ANNUAL REPORT

(2023 –2024)

Title of the Project

FISH CONSERVATION AND STOCK ENHANCEMENT OF FISHERY OF GANGA RIVER BASIN (PHASE III)

Sponsored by: National Mission for Clean Ganga, Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti, Govt. of India

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NMCG CIFRI ANNUAL REPORT (2023-24)

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FISH CONSERVATION AND STOCK ENHANCEMENT OF FISHERY OF GANGA RIVER BASIN (PHASE-III)

Name of the sponsoring agency (Ministry/ Department/ Autonomous Body/ Central PSE)	**:**	**National Mission on Clean Ganga, Ministry of Jal Shakti, New Delhi**
Project Number	**:**	**Ad-35012/1/2023-NMCG-NMCG**
Proposed duration of the proposal/Scheme	**:**	**Three years (2023-26)**
Total cost of the proposal over the proposed duration	**:**	**Rs. 3138.44 lakhs/-**

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National Mission for Clean Ganga (Ministry of Jal Shakti) 1st Floor, Major Dhyan Chand National Stadium, India Gate, New Delhi- 110002

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Foreward

The river Ganga holds immense cultural, spiritual, and ecological significance in India. Beyond its religious importance, the Ganga is a vital lifeline for millions of people, providing water for drinking, agriculture, and industry. The river also supports a diverse ecosystem, including endangered fish species and Gangetic dolphin. Its basin is home to over 400 million people, making it one of the most densely populated regions in the world. Despite facing pollution challenges, the Ganga remains central to the social and economic life of the Indian subcontinent. ICAR-CIFRI has relentlessly worked on the River Ganga with funding from the Ministry of Jal Shakti under the National Mission for Clean Ganga (NMCG). The institute has created a repository of biological and ecological data on the Ganga River System. The study has stressed the importance of conservation and propagation of Indigenous fish species, including Hilsa and awareness of Dolphin conservation with three major components as i) Captive breeding of commercially crucial Indigenous fish species and ranching program through livelihood enhancement and conservation in Arth Ganga concept ii) Establishment of Hilsa stock in the middle stretch of River Ganga iii) Conservation of Mahseer species iv) Stock assessment of fishes in selected tributaries of Gangetic Basin for their conservation v) Community participation and awareness programme on the fish biodiversity conservation in the entire stretch of river Ganga. During the third phase, a total of 54.44 lakh fingerlings of Indian major carps (IMC) Mahseer and other indigenous fishes were released in the river covering five states of the Ganga basin with a view to maintaining and restoring the IMC and Mahseer fish population, increasing fish productivity and boost local economies. Through 144 multilocational awareness campaigns a total of 7,916 fishermen and other stakeholders and locals were educated on the significance of ranching and encouraged to practise conservation measures to safeguard and enhance the indigenous germplasm in the river. Emphasis was also given towards the stock enhancement of Hilsa, (*Tenualosa ilisha*) in the above Farakka Barrage of West Bengal. Furthermore, 16 tributaries and distributaries of the River Ganga, including six floodplain wetlands, were examined for ecological conditions, fish populations, pollution levels, and socio-economic status. The nutritional quality of various edible fish species from the Ganga and its tributaries was assessed. This year's research has established a significant insight on the present-day status of the fish species in the River Ganga and its tributaries.

(B. K. Das)

Executive Summary

In line with the objectives of restoring selected fish species (IMC and Mahseer) of the River Ganga through ranching, programmes were implemented for fish ranching in various depleted stretches of the River Ganga to enhance fish production and conserve native fish stocks. Seventy-six lakh spawns of Indian Major Carps were produced using riverine germplasm. Thirty river ranching programmes were implemented during 2023-24, during which 54.44 lakh fingerlings, comprising Indian major carps (IMC) and Mahseer, were released in five states: Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal. The impact of river ranching has shown a 28% increase in IMC landings in Bhagalpur, Bihar, compared to 1990. Growth trends and fish landing forecasting were also carried out in the Patna stretch of the River Ganga. To assess the ichthyofaunal diversity of the River Ganga, seasonal field campaigns were conducted from December 2023 to December 2024 for sampling, covering all five states. A total of 184 fish species (177 native and seven exotic) belonging to 132 genera were recorded from the site Harsil (Uttarakhand) to Fraserganj (West Bengal). Approximately 10% of the fish species inhabiting the River Ganga are listed as threatened, according to IUCN categories. In addition to microplastic pollution studies, a nutrient profiling study was conducted on 31 commercially important food fish species from the River Ganga. Monitoring the status of fish landing along 17 selected sites covering Uttarakhand, Uttar Pradesh, Bihar and Jharkhand. Broodstock of Mahseer (*Tor putitora*) was developed, and a collection of 6000 Mahseer was also carried out for conservation in the upper stretches of the River Ganga. Fish stock assessment of two Himalayan endemic fish species, viz. Golden Mahseer (*Tor putitora*) and Snow trout (*Schizothorax richardsonii*) were undertaken as part of the monitoring of the species in the natural waters. ICAR-CIFRI under NMCG Phase III have monitored 16 rivers of the Gangetic Basin (viz. Alakananda, Nayar, Saryu, Ramganga, Bhilangna, Yamuna, Gandak, Kosi, Damodar, Rupnarayan, Jalangi, Churni, Adi Ganga, Ichamati, Matla, and Haldi rivers) which are important for fish diversity, ecology, and pollution studies. Furthermore, six different floodplain wetlands were selected, four in the state of West Bengal (Akaipur, Bijpur, Kundipur, and Maniknagar), and two in Uttar Pradesh (Haiderpur and Alwar Tal), which were also monitored for fish diversity, ecology, and pollution studies. To enhance the natural Hilsa population, 28,691 adult and juvenile individuals were released upstream of the barrage along the Prayagraj to Farakka stretch. Four artificial breeding trials were also conducted. Of these, 798 adult Hilsa fish were tagged to understand their migration pathways.

During the study period, more than 2,227 fishermen from the states of Jharkhand and West Bengal were made aware of the Hilsa life cycle, the conservation of Hilsa, and the tagging of Hilsa for migration studies. Based on interactions with fishermen and an awareness programme, it recovered 45 tagged Hilsa from different places, including Murshidabad and Maldah (West Bengal), Jharkhand, and Uttar Pradesh. Seven hundred ninety-seven live Hilsa broodstock and juveniles were collected and captivated in a pond near the Farakka Barrage project to accomplish the objectives of the project. Further artificial breeding of Hilsa was also attempted, releasing 0.3 lakhs of spawns and 5.6 lakhs of fertilized eggs. To create awareness among stakeholders regarding sustainable fisheries, Hilsa conservation and dolphin awareness, 144 awareness programme was conducted during the study period. A total of 7,916 numbers of fishers were sensitized through the awareness campaigns at five states such as Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal on the detrimental effects of destructive methods of fishing like the operation of zero-meshed net and other destructive fishing methods such as use of toxic chemicals or poisoning for fishing and were advised not to catch the juveniles and brooders especially. Special programs focused on 'Dolphin Conservation' were actively conducted during this phase, with particular emphasis on raising public awareness and community involvement. A key highlight was the observance of National Dolphin Day, which served as a platform to engage diverse groups including students, local communities, conservationists, and policymakers. Public talks, and media coverage played a crucial role in disseminating information about the ecological importance of dolphins, especially the endangered Gangetic dolphin (*Platanista gangetica*). These efforts not only highlighted the threats faced by dolphin populations such as habitat degradation, pollution, and accidental entanglement in fishing gearbut also promoted citizen participation in conservation initiatives. Under Phase III project of the National Mission for Clean Ganga (NMCG), significant emphasis was also placed on integrating social and economic dimensions into river conservation strategies. Two key components in this effort were the socio-economic studies of fishing communities and the implementation of the Arth Ganga initiative a framework aimed at linking people and livelihoods with the Ganga River's rejuvenation. These efforts have laid the groundwork for a resilient, community-led model of river stewardship that can be scaled across other river systems in India.

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Units and Abbreviations

µS/cm	MicroSiemens per centimetre
APHA	The American Public Health Association
AB	Above Barrage
AD	Above Dam
BB	Below Barrage
BD	Below Dam
cells/L	Cells per litre
CPE	Carp Pituitary Extract
g/100g	gram per hundred grams
g/L	gram per litre
IMC	Indian Major Carps
ind/L	Individuals per litre
ind/m²	Individuals per square meter
IUCN	International Union for Conservation of Nature
mg/m³	Milligrams per cubic meter
mg/kg	Miligram per kilogram
mg/L	Milligram per litres
MON	Monsoon
POM	Post Monsoon
PRM	Pre-Monsoon
ppm	Parts per million
ppt	Parts per thousand
USEPA	U.S. Environmental Protection Agency
BIS	Bureau of Indian Standards
FRP	Fiber Reinforced Polymer
HDPE	High-Density Polyethylene

1. INTRODUCTION

The river Ganga, originating from the Garhwal Himalaya at an altitude of about 6,000 meters, flows through the Sivalik hills and enters the Indo-Gangetic plains at Haridwar. It then traverses several hundred kilometres through Uttar Pradesh, Bihar, Jharkhand, and West Bengal before finally draining into the Bay of Bengal. The Ganga basin is one of the most densely populated and agriculturally significant regions in the world and is considered the largest groundwater depository on earth. The river is indispensable for human livelihoods, providing water for drinking, irrigation, fisheries, power generation, and religious practices. Hence, the sustainable conservation and restoration of the Gangetic ecosystem are vital, with direct implications for the region's biodiversity and socio-economic stability. River Ganga is a dynamic freshwater ecosystem harbouring over 200 species of fish, many of which are endemic, economically significant, or migratory. This includes the iconic Hilsa (*Tenualosa ilisha*), a flagship species that holds immense cultural and commercial value. However, indiscriminate fishing, habitat fragmentation, and pollution have led to a sharp decline in Hilsa populations, threatening their survival within the river system. Fish diversity serves as a key bioindicator of riverine health, with each species playing a vital role in nutrient cycling, food web stability, and ecological balance. The river's ichthyofauna also supports millions of people through commercial fisheries (such as IMC, Mahseer, catfish, etc.), subsistence fishing, and seed collection for aquaculture.

In recent decades, the Ganga has also seen the introduction of several exotic fish species, including Tilapia, Common carp, and Grass carp, which were introduced primarily for aquaculture but now pose ecological threats by outcompeting native species and altering food chains. These challenges underscore the urgent need for science-based, integrated conservation strategies. To address these concerns, the ICAR-Central Inland Fisheries Research Institute (CIFRI), Barrackpore, along with its Regional Center in Prayagraj, has been consistently involved in monitoring and assessing the river's fish biodiversity, ecological parameters, fish catch trends, livelihoods of fisherfolk, and river habitat quality. ICAR-CIFRI has built an extensive repository of environmental and biological data over the course of several decades. Under the National Mission for Clean Ganga (NMCG), ICAR-CIFRI is implementing the Phase III project titled "Fish Conservation and Stock Enhancement of Fishery of Ganga River Basin", continuing the success of Phase II (2020–2023). A key component of the project involves ranching programs aimed at restoring native fish populations by releasing hatchery-bred fingerlings of Indian major carps and Mahseer into selected river stretches across Uttarakhand, Uttar Pradesh, Jharkhand, and West Bengal. Recognizing the ecological and economic significance of Hilsa, targeted initiatives are underway in the middle Ganga stretch under the Namami Gange programme. These include the ranching and tagging of Hilsa at upstream barrage zones, detailed population studies, and extensive awareness drives among the fisher community, promoting sustainable harvesting practices and habitat protection. Moreover, the current project phase also emphasizes ichthyofaunal and habitat assessments of selected tributaries to understand their role in supporting the Ganga's fish diversity.

These efforts provide critical insights for developing more robust conservation frameworks and restoration strategies that aim to secure the future of the Ganga River's aquatic ecosystem. In conclusion, the river Ganga stands as a lifeline not only for millions of people but also for a vast and diverse array of aquatic life, with fish biodiversity being one of its most vital ecological assets. The increasing pressures from overfishing, habitat degradation, pollution, and the invasion of exotic species highlight the urgent need for proactive and scientifically informed conservation measures. Through initiatives like the ICAR-CIFRI's fish conservation and stock enhancement programs, supported by the National Mission for Clean Ganga (NMCG), significant strides are being made toward restoring native fish populations and improving the overall health of the river ecosystem. Sustainable management, community participation, and ongoing ecological monitoring are crucial to ensuring that the Ganga remains a vibrant, life-sustaining river system for generations to come.

Fish Conservation and Stock Enhancement of Fishery of Ganga River Basin (Phase III)

Component-I: Captive Breeding of Commercially Important Fish Species and Ranching Programme through Livelihood Enhancement and Conservation in Arth Ganga Concept.

Objectives

- Seed production of selected fish species of River Ganga using riverine germplasm.
- Restoration of the selected fish species (IMC & Catfish) of the river Ganga through Ranching.
- Assessing the impact of the ranching program on the river.
- Nutrient profiling of commercially important fish species of river Ganga.

Component-II: Establishment of Hilsa Stock in Middle Stretch of River Ganga through Ranching of Hilsa seed bred through Captive and wild adults.

Objectives

- Ranching of juvenile and adult Hilsa collected from wild and artificially bred to enhance the natural stock of Hilsa in the middle stretch from Prayagraj to Farakka in the river.
- Development of Hilsa broodstock in artificial rearing facilities and larval production.
- Developing a Hilsa nutri-profile database of different size groups for human health and nutritional security.
- Establishing the breeding migratory path in river Ganga by using floy tagging and other cutting-edge methods.
- Identifying the key responsible factors in the decline of Hilsa populations in the selected canals of Sunderbans.
- Sensitizing the fishers on Hilsa conservation and management in the middle stretches of river Ganga from Prayagraj to Farakka through Ballia, Buxar, Patna, Bhagalpur and Rajmahal.

Component- III: Seed Production, Restoration and Stock Assessment of Selected Mahseer Species in Upper Stretches of River Ganga.

Objectives

- Broodstock development and seed production of selected Golden Mahseers of River Ganga using riverine germplasms.
- Restoration of Golden Mahseer (*Tor putitora*) and Chocolate Mahseer (*Neolissochilus hexagonolepis*) in the upper stretch of river Ganga.
- Stock Assessment of Golden Mahseer (*Tor putitora*) and Chocolate Mahseer (*Neolissochilus hexagonolepis*) in the upper stretch of river Ganga.

Component IV: Stock Assessment of Important Fishes in Selected Tributaries and Wetlands of Ganga River Basin for their Conservation and Management.

Objectives

- Assessing the Fish diversity in selected tributaries and wetlands of the Ganga River basin.
- Characterizing the fish stock in important fish in the selected tributaries and wetlands of the Ganga River basin.
- Characterizing different habitat types based on quantitative and qualitative attributes in the selected tributaries and wetlands of the Ganga River basin.
- Identifying the essential fish habitat/key aquatic habitat critical for fish conservation in the selected tributaries and wetlands of the Ganga River basin.

Component V: Community Sensitization on Dolphin and Fish Biodiversity, including Hilsa for Improving the Livelihood of Fishers.

Objectives

- Creating public and fisher's participation in dolphin and fish diversity conservation with special reference to Hilsa.
- Establishing the economic status and contribution of local fishers under 'Artha Ganga' concept of the river Ganga.

2. COMPONENT: I

Captive Breeding of Commercially Important Fish Species and Ranching Programme through Livelihood Enhancement and Conservation in Arth Ganga Concept

2.1. OBJECTIVE I: SEED PRODUCTION OF SELECTED FISH SPECIES OF RIVER GANGA USING RIVERINE GERMPLASM

2.1.1. Captive breeding program of Indian Major Carp (IMC)

A captive breeding programme of Indian Major Carps (Rohu, Catla and Mrigal) was carried out at Balagarh, Hooghly, West Bengal, on 4th August 2024 (Fig. 1 A-H). The objective was to produce wild seed of riverine carps artificially towards restoration and conservation through river ranching. For this purpose, the prospective spawners were previously collected from the different stretches of the Ganga River and stocked in the broodstock pond for gonadal development. Fully matured fishes (weight range: 0.66 to 6.2 kg) were selected for the captive breeding program (Table 1). After a thorough gonadal inspection, the female fish were injected with an initial dose of Carp Pituitary Extract (CPE) @ 2-4 mg/kg body weight through intraperitoneal injection during evening hours and @ 6-8 mg/kg body weight after 5 hrs. A single dose of CPE was provided to the male brood fishes @ 2-4 mg/kg body weight. After a five-hour gap following a second dose of CPE injection, wet stripping was carried out by gently pressing on the lower abdominal portion of the fish to collect the eggs and milt, respectively. The eggs and milt were mixed properly for fertilization and readily transferred to the hatching pool. Approximately 76 lakh spawns of IMC (Rohu: 26 lakhs, Catla: 28 lakhs and Mrigal: 22 lakhs) were produced through this breeding program to restore indigenous prized fishes of the river Ganga through ex-situ conservation. The fertilization rate was estimated to be between 86% and 88%, whereas the hatching rate was 82-86% during breeding activity. After 72 hours of post-hatching, the spawns were stocked in the pre-prepared nursery ponds.

Table 1: List of brood stock and breeding details under captive breeding in 2024

Species	Broodfish Count				Fertilization rate (%)	Hatching rate (%)	Spawn produced (lakh)
	Male (♂)		Female (♀)				
	Nos.	Wt. (kg)	Nos.	Wt. (kg)			
Labeo rohita (Rohu)	42	42.9	44	40.5	88	84	26.0
Labeo catla (Catla)	11	36.8	19	55.8	86	86	28.0
Cirrhinus mrigala (Mrigala)	36	23.8	41	31.5	88	82	22.0
Total	**89**	**103.5**	**104**	**127.80**			**76.0**

Figure 1(A-H): Captive breeding activities of wild caught Indian Major Carps

2.2. OBJECTIVE II: RESTORATION OF THE SELECTED FISH SPECIES (IMC & CATFISH) OF THE RIVER GANGA THROUGH RANCHING

Fish ranching programs were carried out in several areas of the Ganga River as a component of the ICAR CIFRI-NMCG project to restore fish populations. As part of this, ICAR-CIFRI has undertaken a tremendous effort to implement the "National Ranching Program III" from 2023–2024 across several states. ICAR-CIFRI carried out 30 different ranching activities (Table 2) (Fig.2) over time to conserve and restore Indian Major Carps (IMC), Mahseer and other indigenous fish of the river, releasing 54.44 lakh of fingerlings (produced through induced breeding of Gangetic brooders).

