture model (Royle, 2004; Kéry and Royle, 2015) to estimate abundance (λ) of the GD in GB using spatial replicate counts while accounting for imperfect detection. *Platanista gangetica* and *Platanista minor* being identical in their external appearance, have similar physiological requirements (Smith and Braulik, 2009), and thus mean home range of the *Platanista minor* was used as a surrogate for designing the length of the sampling sites for the present study (Toosy et al., 2009). The GD is assumed to have a maximum daily movement of ~25 km given the river stretches are characterized by intermittent shallow and deep pools. Secondly, a linear river stretch of 25 km can be easily surveyed for GD detection within a day without any logistical constraints with a vessel speed of 6–8 km/ hrs. The surveyed stretch of 4635 km was split into 927 BEUs that were considered as spatial sub-units to assess the extent of site use of the GD. Five adjacent BEUs (sampling sites of 25 km) were considered as spatial replicates to accommodate it in site-occupancy and N-mixture framework (MacKenzie et al., 2002; Charbonnel et al., 2014; Searle et al., 2020). We chose a length of 25 km as the best compromise between the need to detect the presence of a species and that of having more than three spatial replicates, as recommended by Hines et al. (2010). Double counting of GD due to overnight movement from surveyed to non-surveyed segments was considered, assuming an equal probability of GD being missed due to opposite-direction movement (Braulik, 2006).

We used 156 sampling sites out of 185 as we did not record GD sightings in the surveyed stretch of the Son River, 180 km stretch of the Chambal River between Pali and Dang Basai and 70 km stretch of the Ganga River between Bhimgoda and Bijnor barrages. For deriving siteoccupancy, the dolphin presence/absence at each spatial unit and the covariates that may influence occupancy and detection probability were included in the analysis (MacKenzie et al., 2006). The covariates were selected based on a *priori* understanding and literature search that may influence the occurrences of GDs (Kelkar et al., 2010; Choudhary et al., 2012; Paudel et al., 2015). The detection covariates are presumed to influence the likelihood of detecting a species, given its presence at a site (p). We considered channel width, effort, and time of the surveyed day as detection covariates for both site occupancy and N-mixture modelling, assuming these variables would influence the detection of a GD given its presence at a site. Site covariates are factors that are hypothesised to influence the probability of a species' site occupancy (ψ). The same suite of variables were selected for estimating abundance (λ) using N-mixture models (Supplementary Table S2). Each of the continuous covariates were z-standardized before analysis and categorical variables were dummy coded following Sunarto et al. (2012), Searle et al. (2020). Variables were checked for multicollinearity using Pearson's correlation test, and variables having Pearson's correlation coefficient ≥ 0.70 were excluded from the analysis following Graham (2003). Additionally, the GD count, along with covariates influencing the abundance, was included in the N-mixture modelling.

In this study, site occupancy models (MacKenzie et al., 2002) were used with detection and non-detection data using the "unmarked" package's 1.2.5 *occu ()* function (Fiske and Chandler, 2011). A multistage modelling approach was adopted, in which covariates influencing detection probability *p* were run first, keeping the occupancy probability Ψ constant. Then, using multivariate occupancy models, we investigated whether environmental covariates influenced detectability (Supplementary Text S2).

The N-mixture model was performed using the *pcount ()* function in "*unmarked*" package in R version 4.1.3 (Fiske and Chandler 2011; R Development Core Team 2022), using R Studio version 2022.02.3 (RStudio Team 2022). We fitted the N-mixture models, combining all the spatial counts data with Negative Binomial distributions (Joseph et al., 2009; Knape et al., 2018) as it allows for modelling over dispersion data with significantly fewer true zeros in the dataset (Wenger and Freeman, 2008; Barão-Nóbrega et al., 2022). We used a numeric upper bound value for K for abundance estimates following multiple trials without affecting the model outcome (Fiske and Chandler, 2011; Kéry and Royle, 2015; Barão-Nóbrega et al., 2022). Models were ranked based on their Akaike Information Criterion (AIC) scores (Akaike, 1974; Burnham and Anderson, 2004) (Supplementary Text S3). The predictor variables associated with top-ranked univariate model were evaluated to determine GD habitat use (Ψ). We then modelled covariates hypothesised to affect detection (p), channel width, effort and time using a global model considering remaining habitat use covariates constant. A final model set was generated for all possible additive combinations of detection and site use covariates with ΔAICc < 2, representing models with substantial empirical support. The goodness of fit for the most parameterized and highest-ranked models were assessed following Mackenzie and Bailey's goodness of fit test (MacKenzie and Bailey, 2004).

The AICc weights of all models in the final model set, in which the covariate appeared, were summed to assess the overall importance of the covariates (Burnham and Anderson, 2004). The sign of the covariate's beta coefficient estimates represented the direction of impact, and only if the beta coefficient's 95 % confidence interval ($\beta \pm 1.96 \times$ SE) did not overlap zero, the effect of covariates was deemed significant. The predicted probability of site occupancy for each site was obtained via model averaging the final model set using the package MuMin (Bartoń, 2013). The sum of squared errors, chi-square, and freeman-tukey tests were used to evaluate the goodness of fit for the top-ranked model and the model with the most parameters in the final model set.

2.3.3. Abundance estimation using correction factor (D_{cf})

GD rely upon their surfacing, however, there is a chance of missing few individuals during the survey. Correction factor for missing/unmarked individuals is an essential precursor to estimate population figure precisely (Vu et al., 2018). Thus, correction factor (D_{cf}) was derived using detection probability extracted from published work conducted in the rivers in the Indian subcontinent and was used as an index to verify the outcome of our model-based results. The mean correction factor for GDs was derived from various studies (Supplementary Table S3). D_{cf} account for missed individuals while conducting

visual encounter surveys (Smith et al., 2006; Richman et al., 2014). The D_{cf} for GD was derived by dividing 1 by detection (p̂) and the corrected population estimates of GD were calculated by multiplying D_{cf} by the total number of GD sightings obtained during the visual encounter survey.