Table 2: List of river ranching programs of Indian Major Carps (IMC), Mahseer and other indigenous fish fingerlings for the period 2023-24

Sl No.	Date	Place	Fish species	Number of fish released (lakhs)
1.	19-01-2024	Barrackpore, West Bengal	IMC	0.50
2.	10-02-2024	Farakka, West Bengal	IMC & Chitala/Sarana	0.50
3.	10-02-2024	Mayapur, West Bengal	Sarana	2.00
4.	11-02-2024	Barrackpore, West Bengal	Sarana	1.00
5.	04-03-2024	Prayagraj, Uttar Pradesh	IMC	0.10
6.	13-03-2024	Ayodhya, Uttar Pradesh	IMC	1.00
7.	07-05-2024	Prayagraj, Uttar Pradesh	IMC	0.10
8.	09-05-2024	Kadadham, Uttar Pradesh	IMC	0.10
9.	11-05-2024	Sirsa, Uttar Pradesh	IMC	0.15
10.	15-05-2024	Mirzapur, Uttar Pradesh	MC	0.25
11.	30-05-2024	Balagarh, West Bengal	IMC & Sarana	3.06
12.	31-05-2024	Balagarh, West Bengal	IMC & Sarana	3.02
13.	05-06-2024	Barrackpore, West Bengal	IMC & Sarana	3.22

14.	06-06-2024	Kalna, West Bengal	IMC	3.37
15.	07-06-2024	Tribeni, West Bengal	IMC	3.12
16.	08-06-2024	Nabadwip, West Bengal	IMC	3.23
17.	12-06-2024	Lalbagh, West Bengal	IMC	3.27
18.	14-06-2024	Bally, West Bengal	IMC	3.16
19.	05-07.2024	Farakka, West Bengal	IMC & Chitala	3.00
20.	05-07.2024	Rajmahal, Jharkhand	IMC	3.00
21.	12-07-2024	Sultanganj, Bihar	IMC	3.00
22.	19-07-2024	Ballia, Uttar Pradesh	IMC	3.00
23.	20-07-2024	Patna, Bihar	IMC	2.50
24.	21-07-2024	Munger, Bihar	IMC	3.00
25.	24-09-2024	Barrackpore, West Bengal	IMC	0.50
26.	24-10-2024	Balagarh, West Bengal	IMC	0.10
27.	04-11-2024	Haridwar, Uttarakhand	Mahseer	0.06
28.	29-12-2024	Tribeni, West Bengal	IMC	1.50
29.	29-12-2024	Kalna, West Bengal	IMC	1.11
30.	30-12-2024	Nabadwip, West Bengal	IMC & Sarana	2.52
			Total	**54.44**

During the period, the fish ranching in River Ganga was conducted in five different states viz. Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal. Amongst all the states, maximum river ranching was conducted in the state of West Bengal (68%), followed by Bihar (17%), Uttar Pradesh (9%), Jharkhand (5%), and Uttarakhand (1%) (Fig. 3).

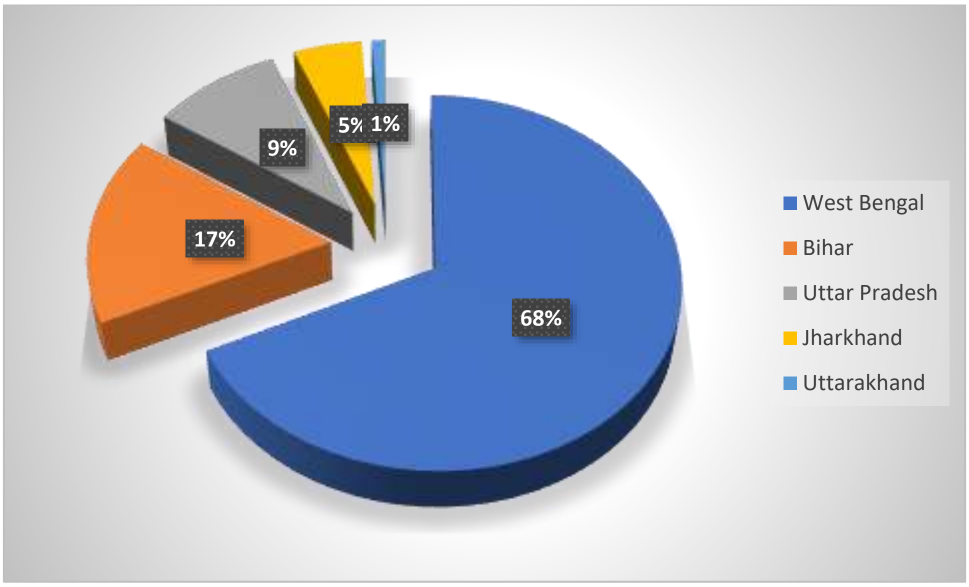


Figure 2: Percent (%) share of ranching conducted

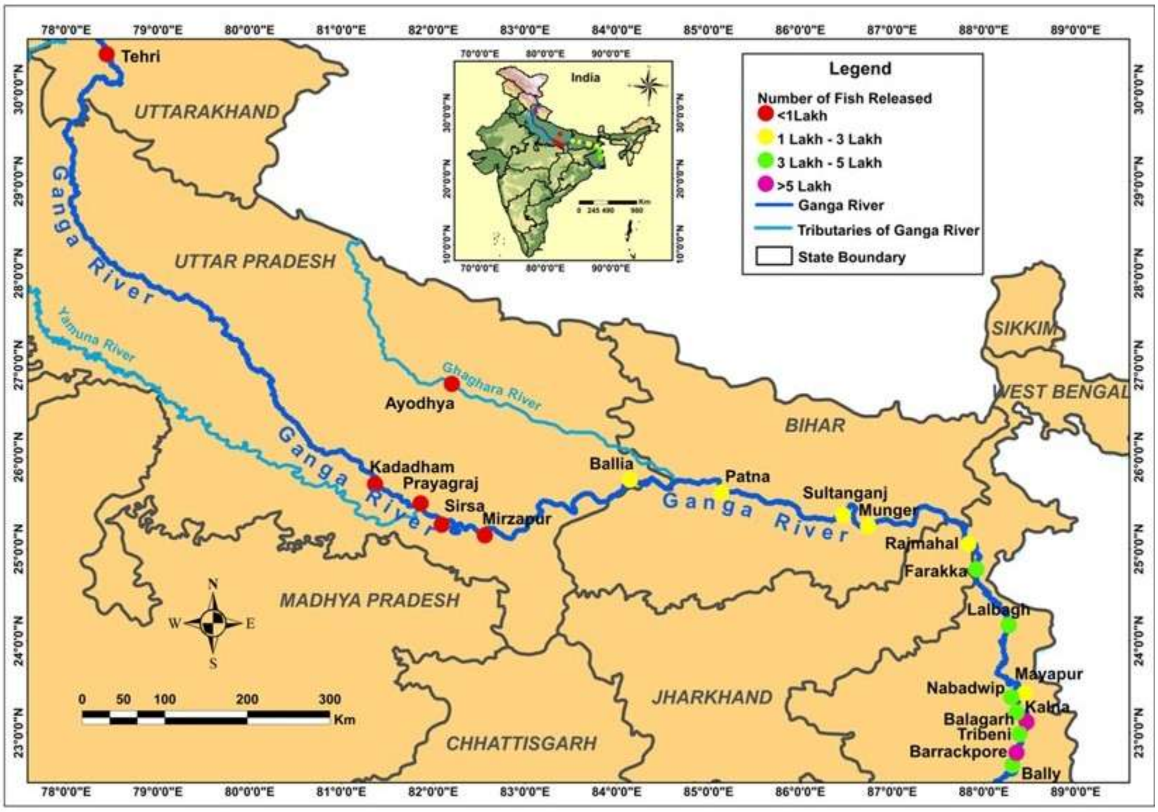


Figure 3: GIS plot showing sites of river ranching conducted during 2023-2024 under NMCG Phase III

2.2.1. Ranching Programme at Barrackpore, West Bengal

The National Ranching Mission-III was inaugurated by the Secretary, Department of Agriculture Research and Education (DARE) cum Director General (DG), ICAR Dr Himanshu Pathak and Deputy Director General (Fisheries) Dr Joykrushna Jena on 19th January 2024. Fifty thousand (0.50 lakh) fingerlings of Indian Major Carps were released into the Ganga River at Barrackpore (Monirampore Ghat), West Bengal, by the ICAR-CIFRI NMCG team during the event (Fig. 4). During the event, a dedicated sampling CIFRI-NMCG boat "Matsyakimanthan" was inaugurated by the Hon'ble Secretary and DG ICAR.

Figure 4 (A-B): (A) Ranching in river Ganga at Barrackpore by Secretary and DG ICAR on 19.01.2024; (B) Inauguration of CIFRI-NMCG sampling boat by Secretary and DG ICAR on 19.01.2024

2.2.2. Ranching Programme at Farakka, West Bengal

Shri G. Asok Kumar, Director General, NMCG, participated in the ranching programme by releasing 0.506 lakhs artificially bred wild IMC germplasm of the river Ganga at Farakka on 10th February 2024. A total of 0.010 lakhs of indigenous Gangetic fish (Punti, Tangra, Kholse, Piyali, Chitala, Bata, and Prawn) were also released during the programme (Fig. 5A).

2.2.3. Ranching Programme at Nabadwip, West Bengal

Shri G. Asok Kumar, Hon'ble Director General, NMCG, also took part in the ranching programme at the Holy Mayapur, Nabadwip, Nadia on 10th 2024. Two lakhs (2.0) native Sarana (Sar Puti) were released into the Ganga River at Prabhupad Ghat, Mayapur, West Bengal during the auspicious event (Fig. 5B).

2.2.4. Ranching Programme at Barrackpore, West Bengal

A ranching programme at Barrackpore (Monirampore ghat) was conducted on 11th February 2024 (Fig. 5C). In the event a total of 0.50 lakhs of native riverine stock of Sarana was released by the Director General (DG), NMCG and other dignitaries.

2.2.5. Ranching Programme at Sangam, Uttar Pradesh

One lakh advanced-size fingerlings of IMC were released into the Ganga River at Sangam Nose in Prayagraj on March 6, 2024 (Fig. 5D). The initiative, under the NMCG project, aimed to replenish dwindling fish populations and contribute to the overall health of the river ecosystem. The event was graced by Shri Umesh Chandra Ganesh Kesharvani, Hon'ble Mayor, Prayagraj, who served as the chief guest. He emphasised the need for collective efforts to ensure the cleanliness and preservation of the river, recognizing its cultural, environmental, and socio-economic significance.

2.2.6. Ranching Programme at Ayodhya, Uttar Pradesh

A river ranching programme was conducted in the Saryu River at Ayodhya in Uttar Pradesh on 13th March 2024 (Fig. 5E). Shri Lallu Singh, Hon'ble Member of Parliament from Ayodhya graced the event. During the event, 1.0 lakh fish fingerlings of Indian Major Carps were released from the Guptar Ghat of Ayodhya.

2.2.7. Ranching program at Prayagraj, Uttar Pradesh

ICAR-CIFRI Regional Center in Prayagraj conducted a ranching program, releasing 10,000 IMC fingerlings into the Yamuna River. Prof. Shashi Kant Duggal, former Director of MNNIT, Prayagraj, was the chief guest of the program. Prof. Duggal emphasized the critical importance of fish diversity and the health of river ecosystems. Special guest Shri Subedar Jagdish Singh Chauhan of the Ganga Task Force, Prayagraj, addressed the gathering, detailing the extensive work undertaken by the Ganga Task Force in protecting and rejuvenating the river. Shri Rajesh Sharma, Convener of the Ganga Vichaar Manch, participated as a special guest under the National Clean Ganga Mission of the Ministry of Jal Shakti, Government of India.

Figure 5 (A-E): Glimpses of Ranching at different places (A: Farakka, B: Nabadwip, C: Barrackpore, D: Sangam and E: Ayodha**)**

2.2.8. Ranching program at Kada Dham, Prayagraj, Uttar Pradesh

ICAR-CIFRI released 10,000 IMC into the river at Kada Dham, Prayagraj on 9th May 2024. Mr. Rajesh Sharma addressed the gathering, emphasizing the importance of conservation and cleanliness of the Ganga. Special guest Shri Binay Pandey highlighted the significance of the ranching program, underscoring the need for special measures to conserve fish populations and restore the quality of Ganga water.

2.2.9. Ranching program at Sirsa, Prayagraj, Uttar Pradesh

Fifteen thousand fingerlings of IMC were released during a ranching program at Sirsa, organized by ICAR-CIFRI Prayagraj under the NMCG project. The event took place at Shriram Pratap Inter College. Shri Shiv Prakash Pathak, the college's principal, served as the chief guest. The ranching activity was conducted in the presence of over 250 students, making it a highly educational and participatory event. Special guest Shri Rajesh Sharma, Convener of Ganga Vichaar Manch under the NMCG, also addressed the gathering.

2.2.10. Ranching program at Mirzapur, Uttar Pradesh

In a separate event at Mirzapur, 25,000 IMCs were released during the ranching program. Sri Navin Mishra, the Fisheries Development Officer, was the chief guest. The ranching was conducted under his supervision, and he addressed over 50 people about the importance of preserving the fish diversity in the river. The entire program was coordinated by Dr. Dharm Nath Jha, in charge of the centre, who explained the objectives of ranching to the public.

2.2.11. Ranching program at Balagarh-Somrabazar, West Bengal

A two-day river ranching program at the Balagarh- Somrabzar stretch was performed on 30th - 31st May, 2024, as part of the "Namami Gange" programme (Fig. 6A). Along with local fishermen and other members of the ICAR-CIFRI NMCG project team, 6.08 lakh IMC fingerlings and indigenous *Systomus sarana* were released into the Ganga River at Balagarh-Somra bazar stretch. Dr. B.K. Das, Director addressed the gathering and urged the local populace to avoid plastics and other pollution.

2.2.12. Ranching program at Barrackpore, West Bengal

On the occasion of 'World Environment Day, 2024', ICAR-CIFRI conducted a river ranching program in Seoraphully Ghat, releasing 3.00 lakh fingerlings of IMC and 0.22 fingerlings of Olive barb into the river Ganga (Fig. 6B). Scientists of the institute along with the NMCG team organised the ranching program and stressed the need to maintain Gangetic health.

2.2.13. Ranching program at Kalna, West Bengal

ICAR-CIFRI released 3.37 lakhs fingerlings of IMC into the river at Kalna, Mahismardini Ghat, West Bengal on 6th June 2024 (Fig. 6C). ICAR-CIFRI NMCG team highlighted the significance of the ranching program to the local fishers, underscoring the need for special measures to conserve fish populations and restore the quality of Ganga water.

2.2.14. Ranching program at Tribeni, West Bengal

ICAR-CIFRI conducted a ranching programme at Tribeni to preserve and revitalise the River Ganga. Three lakh twelve thousand (3.12 lakh) fingerlings of Indian Major Carps were released into the Ganga River at Durgamandir Ghat, Triveni to restore the riverine stock (Fig. 6D).

2.2.15. Ranching program at Mayapur, West Bengal

In Mayapur, ICAR-CIFRI implemented a ranching programme aiming to protect and revitalise the river Ganga. In an effort to replenish the riverine stock, 3.23 lakh fingerlings of Indian Major Carps were released into the Ganga River at Swarupganj Ghat, Mayapur (Fig. 6E).

2.2.16. Ranching program at Lalbag, West Bengal

In Lalbag, Murshidabad, the institute organized a river ranching program aimed at safeguarding and rejuvenating the Ganga River. ICAR-CIFRI NMCG project team culminated in the release of 3.27 lakh fingerlings of Indian Major Carps into the Ganga River at Badha Ghat, Lalbag, Murshidabad. Shri Banamali Roy, the Sub-Divisional Officer (SDO) of Lalbag, attended the program and appreciated all the members of the Namami Gange Project for their tireless efforts.

2.2.17. Ranching program at Bally, West Bengal

Under the holy presence of Maharaj Satishananda, Assistant General Secretary, Belur Math, ICAR-CIFRI implemented a ranching programme and released 3.16 lakh fingerlings of Indian Major Carps into the Ganga River at Barendrapara Ghat, Bally, West Bengal on 14th June, 2024 (Fig. 6F). Respected Maharaj hailed the conception and excellent execution of river ranching and wished for its broader approach all over our motherland among all people. Additionally, Dr. B.K. Das, the Director of the institute, informed the local fishermen about the importance of maintaining the health of the Ganges River system.

Figure 6 (A-F): Ranching at different places (A: Balagarh, B: Barrakpore, C: Kalna, D: Tribeni, E: Mayapur, and F: Bally)

2.2.18. Ranching program at Farakka, West Bengal

ICAR-Central Inland Fisheries Research Institute, Barrackpore, continues its mega 'National Ranching Programme-2024' under the Namami Gange Programme at Farakka, West Bengal, to conserve and restore River Ganga (Fig. 7A). On 5th July 2024, ICAR-CIFRI ranched 0.50 lakh threatened Chitala fish seed at Farakka, West Bengal. Besides this, 3 lakh Rohu, Catla and Mrigal fish juveniles (>10 gm) were also released in the river Ganga.

2.2.19. Ranching program at Rajmahal, Jharkhand

ICAR- CIFRI, Barrackpore at Rajmahal Ghat, Jharkhand, conducted a river ranching program on 5th July 2024. ICAR-CIFRI, Barrackpore ranched 3 lakh fish germplasm of Indian Major Carps (Fig. 7B). An awareness programme was also organised in the presence of Dr B. K. Das, Director, CIFRI and PI, NMCG project. Dr Das highlighted the importance of ranching and conservation, as well as its impacts on the socio-economic development of the fishers' community along the river Ganga.

2.2.20. Ranching program at Sultanganj, Bihar

ICAR-CIFRI conducted a ranching programme at Sultanganj, Bihar, to preserve and revitalise the river Ganga. Three lakh twelve thousand fingerlings of Indian Major Carps were released into the Ganga River at Kamarganj Ghat, Sultanganj, to restore the riverine stock (Fig. 7C). Besides the CIFRI NMCG Project members, Mr Uday Prakash, Deputy Director of Fisheries (Bhagalpur) and local MLA Prof. Lalit Narayan Mandal attended the event.

2.2.21. Ranching program at Ballia, Uttar Pradesh

In Ballia, Uttar Pradesh, ICAR-CIFRI implemented a ranching programme to protect and revitalise the Ganga River. 3.0 lakh fingerlings of IMC were released into the Ganga River at Hukum Chapra ghat, Ballia, to replenish the riverine stock (Fig. 7D). Dr B. K. Das addressed the local fishermen community on the importance of biodiversity and the need for ranching. He also emphasised the growing plastic pollution. Mr Bipin Bihari Ojha (District Fisheries Officer), local Police Inspector Haldi, Mr Arjun Shah and others attended the event.

2.2.22. Ranching program at Patna, Bihar

The institute organised a river ranching program in Patna, Bihar, to safeguard and rejuvenate the Ganga River. ICAR-CIFRI NMCG project team released 2.50 lakh fingerlings of IMC into the Ganga River at Raja Ghat, Patna (Fig. 7E). Dr. N. Vijaya Lakshmi, IAS, currently serving as a Principal Secretary, Fisheries, Government of Bihar, attended the program and appreciated all the members of the Namami Gange Project for their tireless efforts. Shri Taranjot Singh IAS, Director, Animal and Fisheries Resources Deptt. Bihar’s government was also present at the event.

2.2.23. Ranching program at Munger, West Bengal

The ICAR-CIFRI NMCG project team organised a river ranching program in Soji Ghat, Munger, Bihar. At the event, the District Magistrate, Shri Avneesh Kumar, IAS, released 3 lakh fingerlings of IMC (Fig. 7F). Dr. B. K. Das highlighted the importance of ranching and the work taken up by ICAR CIFRI in the river Ganga under Namami Gange. Mr. Shaligram Prasad, District Project Officer of District Ganga, and Mr. Manish Kumar Rastogi, District Fisheries Officer of Munger, attended the event.

2.2.24. Ranching program at Barrackpore, West Bengal

On 24th September, 2024, Dr. Abhilaksh Likhi, Secretary, Department. of Fisheries, Government of India and Dr. Bijay Kumar Behera, Chief Executive, National Fisheries Development Board (NFDB) released 50,000 wild-bred fingerlings of IMC in River Ganga at Barrackpore, gesturing the ongoing mega seed ranching program under NMCG, besides Dr. B.K. Das, Director of ICAR-CIFRI, scientists, technical officers, and research scholars of the Institute, about 100 fishermen and women participated in the event (Fig. 7G). An awareness activity on the significance of responsible fishing on the riverine fisheries and fishers' livelihood was also organised.

Figure 7 (A-G): Glimpses of ranching at different palces (A: Farakka, B: Rajmahal, C: Sultanganj, D: Balia, E: Patna, F: Munger and G: Barrackpore)

2.2.25. Ranching program at Balagarh, West Bengal

ICAR-Central Inland Fisheries Research Institute, on October 24, 2024, released 10,000 wild-bred fingerlings of Indian Major Carps in river Ganga at Barrackpore, gesturing the ongoing mega ranching program under the NMCG project. ICAR-CIFRI has released 12 lakh fingerlings in the River Ganga at Balagarh, West Bengal (Fig. 8). Besides Dr. Sandeep Behera, Senior Consultant (Biodiversity), NMCG and other scientific personnel from the institute, about 25 fishermen and women from the local area participated in the event. An awareness activity on the significance of responsible fishing on the riverine fisheries and fishers' livelihood was also organised.

Figure 8: River ranching at Balagarh on 24 October 2024 by Dr. Sandeep Behera, Senior Consultant (Biodiversity), NMCG, New Delhi

2.2.26. Ranching program at Haridwar, Uttarakhand

On the occasion of '*Ganga Utsav'*, ICAR-Central Inland Fisheries Research Institute, Barrackpore has released about 6,000 Mahseer fingerlings into the River Ganga in the august presence of Shri C. R. Patil, Hon'ble Union Minister of Jal Shakti, Government of India at Haridwar. Fishes were released as a part of the National Ranching program on 4th November 2024 at Chandi Ghat to conserve and restore them (Fig. 9). The event was also attended by Shri Rajbhushan Chaudhary, Hon'ble Minister of State, Ministry of Jal Shakti, Govt of India, Srimati Rekha Arya, Hon'ble Minister, Govt of Uttarakhand, Shri Trivendra Singh Rawat, Hon'ble Ex-CM Uttarakhand and Member of Parliament (LS), Haridwar, Shri Rajeev Kumar Mital, IAS, DG NMCG, Dr. Sandeep Behra Biodiversity Consultant NMCG and Dr. B. K. Das, Director CIFRI.

Figure 9: River ranching at Haridwar on 4th November 2024 on the occasion of 'Ganga Utsav-2024'

2.2.27. Ranching program at Tribeni and Kalna, West Bengal

To celebrate the International Day for Biological Diversity, which the United Nations has recognised, ICAR-CIFRI marked the occasion by releasing 2.61 lakh major carps, including Rohu, Catla, and Mrigal, into the River Ganga at two locations, viz. Tribeni and Kalna in West Bengal on 29th December 2024 (Fig.10A&B). Local fishermen were involved in the event, alongside members of the institute. The event witnessed the participation of 125 local community members and fishermen from both Tribeni and Kalna. The river ranching initiative was led by Dr. B. K. Das, Director, ICAR-CIFRI and the PI of the project. During the event, Dr. Das emphasized the importance of maintaining a clean river Ganga and urged the locals to combat plastic pollution at the grassroot level. An awareness campaign was also conducted to highlight the conservation of Gangetic dolphins and other riverine species.

2.2.28. Ranching program at Nabadwip (Mayapur), West Bengal

ICAR CIFRI, to restore indigenous river Ganga fishes, released 2.52 lakhs of Sarana (*Systomus sarana*) at Holy Mayapur in West Bengal on 30th December 2024 (Fig. 10C). *S. sarana*, commonly known as olive barb and locally as sarputi in West Bengal. 'Sarputi' is a medium-sized minor carp and requires conservation due to over-exploitation, destruction of breeding grounds and environmental degradation. Besides Sarputi, one lakh of IMC was also released at the event. Awareness of dolphins and other riverine diversity was also performed under the presence of Dr. B.K. Das, Director ICAR-CIFRI and PI of the Project.

Figure 10 (A-C): River ranching at A: Tribeni, B: Kalna and C: Nabadwip during International Day for Biological Diversity-2024

2.2.29. First River Field School

In collaboration with Promotion Scheme for of Academic and Research Collaboration, Delft University of Technology, Netherlands, Namami Gange Project and National Institute of Technology, Calicut, India, a first river field school on "Exploring the Food-Energy-Water Nexus in River Ecosystems" was organised during 21-26 October 2024 at ICAR-CIFRI, Barrackpore, West Bengal, India (Fig. 11). The river field school initiated with a strategic approach to understand different stakeholder participation and the complex nexus over the water, food and energy aspects and how water from the river Ganga can be uniformly distributed across different stakeholder demands in various forms. Approximately 10-13 million fishing families in India rely on the river Ganga for their livelihoods. A group activity was organised to understand environmental conflicts over different water projects in India and to identify the drivers, commodities, and their impact on the ecosystem. River Walk in Barrackpore area was organised on this day to share non-technical knowledge for river health assessment, i.e. the visual appearance of water colour, odour, riparian vegetation, land use pattern, bank stability, habitat complexity, macrophyte, macroinvertebrates and fish diversity observation and finally the cultural site along the river, livelihood activities and recreational activities also discussed. Microplastic contamination, river health and decadal changes in water quality in the Ganga River were discussed. Environmental flow, or E-Flow, was also emphasised for river ecosystem sustainability. A model scoring sheet on river health assessment through a citizen science approach was also drafted. The use of software for preparing hydrological models was also demonstrated. A discussion on the spiritual and cultural significance of the River Ganga was held at Belur Math, the headquarters of the Ramakrishna Math and Ramakrishna Mission, West Bengal. An insightful interaction was held with the fishermen of *Shripur Balagarh Anchal Matsyajibi Somobay Samiti* at Balagarh Hooghly, West Bengal, to understand the riverine problems, vulnerabilities and economic instability. The importance of understanding the rich aquatic resources of the river Ganga and long-term strategies to rejuvenate was emphasised in the discussion, followed by 10,000 Indian Major Carp ranched in the river Ganga. A visit to the energy resource generation unit of the river Ganga in Farakka was also organised in the event.

Figure 11: Field school organised by ICAR-CIFRI, Barrackpore

2.3. OBJECTIVE III: ASSESSING THE IMPACT OF RANCHING PROGRAM ON THE RIVER

2.3.1. Growth trends and fish landing forecasting in the Patna stretch of the river Ganga

The study aimed to model and forecast fish landings of the river Ganga in and around Patna city, Bihar, using the Seasonal Auto-Regressive Integrated Moving Average (SARIMA) model. Time-series data on fish landings from 2016-17 to 2023-24 were collected using a landing-based approach and segregated by economically significant fish groups. As per the model-based selection criteria, the actual landings closely matched the forecasted values. Out-of-sample forecasts for 2024-25 to 2026-27 indicated an upward trend, with IMC landings rising from 1.23 to 1.83 tons and major catfish increasing from 7.29 to 7.93 tons (Fig. 12A). Minor catfish landings in the forecast exhibited some fluctuation, starting at 6.06 tons in 2024, rising to 6.36 tons in 2025, and then decreasing to 6.13 tons by 2026. The forecasted data, based on different SARIMA models, showed that the landing rate of fish would increase by 79% (for IMC), 14.30% (for major catfish), and 44.91% (for minor catfish) from 2023 to 2026 (Fig.12 B&C). Currently, fisheries in the River Ganga are declining due to overexploitation, pollution, and dam construction, among other factors. The government is advised to implement various policies, such as river ranching, to ensure stable fish production in the Ganga River stretch near Patna. Increased fish landings and the generation of employment opportunities can significantly and positively contribute to the enhancement of river health. The present findings will also serve as an added reference for fisheries planners and policymakers in the sustainable management of essential fish groups.

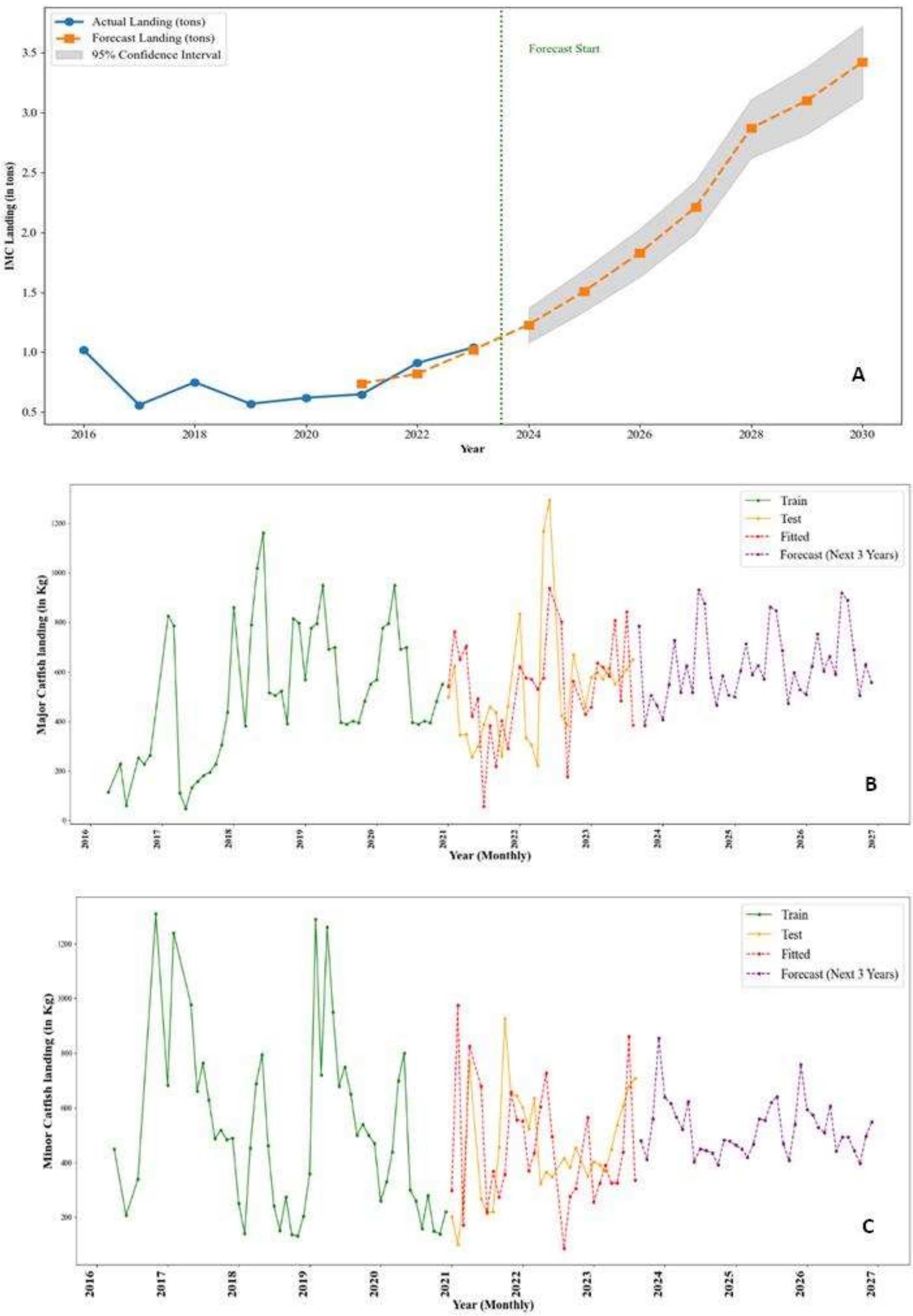


Figure 12 (A-C): A. Forecast of annual landings of IMC B. Major catfish and C. Minor Catfish in River Ganga at Patna

2.3.2. Impact of IMC ranching in Bhagalpur stretch of river Ganga

ICAR-CIFRI has assessed the impact of river ranching from the year 2020-24 particularly in Bhagalpur site of River Ganga. Landing of IMC during 2018-2024 in Bhagalpur stretch of the river was 13.53 tonnes (Fig. 13). The earlier records of fish landing from the year 1959 to 1990 showed an average landing of 7.01 tonnes. Sporadic data on fish landing were available after 1990 till 2016. River ranching at site Bhagalpur initiated from the year 2022 onwards. The fish landing which was 1.20 tonnes in 2019-20 has Showedn a progressive upward trend over last four years. The landing of IMC has increased from 1.20 tonnes to 4.32 tonnes at present Showeding a 5.2 fold increase from 2019. However, compared to the previous data of 1990, the landing has decreased by 28%.

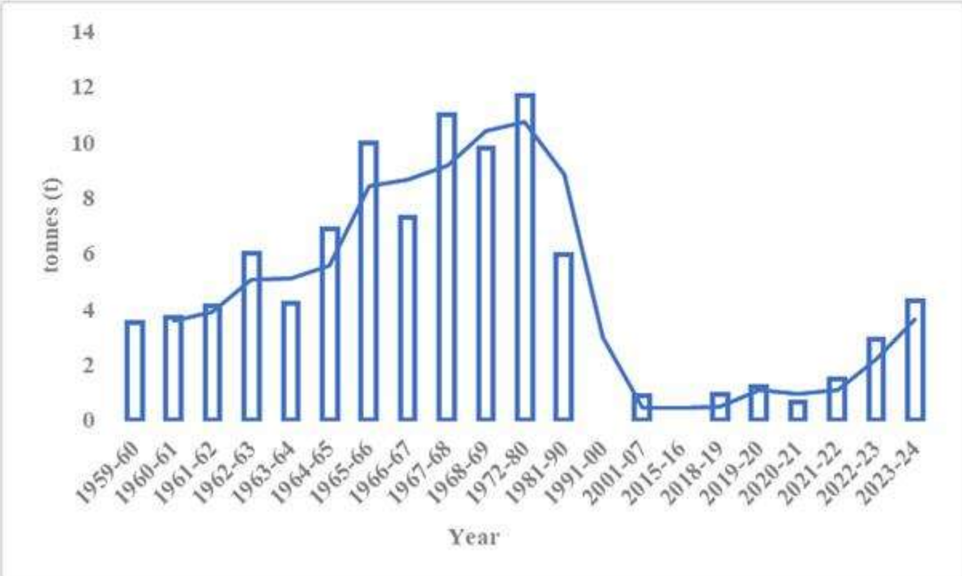


Figure 13: Landing of IMC in Bhagalpur stretch from 1959 to 2024

2.3.3. Sampling in river Ganga

To evaluate the health of this vital waterbody, systematic water sampling was conducted across four major states, viz. Uttarakhand, Uttar Pradesh, Bihar, and West Bengal, covering a total of 20 monitoring stations of different water quality and habitat regimes (Fig. 14). This study aimed to assess the water quality, fish diversity, identify pollution hotspots, and establish baseline parameters for future comparison.

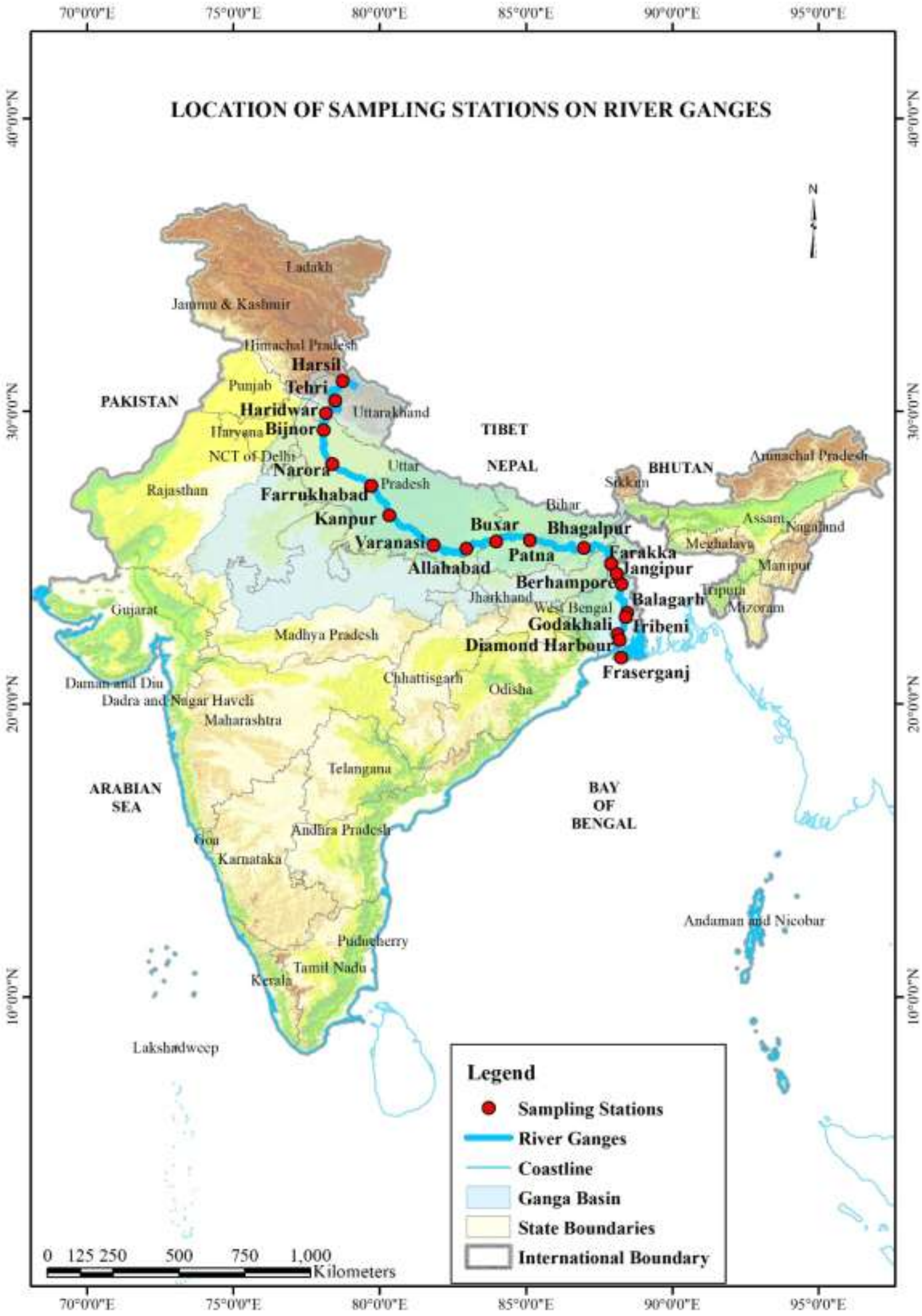


Figure 14: GIS map showing sampling sites in river Ganga

2.3.4. Fish landing in River Ganga

- ICAR-CIFRI has also been monitoring the status of fish landing along 17 selected sites (Haridwar to Barrackpore) of river Ganga covering four states. The data revealed a total landing of 929.21 tonnes from all sites (Fig. 15).

- In the state of Uttarakhand, the mean monthly landing from the site Haridwar was 6.13 tonnes, with peak January (1.82 tonnes) and least during February (0.22 tonnes). The mean annual landing of exotic fish was 2.93±0.51 tonnes.

- The mean monthly landing of 746.49 tonnes was recorded from 10 selected sites of Uttar Pradesh. The highest landing was recorded from the site Kanpur (120.3±5.6 tonnes) followed by Prayagraj (119±5.9 tonnes), Narora (101.7±7.3 tonnes), Gazipur (75.5±3.5 tonnes), Farukkhabad (61.77±2.3 tonnes), Varanasi (61.14±3.4 tonnes), Mirzapur (59.15±2.4 tonnes), Ballia (49.7±1.8 tonnes) and Chunar (24.98±1.72 tonnes) respectively. Out of the total estimated landing, IMC was observed to be highest at Kanpur (50±4.2 tonnes) with lowest at Chunar (2.45±0.15 tonnes) (Fig .16). The landing of exotic fishes (common carp and tilapia) was observed maximum in the site Kanpur (18.07±0.86 tonnes) and least at site Chunar (8.40±0.74 tonnes) (Fig. 17). The catfish landing was observed highest at Kanpur (35±1.87 tonnes) and lowest at Chunar (5.5±0.40 tonnes) (Fig. 18).

- The monthly mean fish landing from three sites, viz., Buxar, Patna, and Bhagalpur in Bihar were recorded to have 123.71 tonnes. The highest landing was recorded from the site Buxar (55.26±2.46 tonnes), followed by Patna (36.85±2.28 tonnes) and Bhagalpur (31±1.74 tonnes). The landing of Indian Major Carps (IMC) was estimated to be 37.61 tonnes, which accounted for 30.4% of the total landing. Site Buxar was confronted with the exotic fishes (common carp and tilapia), with a mean landing of 7.36±0.74 tonnes. The landings of catfishes were observed to be consistent in Buxar (13.7±0.63 tonnes) and Patna (13.43±1.05 tonnes); however, a low value was observed in Bhagalpur (8.8±0.54 tonnes).