$(D_{cf}) = 1/(\hat{p})$, where (D_{cf}) is the correction factor for GD estimates and p̂ is the detection probability.

2.3.4. Conservation priority stretches (CPS)

Scholars have identified conservation priority areas using either species or habitat, or both (Asaad et al., 2017; Maire et al., 2017). The species-based criteria include species of conservation significance, restricted-range species, biological diversity, and areas important for life history stages (e.g. Stewart et al., 2022; Banerjee et al., 2022), and habitat criteria includes unique and rare habitats, fragile and sensitive habitats, ecological integrity, and representativeness (e.g. He et al., 2018). These criteria were further categorized as five factors (habitat cover, species attribute, species richness, geographic range, and species abundance) for identification of priority areas (Assad et al., 2017). We have used flagship-cum-indicator species based approach for identification of conservation priority stretches, which essentially includes species of conservation significance, and ecological integrity criteria. These two criteria represent the four factors suggested by Assad et al. (2017), which makes our approach robust.

We used Maximum entropy (MaxEnt, version 3.4.4) models to predict the potential distribution and to identify conservation priority areas in the GB (Phillips et al., 2017). MaxEnt models are based on the principle of maximum entropy that accounts for presence-only data of rare or threatened species with environmental variables (Elith et al., 2006; Phillips et al., 2017; Clements et al., 2012; Kramer-Schadt et al., 2013) to project future distributions under global climate change impacts (Hu and Jiang, 2011) and considered as one of the efficient models for predicting species distribution models. There are many other well established species distribution modelling approaches such as Generalised Additive Models, Genetic Algorithm for Rule-set Prediction (GARP) and BIOCLIM that uses presence only data. MaxEnt has an advantage over them, as it has a higher predictive accuracy (Elith et al. 2006, Wisz et al. 2008). MaxEnt is suitable for simple as well as complex models with wide array of predictor variables. However, it can produce biases due to over-fitting of the models and influence the predictive performance when using large set of predictor variables (Phillips and Dudík, 2008).

A total of 758 presence locations of GD were used for distribution modelling. We selected 28 variables (Bioclimatic = 19, hydro-morphological = 5, and anthropologic = 4) based on *a priori* understanding of the species ecology and literature search for species distribution modelling using MaxEnt (e.g. Kelkar et al., 2010; Choudhary et al., 2012; Paudel et al., 2015). The bioclimatic layers were downloaded from WorldClim version 2 at a spatial resolution of 2.5 arc minutes (~4.5 km^2) (Fick and Hijmans, 2017) and resampled at 5 km^2 to have a uniform spatial resolution. Each of these variables were checked for multicollinearity, and highly correlated (Pearson correlation $\geq$ 0.70) variables with low ecological influences were removed from the modelling (Zuur et al., 2010).

Finally, presence location of GD, along with 16 uncorrelated ecologically meaningful variables (Bioclimatic = 7, hydro-morphological = 5, and anthropologic = 4) were used to predict the suitable habitat of the species using MaxEnt (Supplementary Table S2). Two key user-modifiable parameters influence the predictive performance of the MaxEnt, *viz.* feature classes and regularisation multipliers (Elith et al., 2010). These parameters were optimized to prevent model over-complexity and/or overfitting. We experimented with multiple combinations of feature classes (L = Linear, Q = Quadratic, P = Product, T = Threshold and H = Hinge) and regularization parameters (0.5, 1.0, 1.5 and 2.0). The models were ranked based on AIC to obtain the best-fit model. The ASCII file of prediction probability was projected to ArcGIS 10.6 and reclassified to generate a probability distribution map. Potential dolphin distribution stretches (probability distribution score > 0.50) were categorised into three major conservation priority stretches, ≥0.70 High Conservation Priority Stretches (CPS1), 0.61–0.70 Moderate Conservation Priority Stretches (CPS2) and 0.51–0.60 Low Conservation Priority Stretches (CPS3).

3. Results

3.1. River characterization

The mean depth of the eight surveyed rivers was 3.49 m (±0.42, n = 927) and among these the Ganga River was the deepest (5.78 m ± 0.27 m). Significant variation in mean depth was found between the rivers (ANOVA, $F = 59.88$, $p < 0.001$). The mean river width was 531.69 m ± 86.65 m, which was more than the mean width of Chambal, Son, Yamuna, Ghaghra and Gandak rivers. The mean channel width shows significant variation across studied rivers (ANOVA, $F = 74.9$, $p < 0.001$). The mean channel flow across the rivers was 531.43 ± 86.65 m^3/s and ranged between 80.31 m^3/s ± 102.37 m^3/s (Rupnarayan River) and 762.36 m^3/s ± 490.45 m^3/s (Ghaghra River). We observed significant difference in the mean flow between rivers (ANOVA, $F = 19.76$, $p < 0.001$). The mean number of meanders (1.34 ± 1.06 meanders/BEU) showed significant variation between rivers (ANOVA, $F = 18.72$, $p < 0.001$). The number of meanders was found to be highest in the Chambal River (1.34 ± 1.06 meanders/BEU). The mean slope (0.75 ± 0.38 degree) across the basin showed significant variation between the studied rivers (ANOVA, $F = 9.75$, $p < 0.001$). The Yamuna River was the steepest among the eight surveyed rivers (1.38 ± 2.4 degree) (Supplementary Table S4).

Our assessment suggests that in comparison to other rivers, the Chambal River is relatively disturbance free due to its protected nature. The mean fishing intensity (22.67 ± 25.70 nets/ BEU) indicated significant variation between the rivers (ANOVA, $F = 9.75$, $p < 0.001$). The fishing intensity was highest for the Rupnarayan River (72.19 ± 61.25 nets/ BEU) and lowest for the Chambal River (0.05 ± 0.21 nets/BEU). The sand mining intensity in the basin was 4.23 ± 3.24 activities (boats, tractor and earthmovers) with highest for the Yamuna River (9.64 ± 28.68) and lowest for the Chambal River (0.59 activities ± 1.47 activities). We found significant differences in the mining activities across studied rivers in the basin (ANOVA, $F = 6.038$, $p < 0.001$). The mean water extraction pumps in the GB was 0.76 ± 0.20 (pumps/ BEU) with highest in the Rupnarayan River (7.5 ± 8.37) and lowest in the Chambal River (0.05 ± 0.21) due to above stated reasons. The occurrences of water extraction pumps within rivers showed a significant variation (ANOVA, $F = 18.57$, $p < 0.001$).