- On the other side, landing from the site Farakka, Malda and Barrackpore in West Bengal was recorded to be 52.98 tonnes during the period. Site Farakka showed the highest landing 35.2±2.78 tonnes, followed by Barrackpore (14.5±1.39 tonnes) and Malda (3.28±0.40 tonnes) respectively. The findings indicated no bulk exotics landing in river Ganga from West Bengal. The mean landing of IMC was recorded to be 0.95±0.06 tonnes.

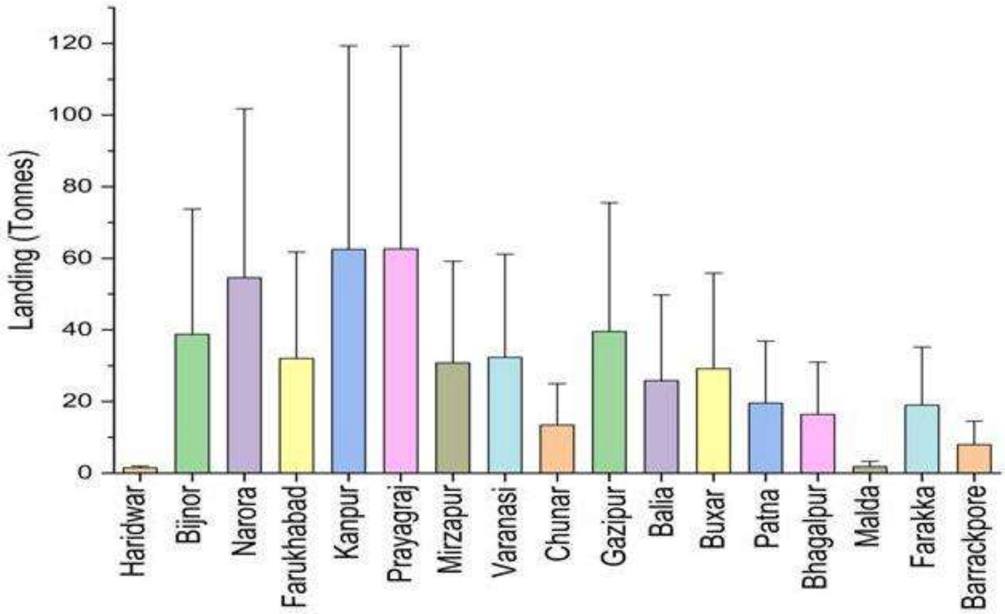


Figure 15: Average monthly fish landing in river Ganga

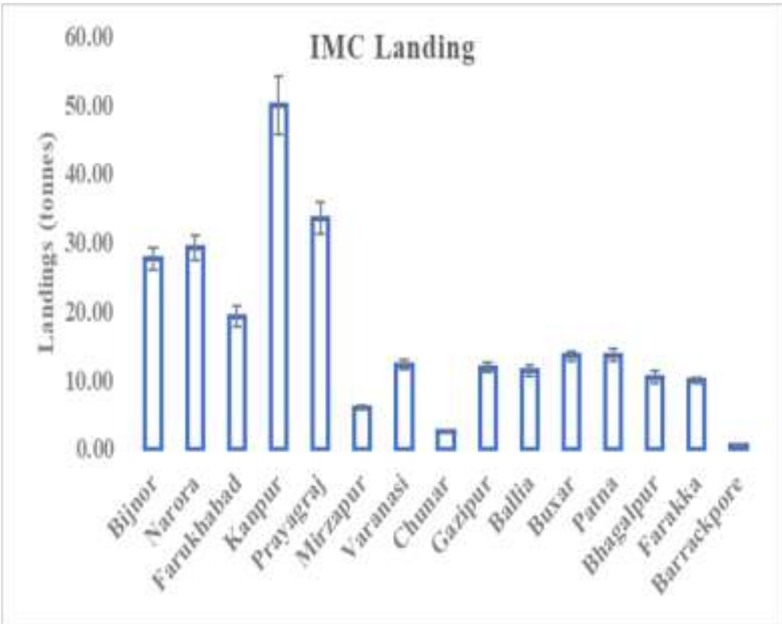


Figure 16: Average monthly IMC landing in river Ganga

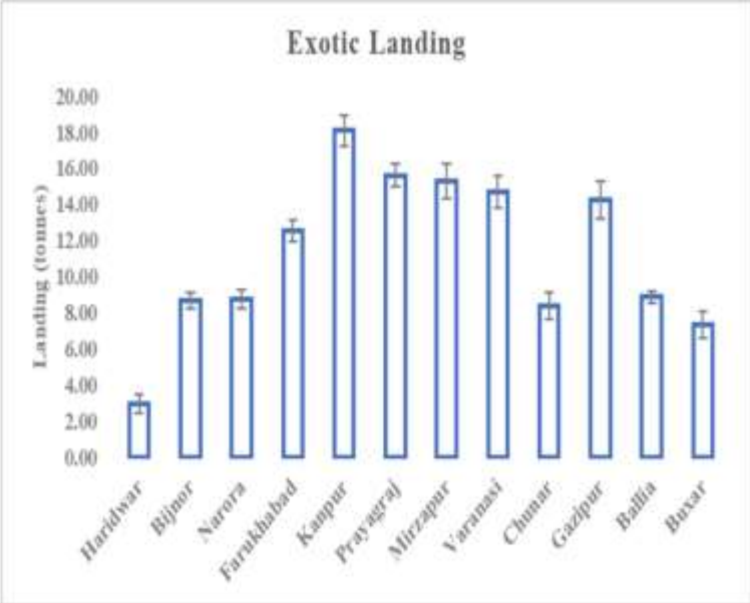


Figure 17: Average monthly exotic fish landing in river Ganga

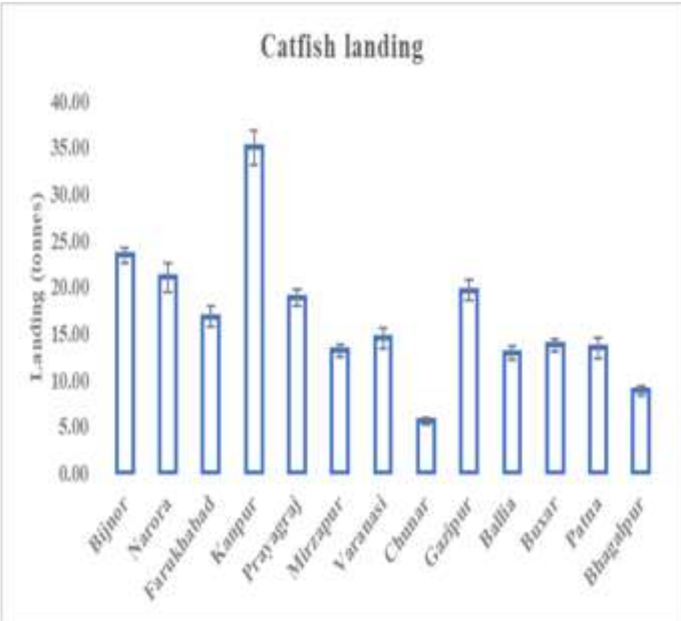


Figure 18: Average monthly catfish landing in river Ganga

2.3.5. Ichthyofaunal diversity of River Ganga

A total of 184 species (177 native and 7 exotics) belonging to 132 genera, 51 families, and 16 orders were recorded from river Ganga (Table 3). The piscine order Cypriniformes showed the highest number of species (n = 68), followed by Siluriformes (n = 21) and Perciformes (n = 13). Cyprinidae was the dominant family in the fish community, accounting for 22% of the total fish diversity, followed by Danionidae (16%), and Sisoridae (5%). During the year, the highest fish species richness was observed at Bijnor (n = 90) and Farakka (n = 70) stations (Fig. 19A&B).

The lowest species richness was recorded at the site Harsil (n = 2) in the upper stretch, Haridwar (n = 21) in the middle stretch, Balagarh in the lower (n = 18) stretch and Diamond Harbor in the estuarine zone.

2.3.6. Seasonal variation of fish diversity in river Ganga

The fish species in the River Ganga showed distinct seasonal variations. These variations are particularly noticeable across the pre-monsoon (PRM), monsoon (MON), and post-monsoon (POM) periods (Fig. 19C). During PRM, fish numbers are generally lower at many sites, with locations like Harsil, Tehri, and Buxar highlighting relatively modest fish species counts. However, some sites, such as Bijnor and Narora, maintained a consistent level of species presence, possibly due to more stable environmental conditions. The PRM period likely prepares fish for the changes in water levels and temperature, with species beginning to adjust for the upcoming breeding cycles. The MON season illustrated a marked shift in fish species numbers. In sites like Haridwar, Bijnor, and Prayagraj, the numbers either remain stable or show a slight increase. This can be attributed to the high-water levels and increased nutrient flow into the river, providing a more conducive environment for fish to thrive. However, some areas, such as Farakka and Fraserganj, were observed to have a decrease in species richness, potentially due to increased turbidity and changes in the river's ecology during heavy rainfall. The MON is often a peak period for fish migration and spawning due to favourable water conditions. POM showed a diverse trend across the sites. While some areas, such as Bijnor, Farukhabad, and Kanpur, exhibited significant increases in species numbers, other sites, such as Patna and Bhagalpur, experienced a noticeable decline. This drop in fish species could be linked to the decrease in water levels and the return of more stable, less turbulent conditions in the river. The POM marks a transition as the river stabilises and particular species may migrate or reduce their activity as water temperatures drop. Overall, the seasonal patterns reflected the river’s fluctuating environmental conditions, such as water flow, temperature, and nutrient availability, which influence the fish populations differently at various locations.

2.3.7. Conservation status

The evaluation of the conservation status of species of the fish species have illustrated that 81% of the recorded fishes are classified under least concern (LC) category, 5% under near threatened (NT), 3% under vulnerable (VU), 2% under endangered (EN) while 6% as data deficient (DD) and 3% as not evaluated (NE) category as per the IUCN Red List Categories and Criteria (2025) (Fig. 19D).

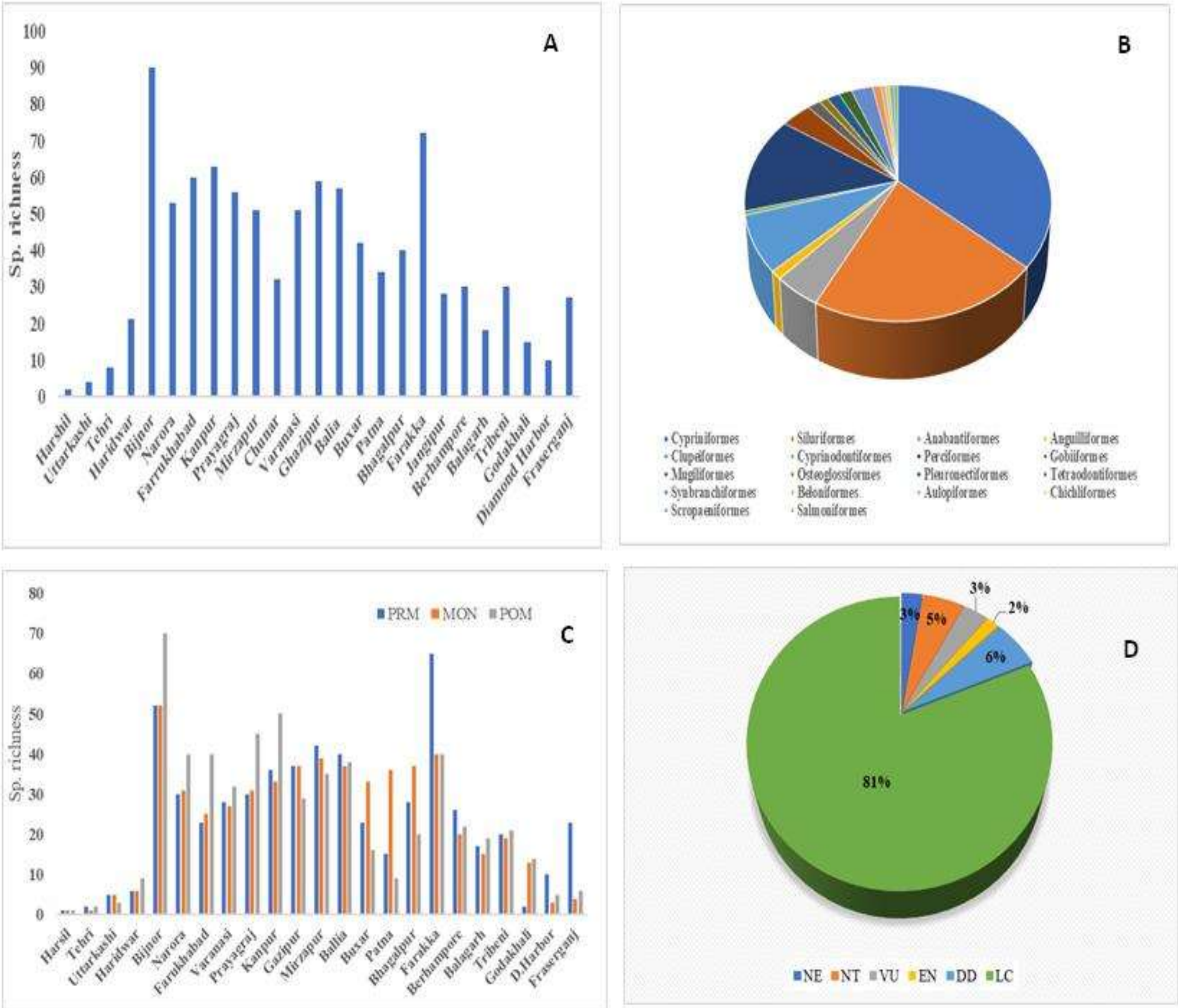


Figure 19 (A-D): A. Site wise fish species richness in River Ganga, B. Order wise representation of the piscine family recorded from River Ganga, C. Season wise fish species abundance in different sites, D. Conservation status of fish species from River Ganga

Table 3: List of site wise fish species recorded from River Ganga

Species	Order	Family	IUCN	Harsil	Uttarkashi	Tehri	Haridwar	Bijnor	Narora	Farrukhaba	Kanpur	Prayagraj	Mirzapur	Chunar	Varanasi	Ghazipur	Balia	Buxar	Patna	Bhagalpur	Farakka	Jangipur	Berhampor	Balagarh	Tribeni	Godakhali	D. Harbor	Fraserganj
Aborichthys elongatus (Hora, 1921)	Cypriniformes	Nemacheilidae	LC					+	+							+												
Acanthocobitis botia (Hamilton, 1822)	Cypriniformes	Nemacheilidae	LC					+	+			+				+	+				+							
Ailia coila (Hamilton, 1822)	Siluriformes	Ailiidae	NT					+		+	+	+	+	+		+	+	+	+	+	+		+	+	+	+		
Ailiichthys punctata (Day, 1872)	Siluriformes	Ailiidae	LC					+			+	+				+												
Amblyceps mangois (Hamilton, 1822)	Siluriformes	Amblycipitidae	LC					+																				
Amblypharyngodon mola (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+		+	+	+	+		+	+												
Anabas testudineus (Bloch,1792)	Anabantiformes	Anabantidae	LC					+		+	+	+			+	+					+				+			
Anguilla bengalensis (Gray, 1831)	Anguilliformes	Anguillidae	NT																		+							+
Anodontostoma chacunda (Hamilton, 1822)	Clupeiformes	Clupeidae	LC																						+			+
Aplocheilus panchax (Hamilton, 1822)	Cyprinodontiformes	Aplocheilidae	LC																		+							
Badis badis (Hamilton, 1822)	Perciformes	Badidae	LC					+												+	+				+			
Bagarius bagarius (Hamilton, 1822)	Siluriformes	Sisoridae	VU					+	+	+	+	+	+	+	+	+	+	+	+	+	+							
Bagarius yarelli (Hamilton, 1822)	Siluriformes	Sisoridae	VU															+	+									
Bangana dero (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+																			
Barilius barila (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+	+	+	+	+		+	+	+											
Barilius vagra (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC			+	+																					

Botia almorhae (Gray,1831)	Cypriniformes	Botiidae	LC			+																						
Botia Dario (Hamilton, 1822)	Cypriniformes	Botiidae	LC				+	+										+			+							
Botia lohachata (Chaudhuri, 1912)	Cypriniformes	Botiidae	LC				+	+					+		+		+		+									
Brachirus pan (Hamilton, 1822)	Perciformes	Sciaenidae	LC																						+	+		
Brachygobius nunus (Hamilton 1822)	Gobiiformes	Gobiidae	NE																									+
Cabdio mora r (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC				+	+	+	+	+	+	+		+	+	+	+	+	+	+							
Chaca chaca (Hamilton, 1822)	Siluriformes	Chacidae	LC					+																				
Chagunius chagunio (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC				+					+			+		+	+										
Chanda nama (Hamilton, 1822)	Perciformes	Ambassidae	LC					+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+			
Channa gachua (Hamilton,1822)	Anabantiformes	Channidae	LC					+																				
Channa marulius (Hamilton, 1822)	Anabantiformes	Channidae	LC					+	+	+	+	+					+			+	+							
Channa striata (Bloch, 1793)	Anabantiformes	Channidae	LC					+	+	+	+	+	+		+	+	+				+							
Channa punctata (Bloch, 1793)	Anabantiformes	Channidae	LC					+	+	+	+	+	+	+	+	+	+				+							
Chelon parsia (Hamilton, 1822)	Mugiliformes	Mugilidae	NT																									+
Chitala chitala (Hamilton, 1822)	Osteoglossiformes	Notopteridae	NT					+	+	+	+	+							+		+							
Cirrhinus mrigala (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+	+	+	+	+	+	+	+	+	+		+	+							
Cirrhinus reba (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC				+	+	+	+	+	+	+	+	+	+	+	+	+		+							
Clarias gariepinus (Burchell, 1822)*	Siluriformes	Clariidae	LC							+																		
Clarias magur (Hamilton, 1822)	Siluriformes	Clariidae	EN																		+							
Clupisoma garua (Hamilton, 1822)	Siluriformes	Schilbeidae	LC					+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+		

Corica soborna (Hamilton, 1822)	Clupeiformes	Clupeidae	LC					+												+	+				+			
Crossocheilus latius (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC				+		+	+	+		+					+		+	+							
Ctenopharyngodon idella (Valenciennes, 1844)	Cypriniformes	Cyprinidae	LC					+	+	+																		
Cynoglossus cynoglossus (Hamilton, 1822)	Pleuronectiformes	Cynoglossidae	LC																								+	+
Cyprinus carpio var *communis* * (Linnaeus, 1758)	Cypriniformes	Cyprinidae	LC			+	+	+	+	+	+	+	+	+	+	+	+											
*Cyprinus carpio var. specularis** (Linnaeus, 1758)	Cypriniformes	Cyprinidae	LC														+											
Danio rerio (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+								+												
Devario devario (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+													+							
Deveximentum insidiator (Bloch, 1787)	Perciformes	Tetraodontidae	DD																						+	+		
Eleotris fusca (Forster, 1801)	Gobiiformes	Eleotridae	LC																						+			
Eleutheronema tetradactylum (Shaw, 1804)	Perciformes	Polynemidae	EN																									+
Erethistes pusillus (Muller & Troschel, 1849)	Siluriformes	Erethistidae	LC																		+							
Escualosa thoracata (Valenciennes, 1847)	Clupeiformes	Clupeidae	LC																									+
Esomus danricus (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+			+						+				+							
Eutropiichthys murius (Hamilton, 1822)	Siluriformes	Schilbeidae	LC							+	+	+	+		+													

Eutropiichthys vacha (Hamilton, 1822)	Siluriformes	Schilbeidae	LC					+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+			
Gagata cenia (Hamilton, 1822)	Siluriformes	Sisoridae	LC					+	+		+	+	+		+	+	+		+	+	+			+		+		
Gagata sexualis (Tilak, 1970)	Siluriformes	Sisoridae	LC																		+							
Garra lamta (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC				+																					
Gerres oyena (Fabricius, 1775)	Perciformes	Gerreidae	LC																									+
Glossogobius giuris (Hamilton, 1822)	Gobiiformes	Gobiidae	LC			+		+		+	+		+		+	+	+	+		+	+			+	+			
Glyptothorax cavia (Hamilton, 1822)	Siluriformes	Sisoridae	LC		+		+	+																				
Glyptothorax gracilis (Gunther, 1864)	Siluriformes	Sisoridae	DD				+	+																				
Glyptothorax telchitta (Hamilton, 1822)	Siluriformes	Sisoridae	LC					+																				
Gogangra viridescens (Hamilton, 1822)	Siluriformes	Sisoridae	LC					+				+			+	+	+											
Gonialosa manmina (Hamilton, 1822)	Clupeiformes	Clupeidae	LC					+	+	+			+	+	+	+	+	+			+							
Gudusia chapra (Hamilton, 1822)	Clupeiformes	Clupeidae	LC						+	+		+	+	+	+	+	+	+	+	+	+			+		+		
Heteropneustes fossilis (Bloch, 1794)	Siluriformes	Heteropneu stidae	LC					+		+							+	+			+			+	+			
Hypophthalmichthys nobilis * (Richardson, 1845)	Cypriniformes	Cyprinidae	DD						+	+	+		+		+	+												
Hypophthalmichthys molitrix * (Valenciennes, 1844)	Cypriniformes	Cyprinidae	NT					+		+	+					+	+											
Hyporhamphus limbatus (Valenciennes, 1847)	Beloniformes	Hemiramp hidae	LC																	+								
Johnius coitor (Hamilton, 1822)	Perciformes	Sciaenidae	LC					+	+	+	+	+	+	+	+		+	+	+	+	+			+	+			
Johnius gangeticus (Talwar, 1991)	Perciformes	Sciaenidae	DD													+									+	+		
Labeo angra (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+																				
Labeo bata (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+	+	+	+			+	+	+	+		+	+							

Labeo boga (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+	+	+	+	+							+	+							
Labeo calbasu (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+				
Labeo catla (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+	+	+	+	+	+	+	+	+	+	+	+								
Labeo dero (Hamilton 1822)	Cypriniformes	Cyprinidae	LC				+	+	+	+	+		+															
Labeo dyocheilus (McClelland, 1839)	Cypriniformes	Cyprinidae	LC				+	+																				
Labeo gonius (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+	+	+	+						+		+	+							
Labeo pangusia (Hamilton, 1822)	Cypriniformes	Cyprinidae	NT									+			+					+								
Labeo rohita (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+	+	+	+	+	+	+	+	+	+		+		+							
Labeo boggut (Sykes, 1839)	Cypriniformes	Cyprinidae	LC					+																				
Lates calcarifer (Bloch, 1790)	Perciformes	Latidae	LC																								+	+
Laubuca laubuca (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC								+	+				+					+							
Leiodon cutcutia (Hamilton, 1822)	Tetraodontiformes	Tetraodontidae	LC																		+							
Lepidocephalichthys guntea (Hamilton, 1822)	Cypriniformes	Cobitidae	LC					+													+							
Macrognathus aculeatus (Hamilton, 1822)	Synbranchiformes	Mastacembelidae	LC																		+							
Macrognathus aral (Bloch & Schneider, 1801)	Synbranchiformes	Mastacembelidae	LC						+																			
Macrognathus pancalus (Hamilton, 1822)	Synbranchiformes	Mastacembelidae	LC					+		+	+	+	+	+	+	+	+	+		+	+							
Macrospinosa cuja (Hamilton, 1822)	Siluriformes	Sciaenidae	DD																									+
Mastacembelus armatus (Lacepede, 1800)	Synbranchiformes	Mastacembelidae	DD					+	+	+	+	+	+	+	+	+	+	+	+	+	+							
Megarasbora elanga (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+																				
Monopterus cuchia (Hamilton, 1822)	Synbranchiformes	Synbranchidae	LC																		+			+	+			
Mystus bleekeri (Day, 1877)	Siluriformes	Bagridae	LC					+		+	+	+	+	+	+	+	+			+	+							
Mystus cavasius	Siluriformes	Bagridae	LC					+	+	+	+	+	+	+	+	+	+	+	+	+	+							

(Hamilton, 1822)																												
Mystus tengara (Hamilton, 1822)	Siluriformes	Bagridae	LC					+		+	+	+	+	+	+	+	+				+							
Mystus vittatus (Bloch, 1794)	Siluriformes	Bagridae	LC				+	+	+	+	+	+		+	+	+	+				+							
Nandus nandus (Hamilton, 1822)	Perciformes	Nandidae	LC					+													+			+				
Naziritor chelynoides (McCelland, 1839)	Cypriniformes	Cyprinidae	VU			+	+																					
Nemacheilus corica (Hamilton, 1822)	Cypriniformes	Nemacheilidae	LC					+																				
Notopterus notopterus (Pallas, 1769)	Osteoglossiformes	Notopteridae	LC					+	+	+	+	+					+		+		+							
Nuchequula blochii (Valenciennes, 1835)	Perciformes	Leiognathidae	NE																						+			+
Odontamblyopus rubicundus (Hamilton, 1822)	Gobiiformes	Gobiidae	LC																					+	+	+		+
Ompok bimaculatus (Hamilton, 1822)	Siluriformes	Siluridae	NT						+	+	+	+	+	+		+		+		+	+							
Ompok pabda (Hamilton, 1822)	Siluriformes	Siluridae	NT					+	+	+	+	+		+		+												
Opsarius barna (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+																				
Opsarius bendelisis (Hamilton, 1807)	Cypriniformes	Cyprinidae	LC			+	+																					
Opsarius tileo (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+																				
Opsarius shacra (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+																				
Oreichthys cosuatis (Hamilton, 1822)	Cypriniformes	Cyprinidae	LC					+																				
Oreochromis niloticus (Linnaeus, 1758) *	Cichliformes	Cichlidae	LC							+	+	+	+		+	+	+											

Abbreviations: '+' Presence; LC- Least Concern, VU-Vulnerable, NT-Near Threatened, NE-Not Evaluated, EN- Endangered, DD-Data deficient, * Exotic fishes

2.3.8. Water quality and Habitat status of river Ganga

2.3.8.1. *Water temperature (°C)*

The water temperature across various locations during different seasons revealed significant variations. The maximum temperature of 33.3 °C was recorded at the site Jangipur during the monsoon season and the minimum was 3.4 °C at Harsil during the post- monsoon season. During the post-monsoon season, the temperatures ranged from a low of 3.4°C at Harsil to a high of 24.1 °C at Farakka, indicating cooler conditions upstream and warmer conditions downstream. In the pre-monsoon season, temperatures increased significantly, with Varanasi downstream recording the highest temperature at 31.5 °C, while Harsil remained cooler at 9.8 °C. The monsoon season brought further increases in water temperatures, with Jangipur reaching the highest at 33.3 °C, and Harsil remaining the lowest at 9.4 °C (Fig. 20). These variations are influenced by seasonal changes, altitude, and geographic location, which impact the thermal regime of the river.

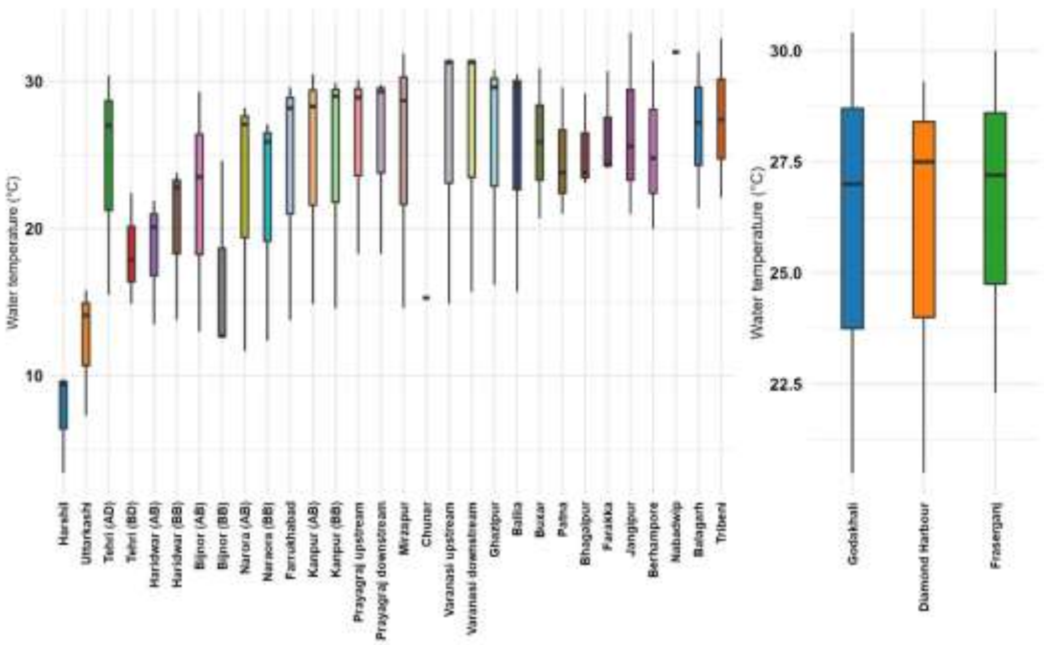


Figure 20: Variations of water temperature across different sites of river Ganga

2.3.8.2. *Water depth (m)*

The depths of the water at various locations varied significantly, and multiple sites during different seasons highlight the fluctuating nature of river systems. The monsoon season brought even greater changes, with Bhagalpur peaking at the maximum depth recorded, 25.4 meters, and the significant increase in water levels is due to the heavy rainfall and increased river flow during the monsoon season, while Harsil recorded a shallow depth of 0.35 meters. During the post-monsoon period, depths range from 0.63 meters at Harsil to 16.8 meters at Bhagalpur. These depths are influenced by the receding floodwaters from the monsoon season, resulting in varying water levels across different sites. In the pre-monsoon period, depths range from 0.68 meters at Harsil to 14.1 meters at Bhagalpur (Fig. 21). The slightly lower water levels are compared to the post-monsoon period. Reflecting the diverse hydrological conditions across different sites and seasons. These fluctuations are influenced by factors such as seasonal rainfall, snowmelt, and tidal effects, impacting water levels and flow dynamics.

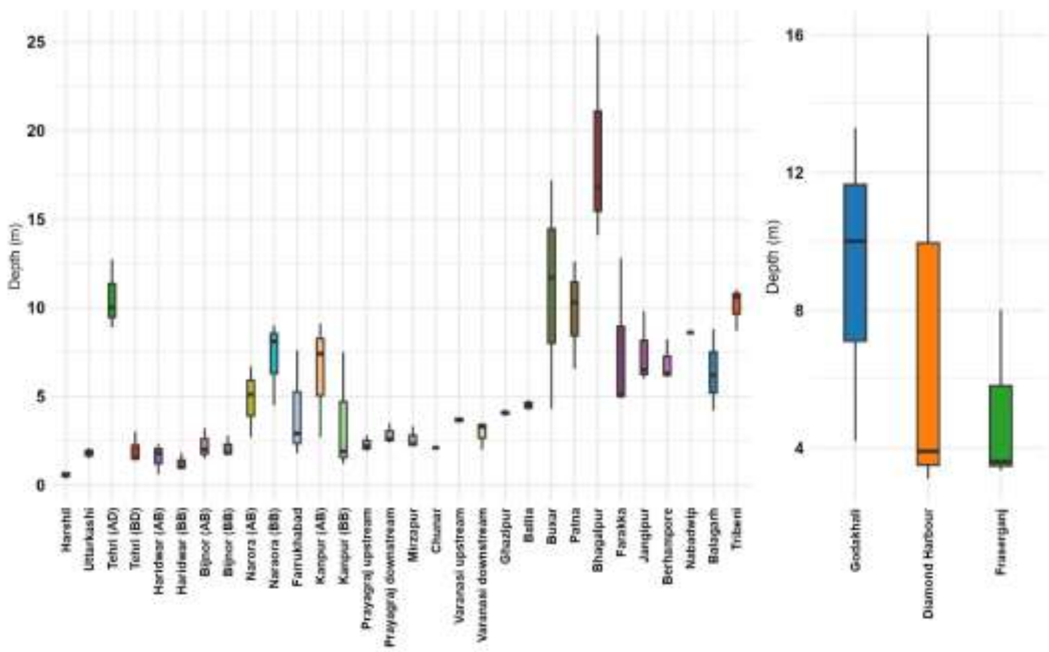


Figure 21: Variations of water depth across different sites of river Ganga

2.3.8.3. *Water pH*

The pH levels across various locations during different seasons display a range of values, from a minimum of 7.1 to a maximum of 9.41, highlighting the varying degrees of acidity and alkalinity in the water. Prayagraj downstream observed the highest pH at 9.41, indicating highly alkaline conditions during post-monsoon, while the lowest pH was 7.1 at Godakhali during pre-monsoon (Fig. 22). During the post-monsoon period, pH levels range from 7.5 at Godakhali and Fraserganj to 9.41 at Prayagraj downstream. The higher pH levels in some areas can be attributed to the increased presence of alkaline substances in the water. In the pre-monsoon period, pH levels vary from 7.1 at Godakhali to 9.25 at Prayagraj upstream. The slightly higher pH levels during this period. During the monsoon period, pH levels range from 7.66 at Varanasi upstream to 8.63 at Naraora BB (Below Barrage). The influx of rainwater tends to dilute the water, lowering the concentration of dissolved minerals and resulting in more neutral pH levels overall. The pH variations are crucial for understanding the chemical dynamics of the water, as pH levels impact the solubility and availability of nutrients and contaminants, as well as the overall health of aquatic ecosystems.

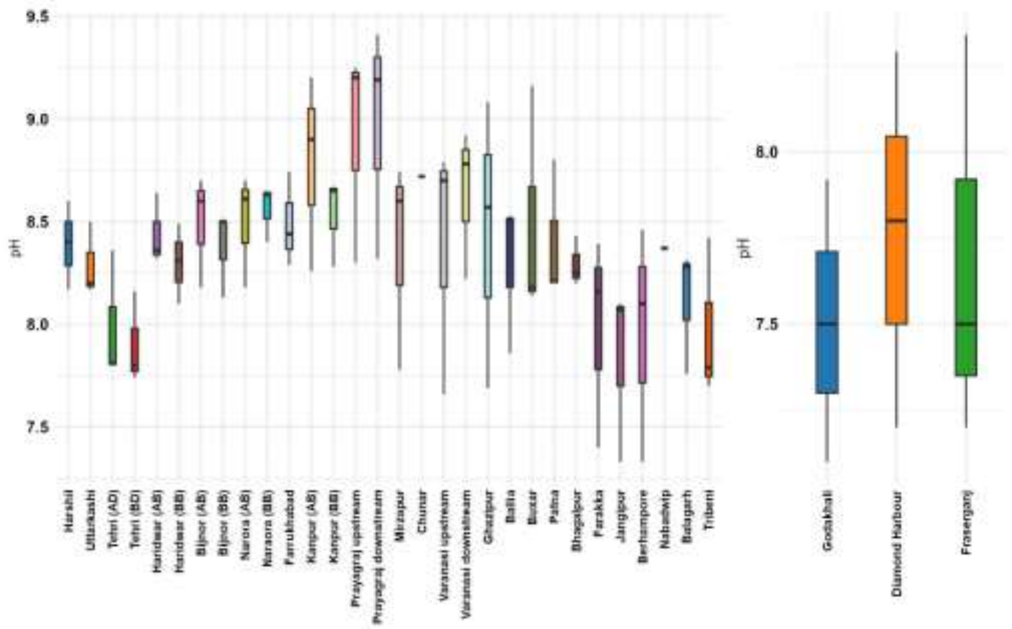


Figure 22: Variations of water pH across different sites of river Ganga

2.3.8.4. *Dissolved Oxygen (mg/L)*

The dissolved oxygen (DO) levels across various locations during different seasons exhibit a significant variation. The maximum DO record was 13.6 mg/L at Prayagraj downstream during the post-monsoon. In comparison, the minimum was 4.2 mg/L at Balagarh during the monsoon season (Fig. 23). The second-highest observation was at Kanpur AB, at 13 mg/L, and Prayagraj upstream, at 11 mg/L**,** reflecting the varying oxygen availability in these water bodies. During the post-monsoon period, DO levels range from 5.2 mg/L at Diamond Harbour to 13.6 mg/L at downstream of Prayagraj. In the pre-monsoon season, DO levels are generally moderate, with a slight decline compared to the post-monsoon period. In the pre-monsoon period, DO levels vary from 5.6 mg/L at Diamond Harbour to 10 mg/L at upstream of Prayagraj. During the monsoon period, DO levels range from 4.2 mg/L at Balagarh to 9.2 mg/L at Haridwar (AB). The influx of rainwater and increased water flow tend to dilute the oxygen concentration, leading to lower dissolved oxygen (DO) levels overall.

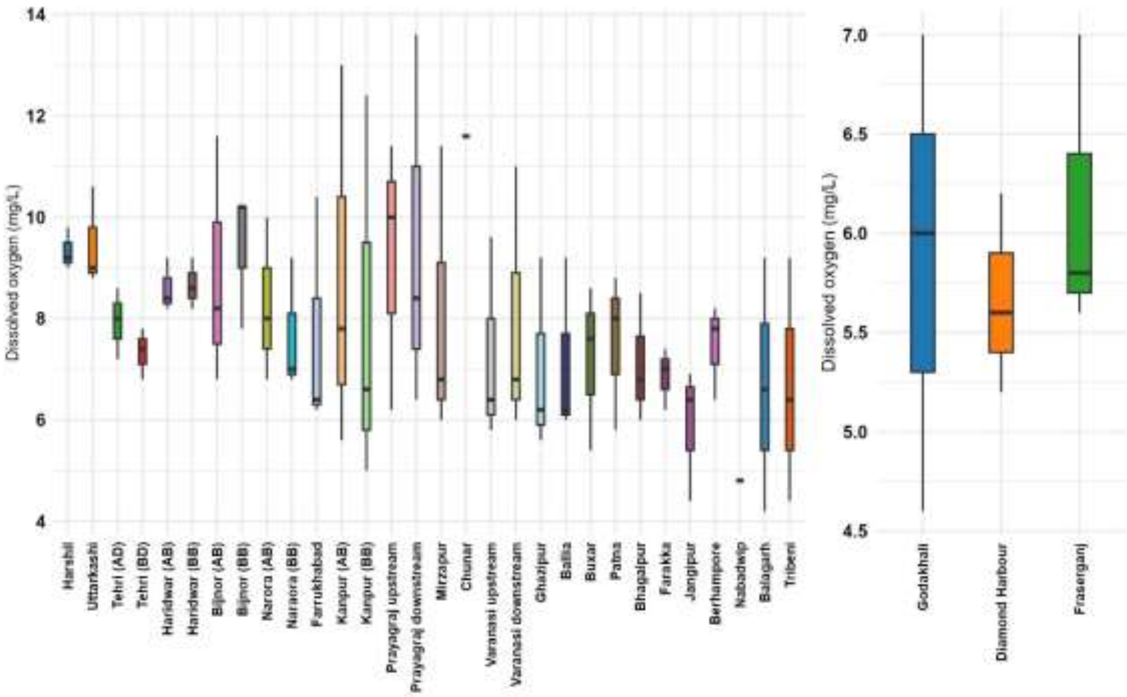


Figure 23: Variation of Dissolved Oxygen across all the sampling sites of river Ganga

2.3.8.5. *Specific conductivity (µS/cm)*

The specific conductivity (Sp. Cond.) levels exhibited a significant range, from a minimum of 77.8 µS/cm at Tehri (AD) during the monsoon to a maximum of 37,800 µS/cm at Fraserganj during the pre-monsoon, highlighting the varying degrees of ion concentration due to saline water. During the post-monsoon period, Sp. Cond. levels range from 97.7 µS/cm at Tehri (AD) to 37,300 µS/cm at Fraserganj (Fig.24). The high conductivity at coastal sites, such as Diamond Harbour and Fraserganj, can be attributed to the presence of residual saline water. In the pre-monsoon period, Sp. Cond. levels varied from 127.5 µS/cm at Uttarkashi to 37,800 µS/cm at Fraserganj. The generally higher values during this period can be attributed to increased evaporation and reduced freshwater inflow, which concentrate the dissolved salts and ions in the water. During the monsoon period, Sp. Cond. levels range from 77.8 µS/cm at Tehri (AD) to 24,500 µS/cm at Fraserganj. The lower values in many sites are due to the dilution effect of heavy rainfall and increased water flow, which reduces the concentration of dissolved ions. The variations in conductivity are influenced by factors such as rainfall, runoff, tidal influx, and anthropogenic activities, impacting the water's ionic composition.