3.2. Distribution and range decline

First ever description of GD range was given by Anderson (1879). In the basin, the GD used to occur between Haridwar and Ganga Sagar prior to the initiation of water resource development projects in the mainstem of the Ganga River during the 19th Century (Supplementary Fig. S2). In the present study, the occurrence of GD in the mainstem Ganga was found to be confined in two disjunct stretches (Fig. 2). The first between Bijnor barrage and Kanpur barrage, and the second one between Fatehpur and Ganga Sagar. The current occurrence of GD in the Ganga, indicates 6.51 % decline in its range, which contributes to 2.74 % decline in the GB. In the Yamuna River, the historical range was between Delhi and Prayagraj (Yamuna - Ganga confluence). During present study GD sightings were recorded downstream of Bareh (Chambal - Yamuna Confluence) up to Prayagraj, indicating 58.57 % decline in the Yamuna, which contributes to 12.04 % decline in its entire distribution range. In the past, the GD sightings in Chambal River were recorded between Batesura and Bareh. However, in present survey the GD distribution was

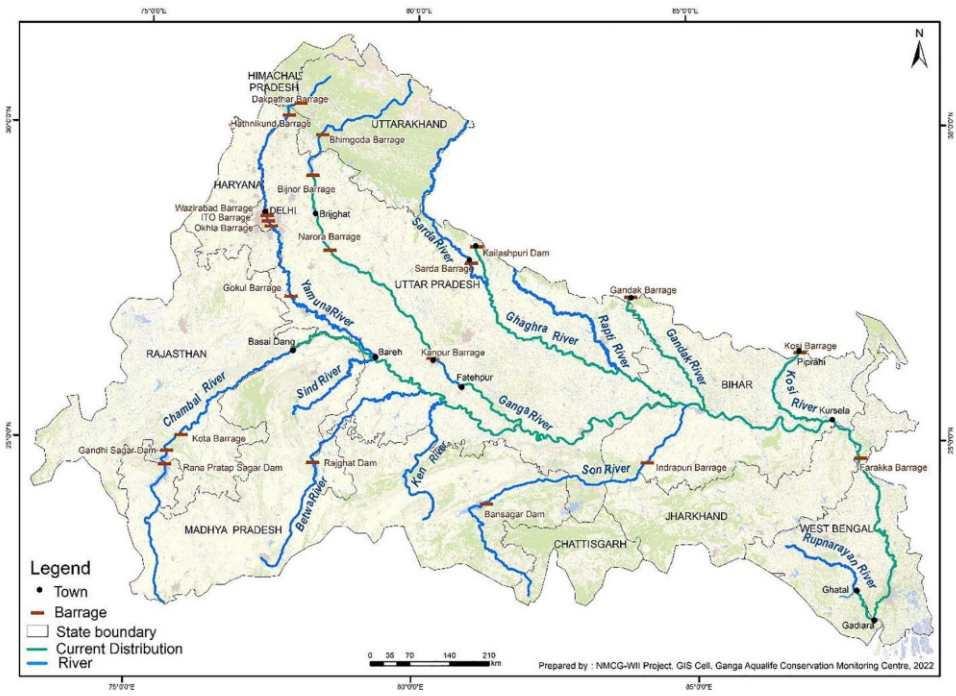

Fig. 2. Current distribution range of Gangetic dolphin in the Ganga Basin, India.

restricted between Basai Dang and Bareh, which suggests range decline of 17.54 % in Chambal, and 0.98 % of its entire distribution range. The GD range decline in the Kosi River was 4.26 % and 0.20 % in its distribution range. The GD distribution was found to be intact in the other northern snow fed tributaries such as Ghaghra, and Gandak. In the present study we recorded no dolphin occurrences from Son River, and is the first report of GD extirpation from entire Son River. The GD is now believed to be extirpated from Ken, Betwa, and middle stretch of Sharda rivers mainly due to reduced depth caused by water abstraction. However, in the Rupnarayan River, we observed increase in GD range, which accounted for 40 % increase from its earlier records, and 0.01 % increase in its entire range. Overall, our estimate suggest that the current