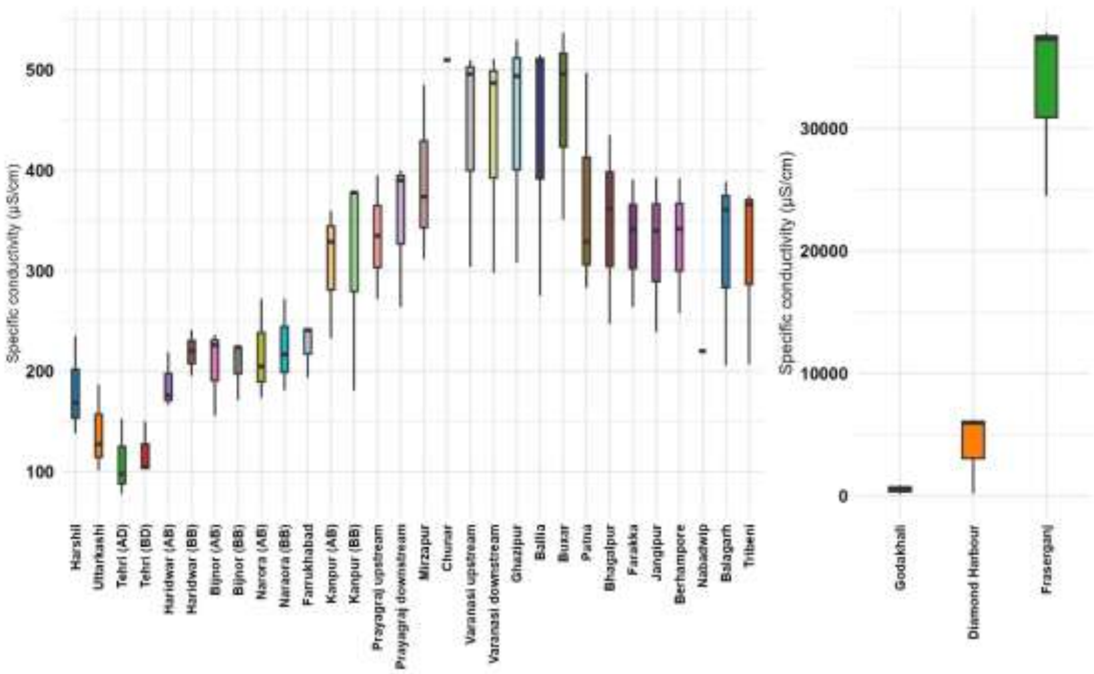


Figure 24: Variation of Sp. conductivity across all the sampling sites of river Ganga

2.3.8.6. *Transparency (cm)*

Transparency levels in water bodies exhibit distinct seasonal variations, with notable differences between the Monsoon, Post-monsoon, and Pre-monsoon seasons. The minimum was 2 cm at Fraserganj during monsoon, and the maximum was 180 cm at Uttarkashi during post-monsoon (Fig. 25). In the post-monsoon season, transparency improves as sediment settles and water clarity increases. However, it remains higher than in the monsoon season. During the post-monsoon period, transparency levels ranged from a low of 24.6 cm at Godakhali to a high of 180 cm at Uttarkashi. During the pre-monsoon season, the transparency ranges from 25 cm at Uttarkashi to 98 cm at Farakka, while during the post-monsoon season, it ranges from 25 cm at Uttarkashi to 98 cm at Farakka. During monsoon season, the transparency ranges from a low of 2 cm at Fraserganj to a high of 99.3 cm at Tehri (AD). Overall, Monsoon sees the sharpest decline in transparency due to increased runoff. The fluctuations are influenced by seasonal rainfall, river flow, and sediment load, which impact water clarity and quality.

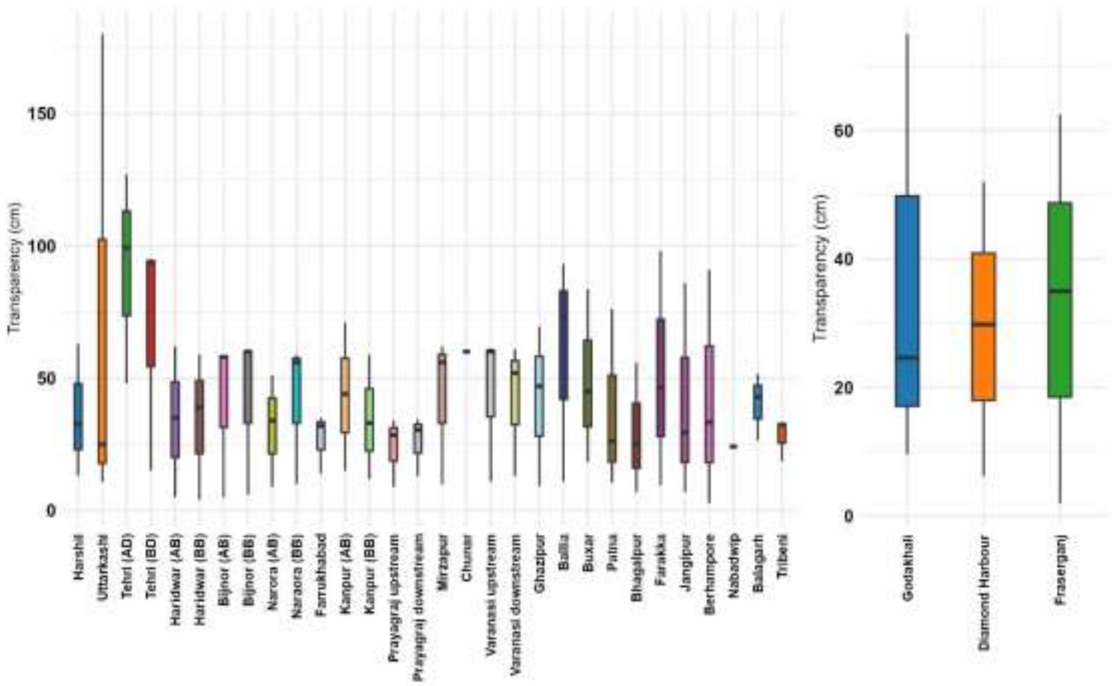


Figure 25: Variation of transparency across all the sampling sites of river Ganga

2.3.8.7. *Turbidity (NTU)*

The turbidity levels across various locations during different seasons reveal a significant range, from a minimum of 2.72 NTU at Harsil during the post-monsoon season to a maximum of 815 NTU at Narora AB during the monsoon season (Fig. 26). During the monsoon season, turbidity levels peak due to heavy rains and increased runoff. Notably high values include Narora AB 815 NTU. Similarly, Haridwar (BB) 538 NTU, Bijnor (AB) 727 NTU, and Prayagraj downstream 647 NTU also showed elevated turbidity, with sediment concentrations peaking during this period. The lowest turbidity was recorded at Harsil (2.72 NTU) and Uttarkashi (2.98 NTU), indicating clearer water during the post-monsoon period. In the post-monsoon season, Prayagraj upstream recorded the highest turbidity at 142 NTU, indicating high levels of suspended particles in the water. In comparison, Harsil had the lowest at 2.72 NTU, reflecting clearer water. The fluctuations are influenced by seasonal rainfall, river flow, and sediment load, which impact water clarity and quality. Monitoring turbidity is crucial for evaluating the degree of water pollution and sedimentation.

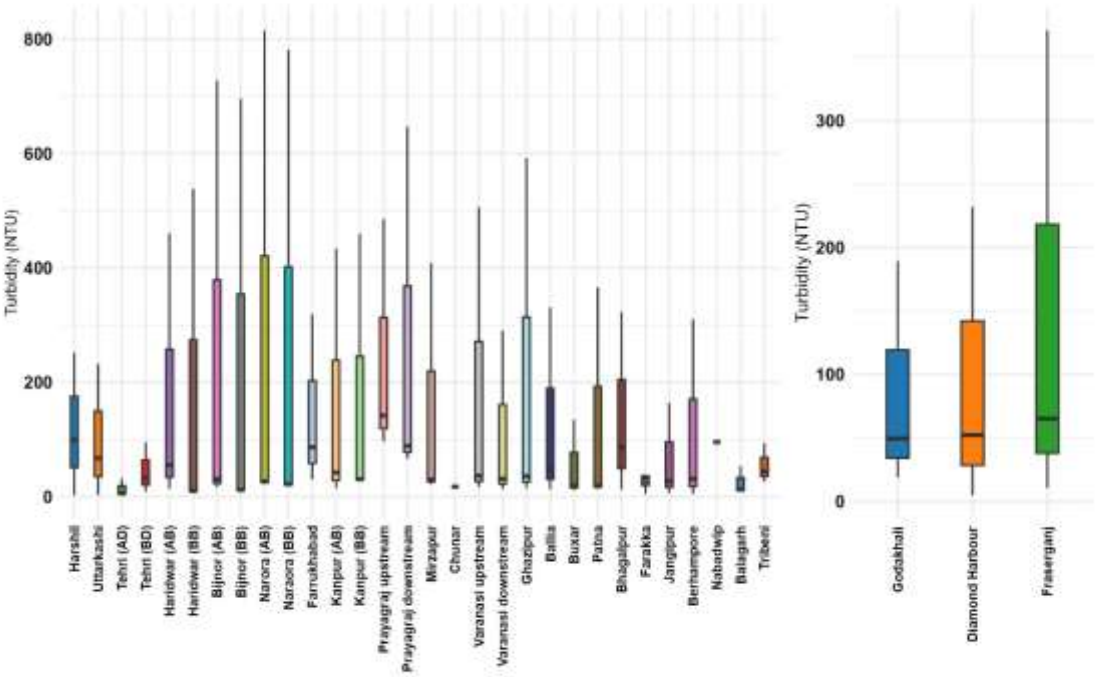


Figure 26: Variation of turbidity across all the sampling sites of the river Ganga

2.3.8.8. *Total alkalinity (mg/L)*

The total alkalinity (TA) levels across various locations and seasons exhibit a wide range, from a minimum of 14 mg/L at Harsil during the monsoon to a maximum of 328 mg/L at Diamond Harbour during the post-monsoon period, indicating the water's buffering capacity against acidification (Fig. 27). During the post-monsoon season, Diamond Harbour exhibited the highest alkalinity at 328 mg/L, indicating a substantial mineral content, likely due to tidal effects. In contrast, Harsil had the lowest at 14 mg/L during the monsoon season. During the pre-monsoon season, Ghazipur and Ballia recorded high alkalinity values of 206 mg/L and 196 mg/L, respectively, indicating a significant buffering capacity. In contrast, Harsil and Uttarkashi had the lowest values at 32 mg/L. The variations in total alkalinity are crucial for understanding the water's ability to neutralize acids and maintain pH stability, which is essential for aquatic life and ecosystem health.

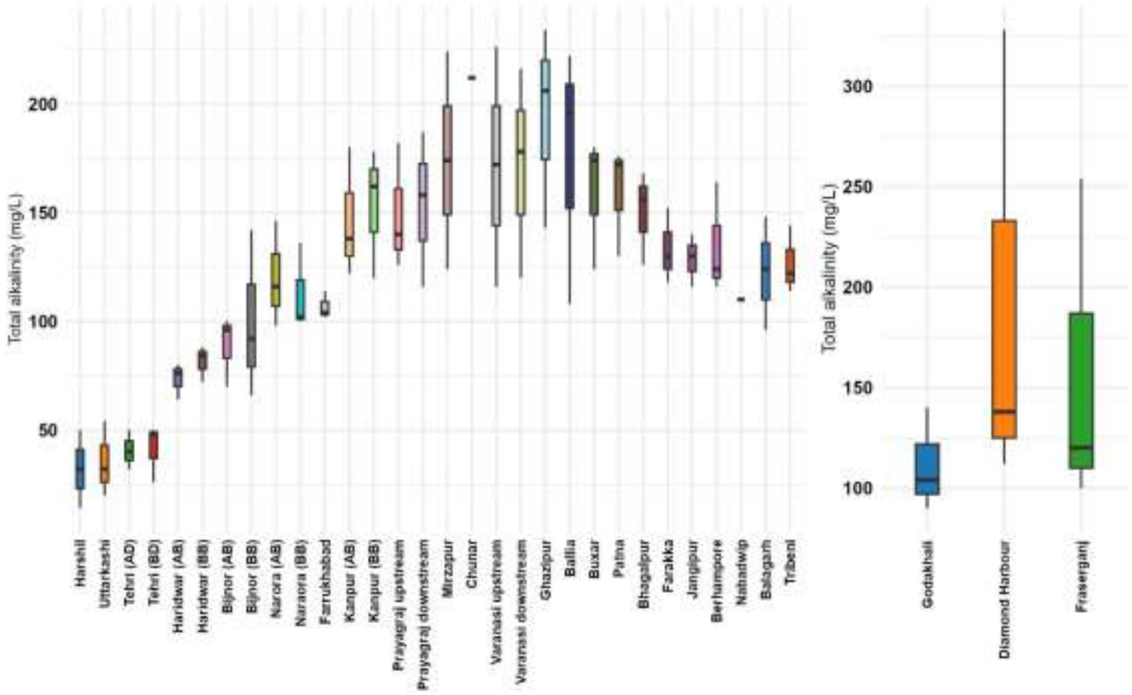


Figure 27: Variation of total alkalinity across all the sampling sites of river Ganga

2.3.8.9. *Total hardness (mg/L)*

The total hardness (TH) levels across various locations and seasons demonstrate a significant range, from a minimum of 40 mg/L to a maximum of 7400 mg/L (Fig. 28). The highest TH value was recorded at Fraserganj, at 7400 mg/L, during the pre-monsoon season, indicating extremely hard water with high concentrations of calcium and magnesium ions, likely due to tidal effects. Conversely, the lowest TH value was observed at Tehri (AD) 40 mg/L during the monsoon season, reflecting softer water. In the post-monsoon season, sites such as Diamond Harbour and Fraserganj also exhibited high TH values, indicating a considerable mineral content. The monsoon season brought some relief with generally lower TH values, although Fraserganj still showed high levels. These variations in total hardness are essential for understanding the water's mineral content and its suitability for drinking, industrial, agricultural, and tidal uses.

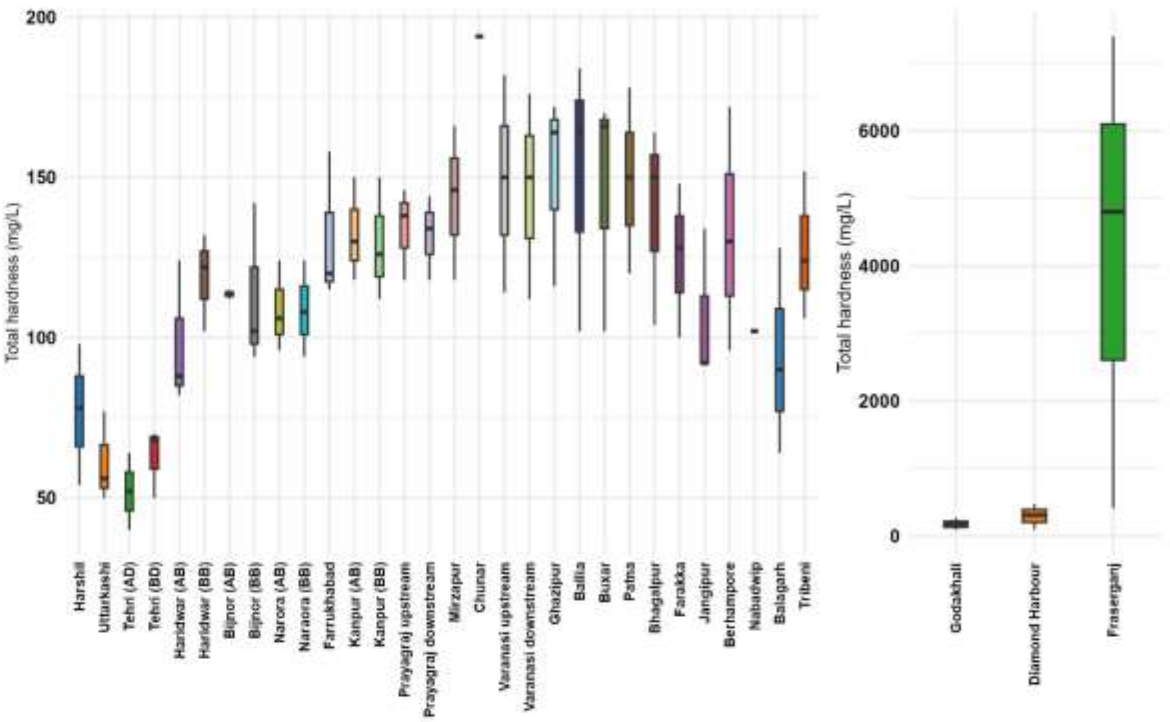


Figure 28: Variation of total hardness across all the sampling sites of the river Ganga

2.3.8.10. *Chlorinity and salinity (ppt)*

The chlorinity and salinity levels across various locations during different seasons exhibit a significant range. In the post-monsoon season, chlorinity values ranged from a minimum of 0.001 ppt at Harsil to a maximum of 15.5 ppt at Fraserganj during pre-monsoon (Fig. 29). Correspondingly, in the post-monsoon season, salinity values ranged from a minimum of 0.002 ppt at Harsil to a maximum of 27.9 ppt at Fraserganj pre-monsoon. During the post-monsoon period, chlorinity values range from 0.001 ppt at Harsil and Haridwar (AB) to 11.2 ppt at Fraserganj, with corresponding salinity levels ranging from 0.002 ppt to 20.306 ppt. The substantial variability is likely due to the dilution effect of monsoon rains, which reduces mineral concentrations in upstream areas while tidal influences and evaporation cause higher concentrations in downstream coastal regions. During the pre-monsoon season, the highest chlorinity was again recorded at Fraserganj, at 15.5 ppt, and the corresponding salinity was 27.999, indicating highly saline conditions characteristic of the estuarine zone. During the monsoon period, chlorinity values range from 0.005 ppt at Uttarkashi to 13.8 ppt at Fraserganj, with salinity values ranging from 0.009 ppt to 24.983 ppt. The influx of rainwater significantly dilutes the mineral content, particularly in upstream areas, while tidal effects and runoff influence the values downstream. The variations in chlorinity and salinity are influenced by factors such as rainfall, river flow, and tidal effects, which impact the salinity dynamics and health of aquatic ecosystems. Locations such as Diamond Harbour and Fraserganj exhibited relatively high chlorinity and salinity levels across different seasons, indicating a consistent influence of saline water in these areas.

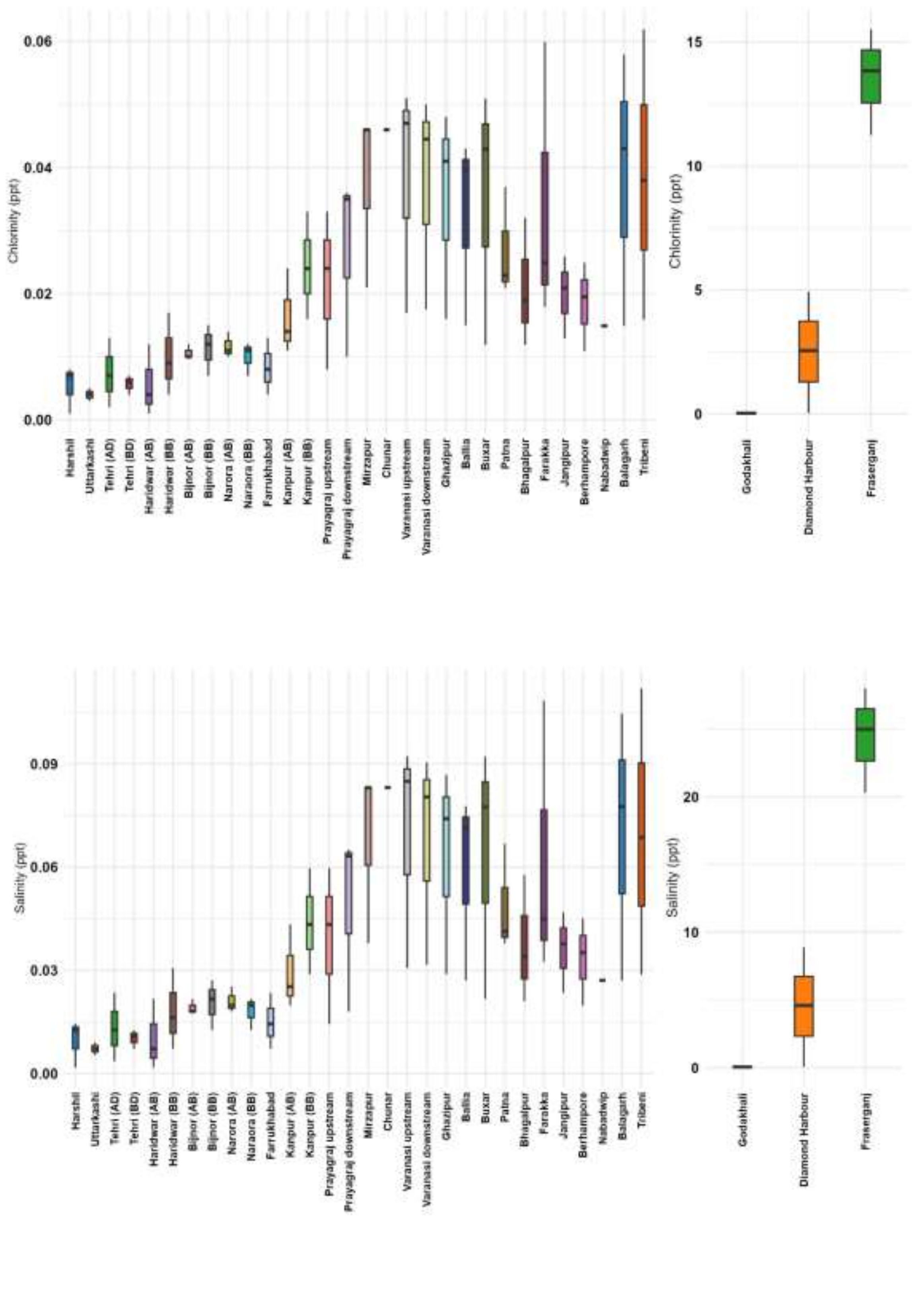


Figure 29: Variation of chlorinity and salinity across all the sampling sites of river Ganga

2.3.9 Pollution status of River Ganga

2.3.9.1. *Biochemical Oxygen Demand (mg/L)*

The biochemical oxygen demand (BOD) levels across various locations and seasons reveal significant variation, ranging from a minimum of 0.2 mg/L at Tehri (AD) during the pre-monsoon season to a maximum of 8.4 mg/L at Prayagraj upstream during the pre-monsoon season (Fig. 30). During the pre-monsoon season, the highest BOD value was recorded at Prayagraj upstream, at 8.4 mg/L, indicating a high level of organic pollution that can deplete oxygen levels and adversely affect aquatic life. Conversely, Tehri (AD) exhibited the lowest BOD value of 0.2 mg/L during the pre-monsoon season, indicating lower organic matter and improved water quality. During the post-monsoon season, BOD levels generally ranged from 0.4 mg/L at Balagarh to 6.8 mg/L at Prayagraj downstream, indicating moderate to high levels of organic pollution. The monsoon season exhibited relatively lower BOD values, with significant readings like 4.12 mg/L at Farrukhabad and 3 mg/L at Bijnor (AB). These variations in BOD levels are essential for understanding the extent of organic pollution and its impact on water quality and aquatic ecosystems across different regions and seasons.

2.3.9.2. *Chemical Oxygen Demand (mg/L)*

The chemical oxygen demand (COD) levels across various locations and seasons exhibit significant variability, ranging from a minimum of 7.54 mg/L to a maximum of 3060 mg/L (Fig. 31). The highest COD value was recorded at Fraserganj at 3060 mg/L, during the pre-monsoon season, due to high tidal effects and high levels of oxidizable matter. Conversely, the lowest COD levels were observed at Farrukhabad, 7.54 mg/L, during the post-monsoon season, reflecting better water quality with less organic matter. In the post-monsoon season, Bhagalpur, Farakka, Jangipur, and Berhampore also exhibited high COD values, indicating significant pollution levels, while sites like Varanasi, upstream and downstream, recorded moderately high values. During the pre-monsoon season, areas such as Prayagraj upstream and downstream, and Varanasi exhibited elevated COD levels, indicating substantial organic load and potential adverse effects on aquatic life. The variations in COD levels are crucial for understanding the extent of organic pollution and its impact on water quality and ecosystem health across different regions and seasons.

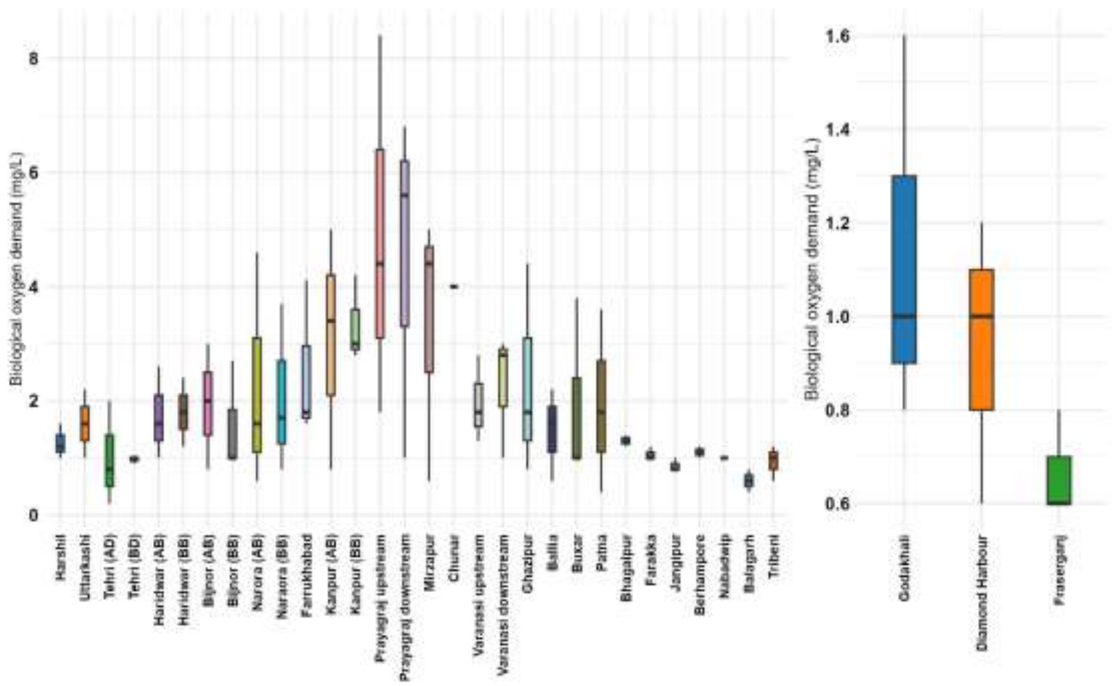


Figure 30: Variation of BOD across all the sampling sites of river Ganga

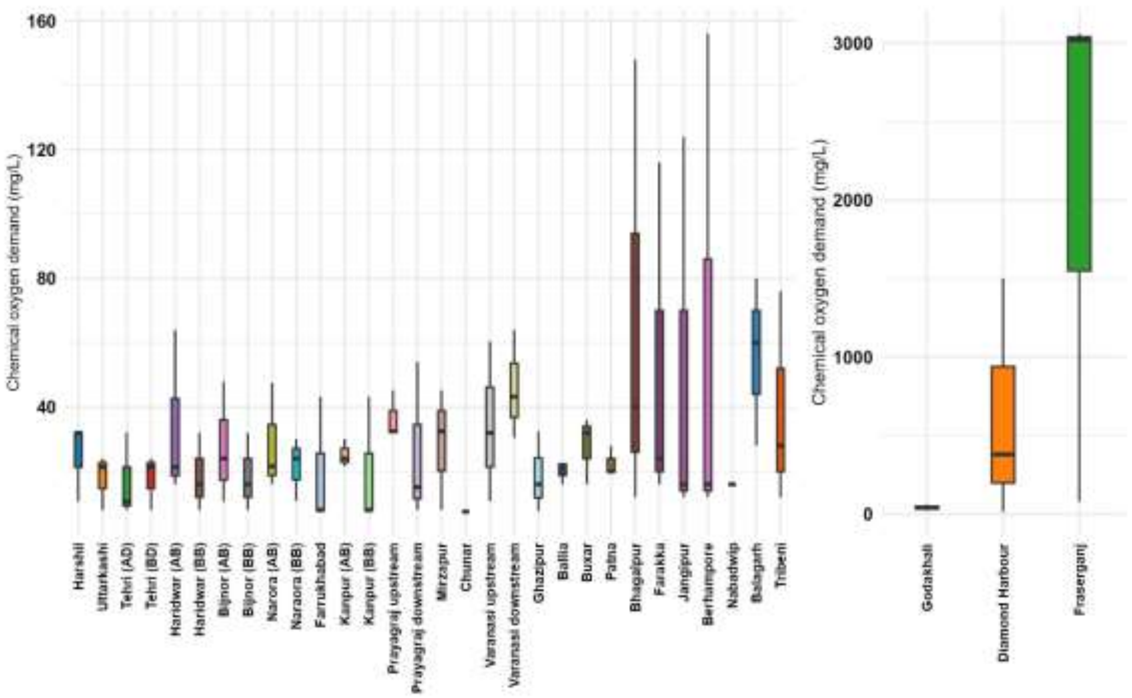


Figure 31: Variation of COD across all the sampling sites of the river Ganga

2.3.10. Nutrient status of River Ganga

2.3.10.1 *Total phosphorus (mg/L)*

The total phosphorus (TP) levels across various locations and seasons ranged from a minimum of 0.016 mg/L at Tehri (AD), during the post-monsoon season, to a maximum of 0.855 mg/L at Ghazipur, during the pre-monsoon season (Fig.32). During the post-monsoon season, Mirzapur exhibited the highest TP value at 0.709 mg/L, indicating elevated nutrient levels that can contribute to eutrophication. Conversely, Tehri (AD) recorded the lowest TP value at 0.016 mg/L, suggesting lower nutrient presence. The monsoon season showed a mix of TP values, with Kanpur BB reaching 0.211 mg/L and Bhagalpur exhibiting one of the lowest values at 0.0583 mg/L. These fluctuations in TP levels are influenced by seasonal changes, runoff, and anthropogenic activities, which impact the nutrient dynamics and the health of the aquatic ecosystem.

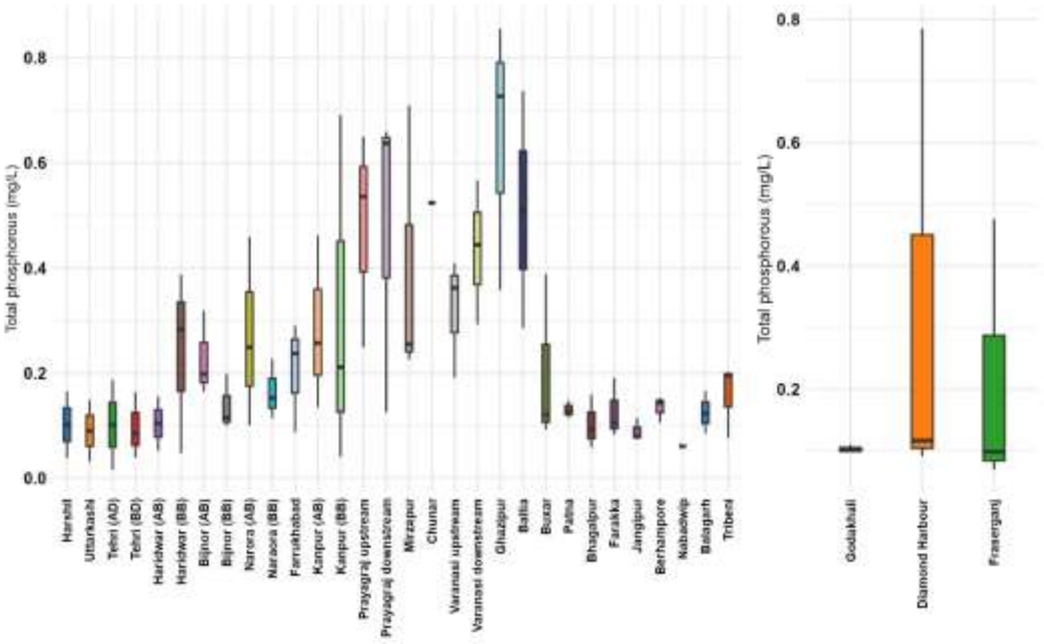


Figure 32: Variation of Total phosphorus across all the sampling sites of the River Ganga

2.3.10.2. *Total nitrogen (mg/L)*

The total nitrogen (TN) levels across various locations and seasons exhibited a significant range, from a minimum of 0.013 mg/L to a maximum of 9.228 mg/L, reflecting varying nutrient concentrations (Fig. 33). In the pre-monsoon season, Kanpur BB reached the peak TN value at 9.228 mg/L, indicating substantial nutrient enrichment, while in the monsoon season Berhampore exhibiting one of the lowest values at 0.0128 mg/L. During the post-monsoon season, the Varanasi upstream recorded the highest TN value at 1.053 mg/L, indicating elevated nutrient levels. Conversely, Farrukhabad showed a relatively lower TN value of 0.102 mg/L, suggesting lower nutrient presence. During the pre-monsoon season, Kanpur BB reached its peak TN value of 9.228 mg/L, indicating substantial nutrient enrichment, whereas Tehri (AD) had a relatively low TN level of 0.105 mg/L. The monsoon season exhibited diverse TN values, with Narora BB reaching a maximum of 1.828 mg/L and Berhampore displaying one of the lowest values at 0.0128 mg/L. The fluctuations in TN levels are influenced by seasonal changes, agricultural runoff, and anthropogenic activities, which impact the nutrient dynamics and the health of the aquatic ecosystem.

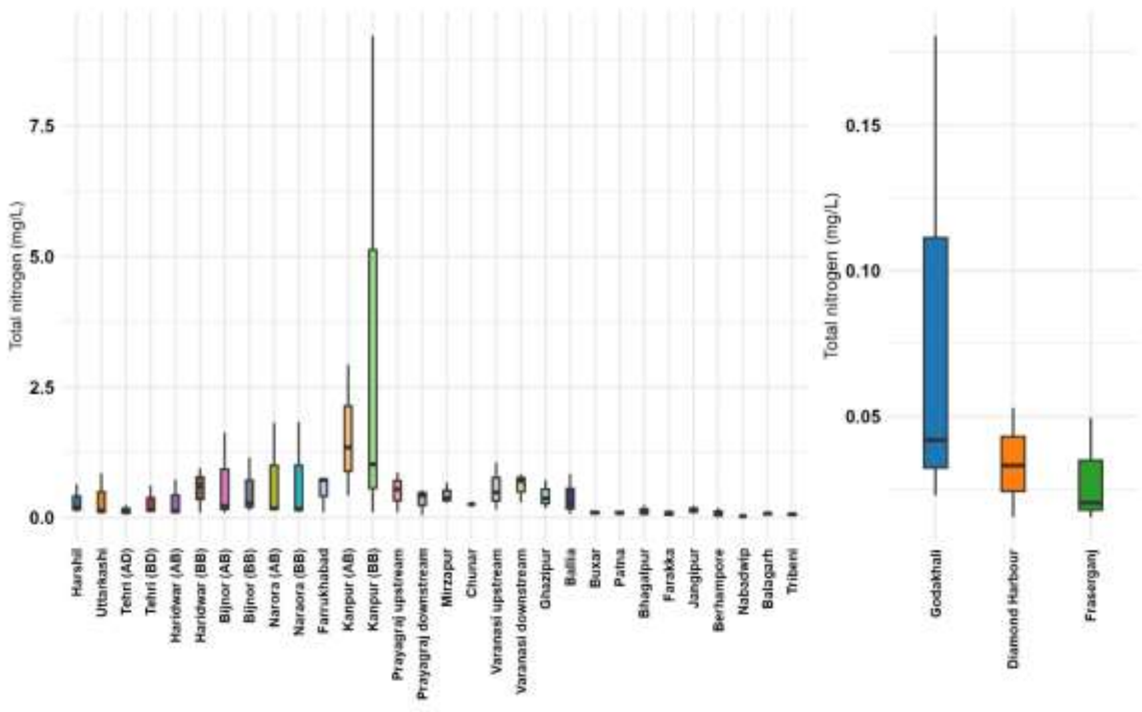


Figure 33: Variation of Total N. across all the sampling sites of the river Ganga

2.3.10.3. *Silicate (mg/L)*

The silicate (SiO4) levels across various locations and seasons showed a considerable range, from a minimum of 1.148 mg/L to a maximum of 139.92 mg/L, indicating diverse conditions in these water bodies (Fig. 34). The monsoon season exhibited increases, with Patna reaching an exceptional 139.9 mg/L, indicating a substantial influx of silicate, possibly from soil erosion or runoff. On the other hand, Farrukhabad had the lowest silicate level of 1.12 mg/L during this season. During the post-monsoon season, Buxar recorded the highest silicate concentration at 20.1 mg/L, suggesting significant input of silicates, which are essential for diatom growth.

Conversely, Farrukhabad exhibited a lower concentration of 9.1 mg/L, reflecting different silicate dynamics. The variations are influenced by factors such as seasonal changes, river flow, and geological inputs, impacting the nutrient dynamics and productivity of aquatic ecosystems.