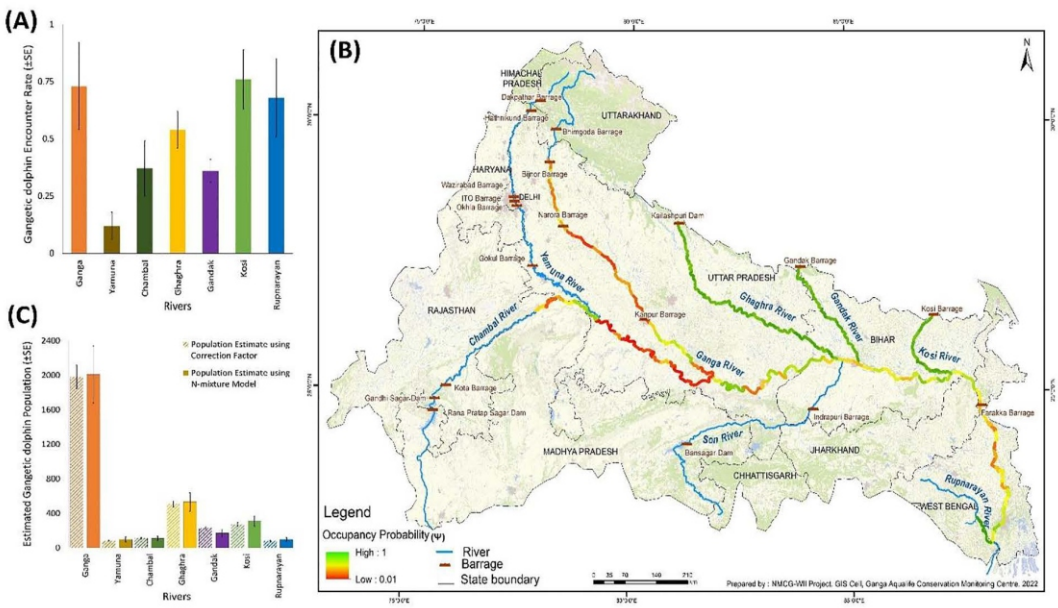

Fig. 3. (A) Encounter rate of dolphin sightings per km in eight major rivers of Ganga Basin, India, (B) Model averaged estimates of Gangetic dolphin site occupancy (Ψ), and (C) abundance estimate of Gangetic dolphin using *N*-mixture and correction factor (D_{cf}).

distribution range of the GD has been reduced by almost 24.37 % (1245 km) in the GB since 1878 and 7.44 % over the last two decades (Supplementary Table S5).

3.3. Encounter rate

In total, 2151 sightings of surfacing GDs were recorded in 4635 km survey stretch of eight rivers. Maximum of 1303 (60.57 %) sightings were recorded from the Ganga River followed by Ghaghra, Kosi, Gandak, Chambal, and Rupnarayan rivers, and least from the Yamuna River (Supplementary Table S6). The overall mean encounter rate was 0.51 ± 0.11 sightings/km that indicated significant variation across the surveyed rivers (ANOVA, $F = 3.08$, $p < 0.001$). We recorded the highest dolphin encounter rate in the Kosi (0.76 ± 0.13 sightings/km), followed by Ganga, Rupnarayan, Ghaghra, Chambal, Gandak and Yamuna Rivers (0.12 ± 0.06) (Fig. 3A). No dolphins were recorded from the Son River.

3.4. Factors affecting dolphin site occupancy and abundance

GD was detected in 132 out of 156 sampling units of 25 km linear stretch, accounting for a naïve occupancy of 0.85. The estimated mean detection probability was (p̂) 0.60 ± 0.03, and the mean probability of site occupancy was $\hat{\Psi} = 0.85 \pm 0.04$.

In total, 35 models, including univariate and multivariate, were generated to infer the influence of predictor variables on the detection probability (p) and site occupancy (Ψ) of the GD. The best fit model (AICc = 0.0) for site occupancy (Ψ) includes channel depth, meander and river, and for detection probability (p) includes channel width as the best predictor variable (Table 1A). Model averaged estimates revealed high GD site occupancy across the study area (Fig. 3B). The variables defining the site occupancy, *viz.* depth summed model weight (Σw = 1.00), meanders (Σw = 1.00), and individual rivers (Σw = 1.00) were found to be positively associated with GD occurrence (Table 1B). In contrast, channel width (Σw = 1.00) defining the detection probability showed a negative but insignificant association as beta coefficient yield overlapping zero (β ± SE = 0.11 ± 0.08) (Supplementary Fig. S3).

A total of 31 N-mixture models considering all possible combinations of covariates (univariate and multivariate) were generated under Negative Binomial distribution. The best fit model for abundance (λ) includes channel depth, meanders and individual rivers, and for detection probability (p) include channel width and effort (Table 2A). Based on model-averaged parameter estimates, channel depth (Σw = 1.00), meanders (Σw = 1.00) and river (Σw = 1.00) were the best predictors of the dolphin abundance (Table 2B). As seen in the site occupancy modelling, we observed a positive influence of channel depth, and meanders on GD abundance. Although parameters like individual river appeared in the final model set, the influence of it varied from river to river. Ganga, Ghaghra and Kosi had a significant positive influence on abundance, whilst the remaining had no influence (Table 2B). Channel width significantly negatively impacted detection probability (Σw = 1.00), while effort was positively associated with the detection probability of GD in the GB (Σw = 1.00) (Supplementary Figs. S4 and S5).

Table 1
Results of site occupancy model selection (A) Best model for Gangetic dolphin site occupancy (B) Parameter estimates (SE) of the final model set (ΔAICc < 2) for models estimating Gangetic dolphin site occupancy.

(A) Best models for Gangetic dolphin site occupancy (Ψ)

	Model	nPars	−2*LogLike	AICc	Δ AICc	AICwt
1	Ψ (cd + me + river), p(cw)	11	467.81	957.62	0	0.66
2	Ψ (cd + me + river), p(cw + effort)	12	467.81	959.63	2	0.24

(B) Parameter estimates (SE) of the final model set

	Model	β (cd)	β (me)	β (Yamuna)	β (cw)
1	Ψ(cd + me + river), p (cw + effort)	0.82 (0.46)	2.56 (0.87)	−3.34 (1.50)	0.11 (0.08)
2	Ψ(cd + me + river), p (cw + effort + time)	0.82 (0.46)	1.04 (0.10)	−3.37 (1.51)	0.11 (0.08)

Δ AIC is the relative difference in AIC values compared with the top ranked model; where AIC is Akaike' s information criterion; AICwt is the Akaike weight of the model; nPars is the number of parameters; -LogLike is the negative log likelihood value; Ψ is estimated site occupancy; p is the estimated detection probability; Lambda (λ) is the abundance estimates. Cd channel depth; me meanders; river individual river; cw channel width.

3.5. Population estimation

3.5.1. Population estimation based on N-mixture model

The overall abundance estimate of GD across the GB was 3330 ± 620 individuals (Confidence Interval (CI) = 2304–4668; Coefficient of Variance (CV) = 18.61) (Fig. 3C), the abundance was highest in Ganga River (60.36 %) with estimated 2010 ± 332 individuals (CI = 1455–2718; CV = 16.52). Of all tributaries, the Ghaghra River holds the second largest population of GD (16.01 %) with an abundance estimate of 533 ± 108 individuals (CI = 350–766; CV = 20.34) followed by the Kosi River (9.34 %) with an estimate of 311 ± 59 individuals (CI = 209–434; CV = 18.81) and Gandak River accounted for 169 ± 45 individuals (CI = 95–268; CV = 26.53). The abundance estimate for Chambal River was 111 ± 27 individuals (CI = 70–172; CV = 24.54) followed by Rupnarayan River with an estimate of 99 ± 21 individuals (CI = 64–146; CV = 20.85). The abundance estimates were least in the Yamuna River at 97 ± 28 individuals (CI = 61–164; CV = 29.33), which accounted for 2.91 % of the total estimated population in the basin (Table 3A).

3.5.2. Population estimation based on correction factors (D_{cf}) derived from other studies

The estimates of GD abundance were obtained by multiplying the mean correction factor ($D_{cf} = 1.52$) by the number of GD sightings in each river. The estimated population of GD in the GB was thus 3270 ± 229 individuals (CI = 2821–3718). The highest estimated number of GD for the Ganga River was 1981 ±138 individuals (CI = 1709–2252). Similar to the estimate obtained using N-mixture, the Ghaghra River was estimated to have the second largest population of GD at 509 ± 36 individuals (CI = 439–579) followed by Kosi River with an estimate of 272 ± 19 individuals (CI = 235–309) and Gandak River accounted for 231 ± 16 individuals (CI = 199–263). The abundance estimate of Chambal River was 114 ± 8 individuals (CI = 98–130) followed by Rupnarayan River with an estimate of 82 ± 6 individuals (CI = 71–93). The estimated population of GD was least in the Yamuna River at 81 ± 6 individuals (CI = 70–92) (Table 3B).

3.6. Identification of conservation priority stretches (CPS)

We obtained a total of 124 models considering multiple combinations of feature classes and regularization multipliers (Supplementary Table S7). The prediction model generated using cross validation with 500 iterations had an Area Under Curve [AUC = 0.91 (SD 0.0089)] (Fig. 4A). The SDM analysis revealed that eight bioclimatic variables *viz.* fishing, annual mean temperature (Bio 1), channel flow, precipitation of driest quarter (Bio 17), precipitation of warmest quarter (Bio 18), precipitations of the wettest month (Bio 13), meanders, and depth had ≥ 5 % contribution in defining GD distribution under current climate conditions. The predicted potential distribution of GD showed that the contribution of fishing was maximum (18.4 %) followed by annual mean temperature (15.5 %) and channel flow (12.9 %) (Supplementary Table S8).

The species distribution obtained using MaxEnt models predicted

Table 2
Results of *N*-mixture model selection (A) Best models for Gangetic dolphin abundance (λ) (B) Parameter estimates (SE) of the final model set (Δ AICc < 2) for models estimating Gangetic dolphin abundance.

(A) Best models for Gangetic dolphin abundance (λ)

	Model	nPars	−2*LogLike	AICc	Δ AICc	AICwt
1	λ(cd + me + river),p(cw + effort)	13	1942.35	3910.69	0	0.56
2	λ(cd + me + river),p(cw + effort + time)	14	1941.57	3911.15	0.45	0.44

(B) Parameter estimates (SE) of the final model set

	Model	β (cd)	β (me)	β (Ganga)	β (Ghaghra)	β (Kosi)	β (cw)	β (effort)
1	λ(cd + me + river),p (cw + effort)	0.20(0.08)	1.03(0.10)	1.88(0.32)	1.11(0.33)	1.01(0.39)	−0.23(0.04)	0.11(0.03)
2	λ(cd + me + river),p (cw + effort + time)	0.20(0.08)	1.04(0.10)	1.88(0.32)	1.11(0.33)	1.00(0.39)	−0.23(0.04)	0.11(0.03)

Beta coefficients (β) shown in bold indicate significant impact on site occupancy of the model as 95 % CI / 0 (β ± 1.96*SE). River which were insignificant are not included in the table. Cd channel depth; me meanders; river individual river; cw channel width.

Table 3
River wise abundance estimates of the Gangetic dolphin in the Ganga Basin (A) using *N*-mixture model (B) using Correction factor (D_{cf}).

(A) Abundance estimate using *N*-mixture

River	Surveyed length (km)	Mean ± SE	95 % CI-lower	95 % CI-upper	CV
Ganga	2070	2009.76 ± 332.04	1454.95	2718.18	16.52
Yamuna	435	97.14 ± 28.49	60.98	164.05	29.33
Chambal	405	110.86 ± 27.2	70	172	24.54
Ghaghra	615	532.83 ± 108.38	349.95	766.03	20.34
Gandak	295	169.02 ± 44.84	94.98	268	26.53
Kosi	235	311.38 ± 58.56	209	434.05	18.81
Rupnarayan	80	99.48 ± 20.74	64	146	20.85
Ganga Basin	4135	3330 ± 620	2304	4668	18.61

(B) Abundance using correction factor (D_{cf})

River	Surveyed length (km)	Observed sightings	Population estimates $D_{cf} = 1.52$ ± SE	95 % CI-lower	95 % CI-upper
Ganga	2070	1303	1981 ± 138.49	1709.12	2252.00
Yamuna	435	53	81 ± 5.63	69.52	91.60
Chambal	405	75	114 ± 7.98	98.38	129.62
Ghaghra	615	335	509 ± 35.61	439.41	578.99
Gandak	295	152	231 ± 16.16	199.38	262.70
Kosi	235	179	272 ± 19.03	234.79	309.37
Rupnarayan	80	54	82 ± 5.74	70.83	93.33
Ganga Basin	4135	2151	3270 ± 228.62	2821.43	3717.61

~5000 km of river stretch including historic and current distribution range of the GD (Supplementary Table S5). Of the total predicted distribution, 2040 km (40.8 %) of stretch was found suitable (probability distribution score ≥ 0.50) for GD in the GB (Table 4). Identification and classification of priority stretches based on potential distribution map of the GD revealed that 12.2 % (610 km) of the river stretches fall under High Conservation Priority Stretch (CPS1) (>0.70), 14.3 % (715 km) under Moderate Conservation Priority Stretch (CPS2) (0.61–0.70) and 14.3 % (715 km) under Low Conservation Priority Stretch (CPS3) (0.51–60). The majority of the CPS1 was confined between the Ganga-Yamuna and Ganga-Kosi confluences (Fig. 4B), while the remaining CPS1 was located in the tributaries. Among the rivers that showed suitable habitat, the Ganga River had the largest contiguous, highly suitable river segment of 200 km in the basin representing 6.5 % of total available stretch. CPS2 and CPS3 were interspersed with CPS1 of the Ganga River and its tributaries (Fig. 4C and 4D).

4. Discussion

Rivers are dynamic systems that vary with changes in flow regimes, which regulate intricate hydro-morphological processes (Zeiringer et al., 2018). Species occurring in these habitats are highly reliant on established patterns of habitat dynamics maintained by the natural hydrologic regime and their biology is closely linked with seasonal change in the hydrological regime (Poff et al., 1997; Thorp et al., 2006). However, anthropogenic stressors have disrupted the natural hydrological cycle resulting in biodiversity loss and interrupted vital ecological processes in these ecosystems (Dudgeon et al., 2006; Strayer and Dudgeon, 2010, Alizadeh et al., 2018). These underlying effects make maintaining critical ecological processes in these threatened ecosystems challenging. Studies have highlighted the importance of dedicated geographical areas identified through comprehensive scientific methods in maintaining biodiversity and ecological functioning (Belote and Wilson, 2020). In the present study the GD sighting was used to derive their distribution patterns, abundance, *vis-à-vis* influence of hydrological, anthropogenic and climatic factors and prioritise conservation for long-term survival of the aquatic species and functioning of riverine ecological process.

The distribution pattern of GD in the Basin revealed a decline in its range since 1878. The observed sightings of GD showed clustered distribution and relatively high sightings in lower stretches of the rivers where mean depth, confluences, river constrictions and meanders were significantly high (Sinha & Kannan, 2014; Choudhury et al., 2019). The low sightings of GD in the upper stretches of the river was attributed to small cross-sectional area with high degree of channel bifurcation and comparatively low flow with shallow depth. The encounter rate also varied across the study area with several stretches showing an increase while others showed a decline. The difference in hydrological regimes of surveyed rivers due to their nature of origin and course through different biogeographic zones and terrain types would have resulted in variation in GD occurrence across the basin.

The reduction in distribution range, specifically in the upstream of the river, is likely due to the structural barriers, which alters the hydrological regime and disrupts lateral connectivity. Additionally, water development projects such as dams, barrages and embankments are likely to interrupt dolphin movement and result into fragmented populations. The impact of anthropogenic activities such as fishing, in-stream mining and heavy vessel movement also led to disruption of

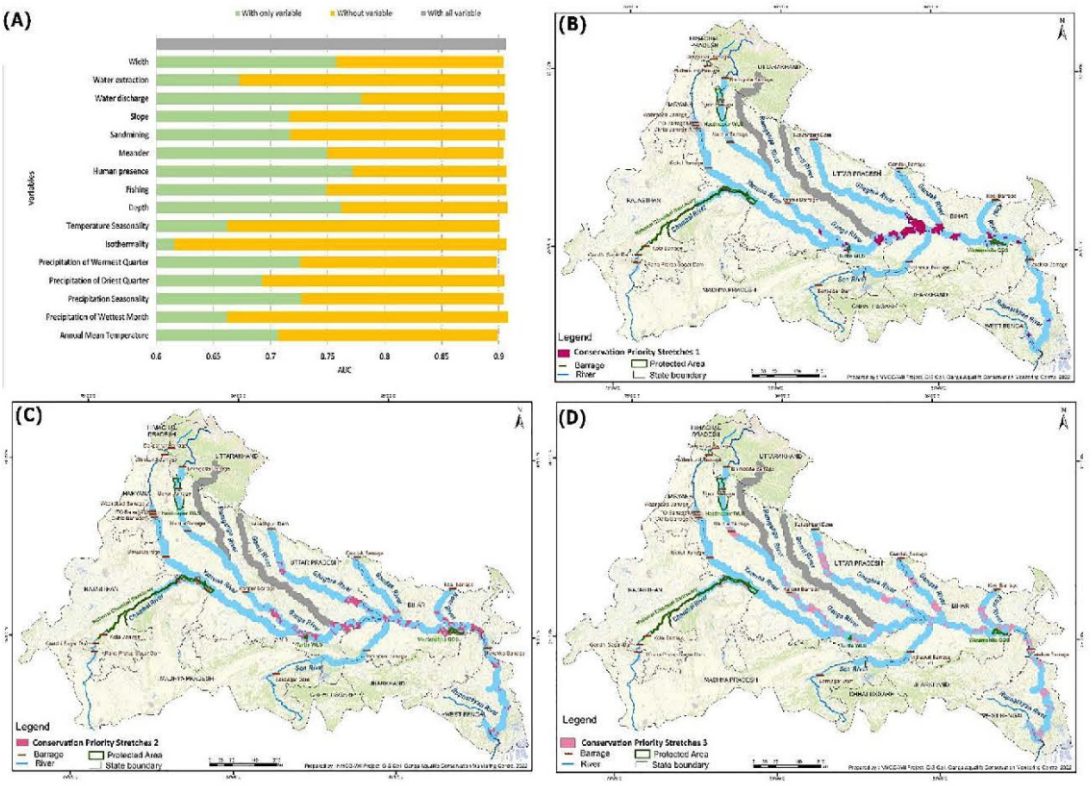

Fig. 4. Identification of Conservation priority river stretches in the Ganga Basin, (A) Jackknife test using AUC on test data, (B) Conservation Priority Stretches 1, (C) Conservation Priority Stretches 2, (D) Conservation Priority Stretches 3.

Table 4
Length of identified priority river stretches in Ganga Basin for conservation. The values in parentheses are the percentage (%) of priority river stretches for each category.

River	Total length (km)	Surveyed length (km)	High Priority Stretches (CPS1) (km)	Moderate Priority Stretches (CPS2) (km)	Low Priority Stretches (CPS3) (km)
Ganga	2525	2070	325 (6.5)	435 (8.7)	310 (6.2)
Yamuna	1435	435	20 (0.4)	50 (1.0)	45 (0.9)
Chambal	960	405	85 (1.7)	60 (1.2)	50 (1.0)
Ghaghra	1123	615	85 (1.7)	55 (1.1)	150 (3.0)
Son	784	500	5 (0.1)	5 (0.1)	20 (0.4)
Gandak	775	295	5 (0.1)	35 (0.7)	75 (1.5)
Kosi	729	235	70 (1.4)	45 (0.9)	45 (0.9)
Rupnarayan	280	80	15 (0.3)	30 (0.6)	20 (0.4)
Total	8346	4635	610 (12.2)	715 (14.3)	715 (14.3)

connectivity between tributaries and the mainstem river (Aggarwal et al., 2020; Paudel and Koprowski, 2020; Samad et al., 2022). The lower stretches of the river, due to the hydrological complexities particularly availability of higher mean depth, confluences, meanders, unbraided channel and possibly low impacts of dams and barrages are suitable for GD presence (Sinha and Sharma, 2003b; Choudhary et al., 2006; Kelkar et al., 2010; Behera et al., 2013; Mazumder et al., 2014).

Consistent with the findings of Kelkar et al., (2010), Bashir et al., (2012), Paudel et al., (2015), the site occupancy and N-mixture models revealed a positive association of GD site occupancy and abundance with channel depth, meanders, and river type, particularly in mainstem Ganga and snow-fed tributaries such as Ghaghra, Gandak and Kosi rivers. (Tables 1B and 2B). Findings of Kelkar et al. (2010) explained that a high occurrence of GD occurred at > 5.2 m depth, and also emphasized that a contiguous series of deep pools with high prey availability are suitable for providing ample space for dolphin movement. Owing to the physiological needs of the GD, the deep pools, meanders and confluence tend to provide ample foraging opportunities, predator avoidance and escape from entrapment in shallow pools (Kelkar et al., 2010; Bashir et al., 2010; Khanal et al., 2016; Choudhury et al., 2019; Paudel et al., 2021). The deep pools are good fish habitat, thus have high fish abundance (Smith et al., 1998; Zhou et al., 2022), which results in increased foraging ability of GD by reducing foraging time and degree of metabolic investment. The deep pools provide the highest possible usable area for GD due to presence of higher cross-sectional area, and depth (Braulik et al., 2012; Paudel et al., 2021). Low-velocity in the deep pools favour efficient diving for prey capture and predator avoidance, if necessary. Further, the significance of deep pools increases particularly during the low-water season when suitable habitat shrinks manifolds compared to the high-water season (Braulik et al., 2012; Paudel et al., 2021; Samad et al., 2022; Sharma et al., 2022) and GD tend to occupy and congregate in these deeper areas for their survival (Bashir et al., 2010; Kelkar et al., 2010).

N-mixture models have been applied to a wide range of wildlife species ranging from invertebrates to large mammals (Paudel et al., 2015; Kidwai et al., 2019; Manica et al., 2019; Searle et al., 2020; Than et al. 2020; Barão-Nóbrega et al., 2022), that explicitly allow for assessing abundance estimates and detection probability from a repeated count data of unmarked individuals (Kéry and Royle, 2015; Bötsch et al., 2020). N-mixture model is cost effective and widely used to estimate the abundance of population from count data with both spatial and temporal replications while accounting for imperfect detection

(Royle, 2004; Joseph et al., 2009). There are many alternative sampling methods exist for obtaining estimates of abundance such as capture-recapture, distance and multiple-observer sampling; however the N-mixture model is comparatively cost-effective and requires minimum effort for data collection and does not require individuals to be identified (Dennis et al., 2015). Nonetheless, N-mixture model is particularly promising for wildlife studies because it has the potential to produce estimates that are comparable to those obtained by intensive surveys such as capture-mark-recapture approaches.

Previous studies were conducted in different time scales and were subjected to disjunct pockets. The available studies utilizing similar methodology were either conducted in small segments of high GD occurring stretch (Paudel et al., 2015) or for different species, rivers or terrestrial systems with varied geomorphological characteristics (Barão-Nóbrega et al., 2022; Than et al., 2020; Searle et al., 2020). Hence direct comparison of efficacy of N-mixture model in riverine system is not feasible as the present study is the first ever comprehensive survey conducted in the major rivers of the GB whichis beyond the scale of comparison to earlier studies (e.g. Paudel et al., 2015; Than et al., 2020).

The findings of N-mixture model also revealed that channel depth, meanders and river type act as a crucial factor in determining GD abundance, which is evident from the fact that lower segments of the river are laden with deep pools and have more meanders. Channel width and efforts were considered as covariates of detection as it was quite obvious from the fact that increase in channel width resulted in decreasing detection of GD as it disrupts visual efficiency of the observer. Under such conditions, efforts of the observer team to detect individuals would be considered for optimizing detection.

This is the first study from India that employed the N-mixture models in large riverscapes to assess the abundance of GD and one of the first to do so for a flagship species in freshwater systems. Presumably, we can argue that the N-mixture framework applied to heterogeneous datasets offers a flexible approach for abundance estimates when ecological conditions are conducive for optimizing detectability, and provided reliable and insightful abundance estimates of GD and its detection across the study site. Earlier, the approach had been successfully employed to obtain abundance estimates of GD in the Karnali River of Nepal (Paudel et al., 2015). We also compared the estimates of GD derived from the N-mixture models with the correction factors (D_{cf}) extracted from published literature while accounting for imperfect detection. Both the approaches resulted in similar estimates as the probability of detection (p) was 0.66 and 0.65 for correction factor and N-mixture model, respectively. The mean population estimates of the individual rivers followed similar pattern as derived using correction factors for the GD. However, the abundance estimates of GD generated using N-mixture models cannot be exclusively interpreted as absolute abundance, as individuals whose home range spans multiple sites would have been accounted for multiple times within their home range (Link et al., 2018; Nakashima, 2020). Nevertheless, it can be safely said that the derived abundance of GD using correction factors (D_{cf}) (Fig. 3B) as an indices and the population estimates derived from N-mixture model make appropriate inferences about abundance across the riverscapes.

We believe that the N-mixture model, as compared to the conventional direct count method, would yield reliable abundance estimates for the heterogeneous detection population like GD that spend most of their time underwater. The N-mixture model is regarded as most suitable framework for estimating abundance (λ) and detectability (p) of unmarked individuals, which describes count data (sightings) replicated in time and space. Our analysis demonstrates that sighting-based occupancy modelling can be employed to monitor top predator's habitat use across large riverscapes such as GB (Bashir et al., 2012; Paudel et al., 2015). Findings of occupancy surveys and its insights can therefore be supplemented to mark-recapture surveys that yield robust population estimates at finer scales. However, the present work proposes robust survey designs combining visual and acoustic framework to yield reliable population estimates of GD where the acoustic survey will aid in underwater missing animals (Richman et al., 2014). This approach would greatly enhance the detection probability of GD; hence, reliable estimates can be used to formulate strategies for conserving viable populations along its distribution range, including GB.

In our study, the predicted probability distribution used for prioritisation of conservation stretches was supported by high AUC (0.91 ± 0.0089). We highlight the potential bioclimatic variables governing GD distribution under the current climate change scenario and modelled probable high distribution stretches for prioritisation. Several identified priority stretches fall within the delineated boundaries of the Protected Areas (PAs) such as the Turtle Sanctuary, the Vikramshila Gangetic Dolphin Sanctuary and the National Chambal Sanctuary. The highest priority for conservation should focus on the stretches that are currently outside the PA network and are suitable for dolphins. These stretches were mostly confined in around the confluence of tributaries with the mainstem Ganga River. In the wake of growing demand for river resources and increasing threats to the freshwater ecosystem, it is crucial to protect these CPS to prevent habitat degradation and species loss. Societal reliance on the services provided by vast expanses of river stretches complicate management interventions, particularly those aimed at offsetting human footprints on riverine ecosystem (Pracheil et al., 2013). The identified river stretches with high biodiversity value in the Basin give an opportunity for targeted conservation actions and provide options to conserve the optimal stretches of the river for the continued flow of ecosystem services. This may serve as a blueprint for biodiversity conservation while preserving the societal benefits without de-linking the natural resources and human ecological requirements (Wang et al., 2015).

5. Conclusions

The GB is one of the largest and most densely populated regions of the world that supports more than 25,000 floral and faunal species and serves as a lifeline for over 650 million people (Dwivedi et al., 2018; Hussain et al., 2020). Over the past decades, population growth, agricultural and industrial expansion have led to the over-exploitation of riverine resources leading to its fragmentation. The inadequate water management policies to address the extensive use of water for irrigation, industry, and public supply have emerged as obstinate challenges for river conservation. Furthermore, the future climate change scenarios encompassing melting headwater glaciers, and changes in rainfall patterns have triggered extreme events and altered drought and flooding cycles that threaten the natural flow regime of the rivers. These adversely affect the species diversity of the basin, which are either currently endangered or are likely to become endangered in the foreseeable future. The riverine impoundments and reservoir-induced habitat fragmentation restrict connectivity in the aquatic system and impede natural migration of the aquatic fauna resulting in spatially and genetically fragmented populations. Conservation prioritisation of river stretches has been advocated to counter the impact of negative factors, and enable the riverine ecological process and functioning.

The first ever comprehensive surveys conducted in all major rivers in the GB covering a length of 4635 km revealed that the basin holds ~65 % of the total population of the GD. We also identified a 610 km river stretch, accounting for 12.2 % of the GB as a high conservation priority stretch (CPS1) for the conservation of the GD and other riverine associated species. The sub-optimal stretches between the CPSs need to be restored to enhance the connectivity and improve ecological functioning within the basin. Conservation of these stretches will provide a safety net against the cascading ecological and socio-economic impacts of climate change.

The assessment of large river habitats and estimation of the abundance of cryptic species within a vast stretch of linear system is a challenge for field ecologists. To overcome this limitation and challenge, a survey protocol for field observation and data recording was developed after thorough review of published literature and pilot survey. This

protocol was then followed by the multiple survey teams, deployed across the GB. In future, the population estimation of Gangetic dolphin in the GB can be further validated using the capture-mark-recapture framework, which can elucidate the loss of information due to under or over-estimates occurring due to false-negative or false-positive counts of the species, respectively (Barker et al., 2018). Further, spatio-temporal variation in the GD sightings can be estimated using a dynamic version of the N-mixture modelling approach using multi-season data, and multi-species-based ensemble modelling can be applied for delineating CPS in a river system.

CRediT authorship contribution statement

Goura Chandra Das: Data curation, Formal analysis, Software, Writing – original draft. **Surya Prasad Sharma:** Data curation, Formal analysis, Writing – original draft. **Sk Zeeshan Ali:** Data curation, Formal analysis, Visualization. **Saurav Gawan:** Data curation. **Aftab Alam Usmani:** Data curation. **Arkojyoti Sarkar:** Data curation. **Suyash Katdare:** Data curation. **Ajay Rawat:** Data curation. **Pichaimuthu Gangaimaran:** Data curation. **Ashish Kumar Panda:** Data curation. **Umang Agnihotri:** Data curation. **Aishwarya Ramachandran:** Visualization. **Srijani Guha:** Visualization. **Shivani Barthwal:** Supervision, Writing – review & editing. **Jeyaraj Antony Johnson:** Supervision, Writing – review & editing. **Ruchi Badola:** Conceptualization, Funding acquisition, Project administration, Supervision, Methodology, Writing – review & editing. **Syed Ainul Hussain:** Conceptualization, Funding acquisition, Project administration, Supervision, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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