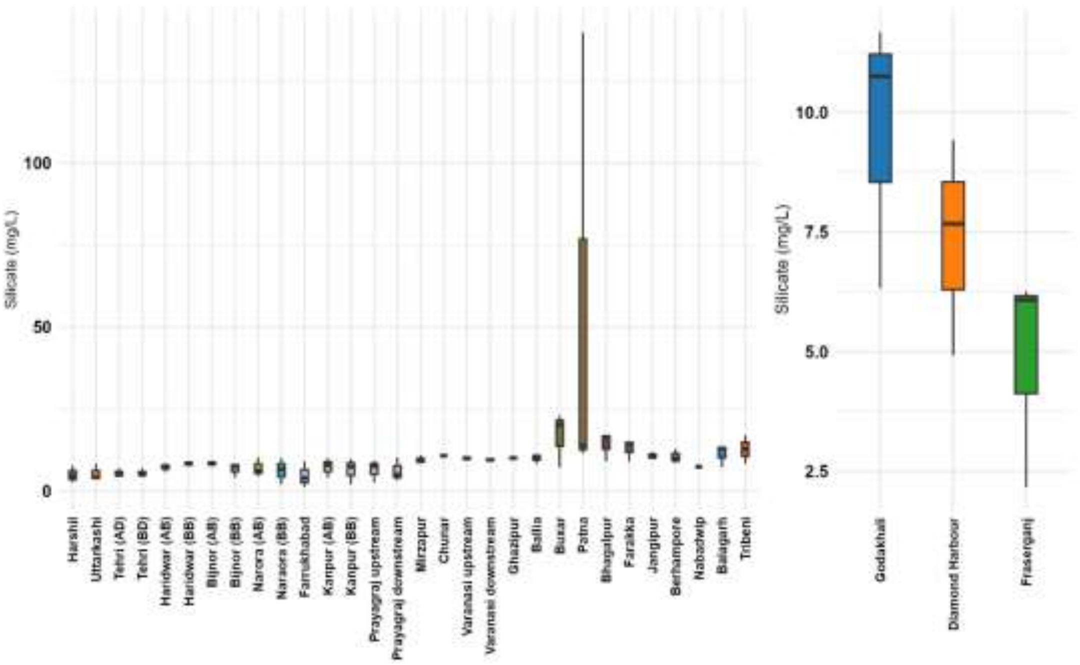


Figure 34: Variation of silicate across all the sampling sites of the river Ganga

2.3.10.4. *Total chlorophyll (mg/m^3)*

The total chlorophyll levels across various sites and seasons display a significant range, from a minimum of 1.068 mg/m^3 to a maximum of 348.7 mg/m^3, reflecting diverse phytoplankton biomass in these water bodies (Fig. 35). During the post-monsoon season, Prayagraj downstream recorded the highest total chlorophyll level at 348.7 mg/m^3, indicating a substantial presence of phytoplankton, which could lead to algal blooms and affect water quality. High values in urban areas such as Prayagraj and Kanpur indicate significant organic input and nutrient enrichment. Conversely, Tehri (BD) exhibited the lowest total chlorophyll value at 1.068 mg/m^3, suggesting lower algal productivity. In the pre-monsoon season, Prayagraj upstream and downstream continued to show high chlorophyll levels at 111 mg/m^3 and 100.4 mg/m^3, respectively, reflecting significant algal biomass. The levels are generally lower than in the post-monsoon period, reflecting reduced nutrient availability as water levels recede. The monsoon season brought variations, with Godakhali reaching a notable high of 44 mg/m^3, and several sites, including Narora AB, Kanpur BB, and Prayagraj, showing lower values of around

1.068 mg/m³. The monsoon rains dilute nutrient concentrations, resulting in lower overall chlorophyll levels. However, coastal and downstream sites, such as Godakhali.These fluctuations in total chlorophyll levels are influenced by factors such as nutrient availability, water temperature, and seasonal changes, impacting the primary productivity and ecological balance of aquatic ecosystems.

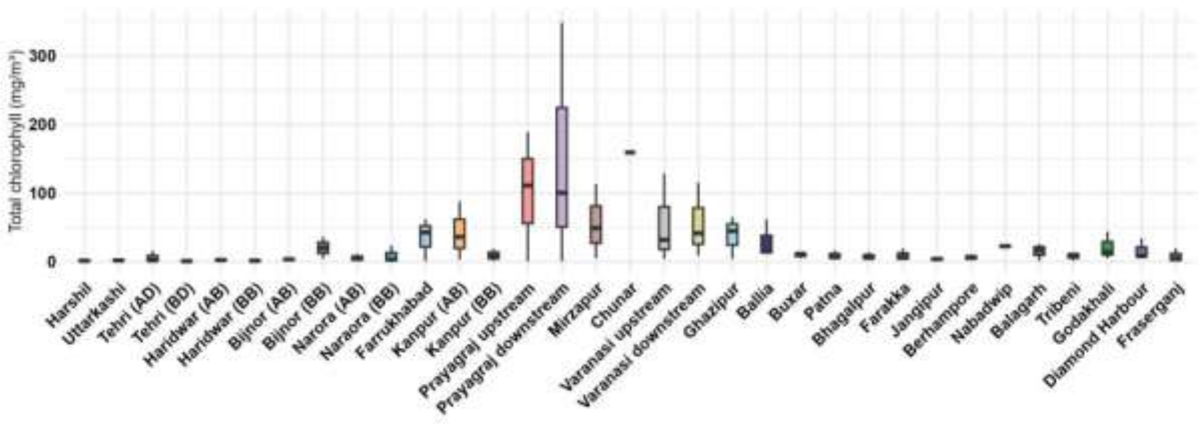


Figure 35: Variation of total chlorophyll across all the sampling sites of the river Ganga

2.3.10.5. *Total Solids, Total Dissolved Solids and Total Suspended Solids (g/L)*

The total solids (TS), total dissolved solids (TDS), and total suspended solids (TSS) levels across various sites and seasons exhibit a wide range, reflecting the diverse conditions of these water bodies (Figs. 36-38). TS values ranged from 0.05 g/L to 55.248 g/L, indicating significant variations in particulate and dissolved matter. The highest TS concentration was observed at Fraserganj during the pre-monsoon season (55.248 g/L), due to tidal effects, while Tehri (AD) had the lowest (0.05 g/L) during the monsoon season. TDS levels varied from 0.004 g/L to 9.48 g/L, with the maximum at Fraserganj post-monsoon and the minimum at Berhampore pre-monsoon, indicating differing degrees of dissolved mineral content. TSS levels ranged from 0.01 g/L to 54.632 g/L, again peaking at Fraserganj pre-monsoon and the lowest at Tehri (BD) pre-monsoon, reflecting diverse suspended particle concentrations. These fluctuations are influenced by factors such as seasonal rainfall, river flow, sediment load, and tidal effects, which affect water clarity and quality.

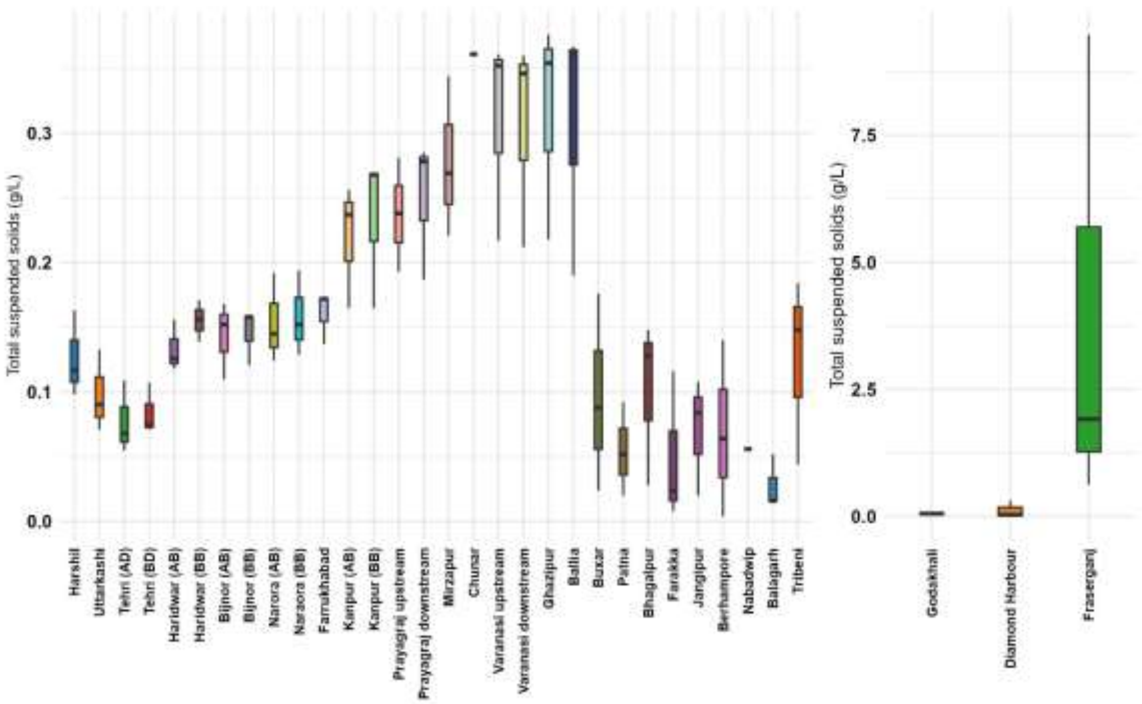


Figure 36: Variation of TSS across all the sampling sites of the river Ganga

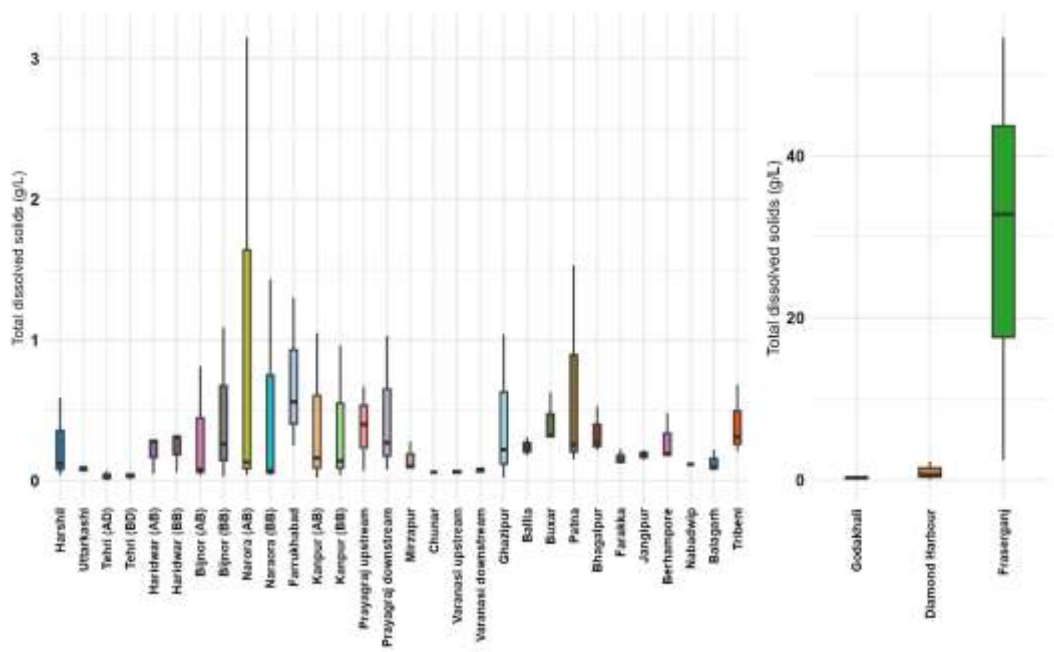


Figure 37: Variation of TDS across all the sampling sites of the river Ganga

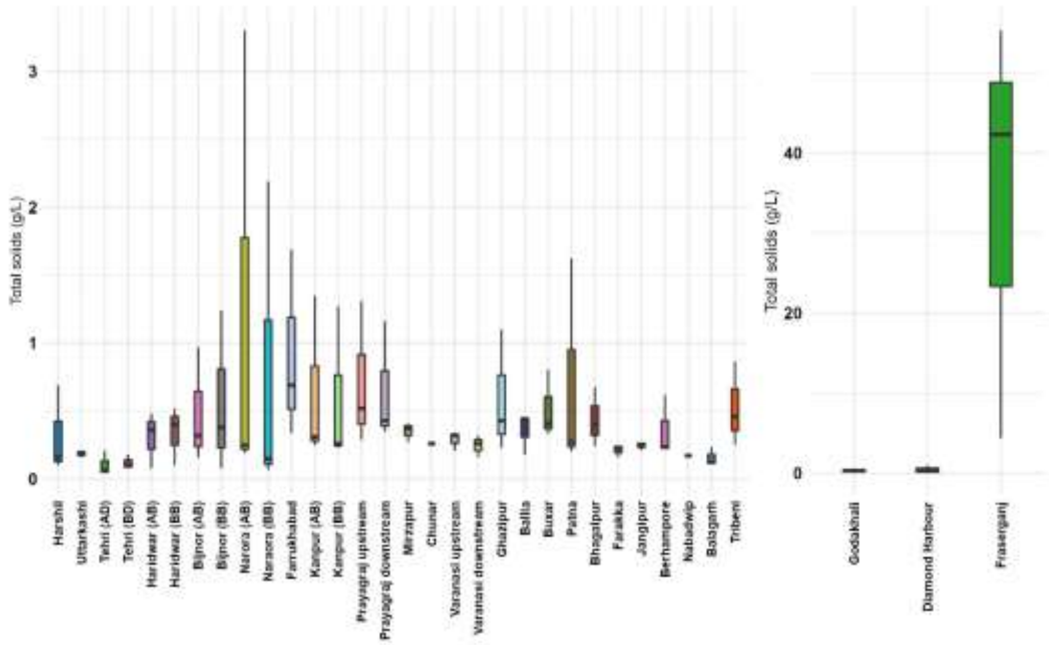


Figure 38: Variation of TS across all the sampling sites of the river Ganga

2.3.11. Plankton status of river Ganga

2.3.11.1. Upper and middle stretch

A total of 101 species of phytoplankton belonging to 5 phyla and eight classes were recorded from the upper stretch of the Ganga River. The major algal groups represented by Bacillariophyceae (54 species), followed by Chlorophyceae (22 species), Cyanophyceae (9 species), Coscinodiscophyceae and Zygnematophyceae (4 species each), Mediophyceae and Trebouxiophyceae (3 species each), Euglenophyceae (2 species). During the post-monsoon season, Mediophyceae was the dominant class with an abundance of (4.7×10^4 cells/L), Cyanophyceae (2.6×10^4 cells/L) and Bacillariophyceae (1.6×10^4 cells/L) at Haridwar BB. Euglenophyceae and Coscinodiscophyceae recorded maximum abundances of (9.2×10^3 cells/L) and (8.7×10^3 cells/L) at Haridwar BB and Tehri AB, respectively, while Trebouxiophyceae and Chlorophyceae exhibited maximum abundance at (5.5×10^2 cells/L) and (4.2×10^2 cells/L) at Haridwar AB and Bijnor BB, respectively (Fig. 39). The absence of Zygnematophyceae during this season could be attributed to changes in hydrological conditions following the high-flow season, which may not be conducive for its growth. The group Zygnematophyceae typically thrive in more stable, low-flow environments, and the higher flows and disturbances during the monsoon may have inhibited their growth and survival in the post-monsoon season. During pre-monsoon season, Mediophyceae remained the dominant class with an abundance of (4.6×10^5 cells/L), Coscinodiscophyceae (3.4×10^4 cells/L), Bacillariophyceae and Cyanophyceae exhibited an abundance of (3×10^4 cells/L) and (2.8×10^4 cells/L), while Zygnematophyceae and Euglenophyceae exhibited a similar abundance of (1.3×10^4 cells/L), Chlorophyceae recorded an abundance of (7.4×10^3 cells/L) at Bijnor AB. Overall, the dominance of all classes during the pre-monsoon period at Bijnor AB. During the monsoon season, Mediophyceae continued to dominate with an abundance of (3.4×10^4 cells/L), Trebouxiophyceae (1.7×10^4 cells/L) at Haridwar BB. Cyanophyceae (1.4×10^4 cells/L) at Bijnor BB, Coscinodiscophyceae (1.1×10^4 cells/L) at Haridwar BB, Zygnematophyceae and Chlorophyceae exhibited the abundance at (7.5×10^3 cells/L) at Tehri AB. Bacillariophyceae and Euglenophyceae showed an abundance of (6.2×10^3 cells/L) and (3.6×10^3 cells/L) at Tehri AB and Tehri BB, respectively. Euglenophyceae was only recorded at Tehri BB.

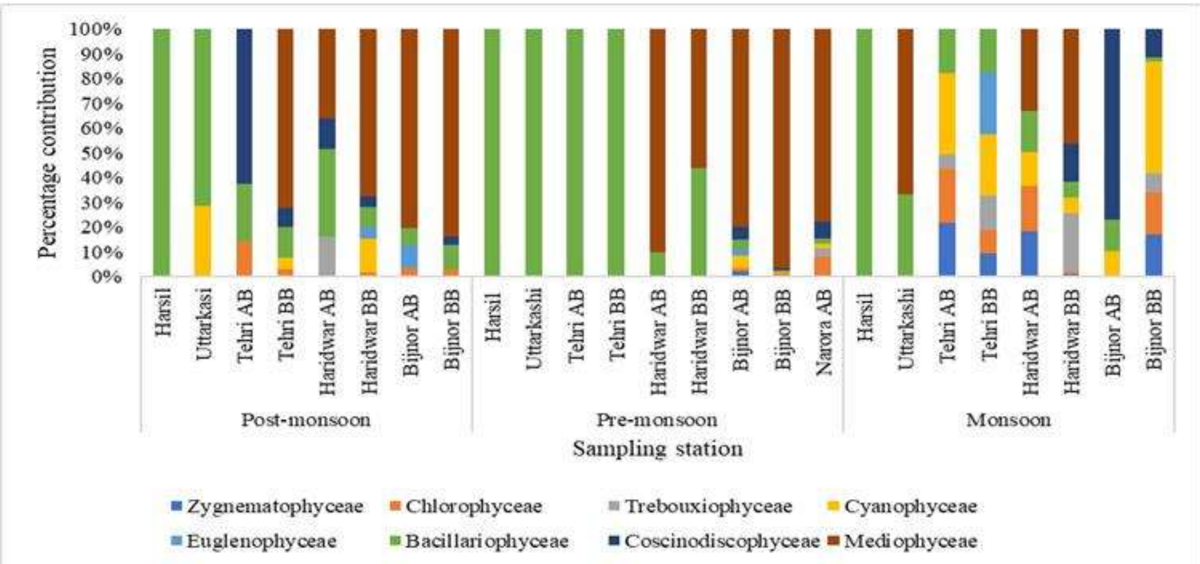


Figure 39: Percentage contribution of phytoplankton community in upper stretch of river Ganga

Thirty-three genera of zooplankton, belonging to 10 groups, five phyla (Rotifera, Arthropoda, Ciliophora, Protozoa and Amoebozoa) were recorded from the upper and middle stretches of the Ganga River. Among the zooplanktons, Rotifera accounted for 23 genera, followed by Arthropoda (6), Ciliophora (1), Protozoa (1), Chlorophyta (1) and Amoebozoa (1). The density of zooplankton at the middle stretch ranged from 8 to 82 ind/l, i.e. minimum during monsoon and maximum during winter. The group Rotifera contributed the highest density, followed by Arthropoda. Rotifera, a class of zooplankton, are also sensitive to water quality and frequently flourish in habitats that are polluted or rich in nutrients; additionally, the maximum abundance of Rotifera occurs during the winter season. The dominance of Branchiopus sp. was reflected in its maximum density (32 cells/L). The substantial presence of this species during the winter season was attributed to its richness in *Branchiopoda* species the maximum dominance of this group at Varanasi DS. The findings indicate that seasonal variations, particularly between the monsoon and winter seasons, have a significant impact on the distribution and abundance of plankton in the Ganga River. The increased nutrient availability and possibly altered water quality during winter likely contribute to the dominance of Rotifera, especially *Branchinous* sp. The high density of zooplankton, especially Rotifera, during winter suggests that this period offers optimal conditions for their growth. The sensitivity of Rotifera to water quality, particularly in nutrient-rich or polluted environments, underscores the importance of monitoring these organisms as bioindicators of river health. The observed dominance of *Branchinous* sp. in Varanasi DS might be associated with local ecological conditions, which warrant further study to understand the factors driving these seasonal patterns and their implications for river ecosystem dynamics. The total zooplankton density varied from 56 ind/l to 2 ind/l, i.e., minimum at Harsil and maximum at Haridwar BB. Among the zooplankton groups, Ciliophora (59 %) followed by Rotifera (20%), Arthropoda (15%), and Chlorophyta (6.00%) (Fig.40). The significant variation in zooplankton density between Haridwar BB and Harsil suggests that local environmental factors, such as water quality, nutrient availability, and habitat conditions, may play a crucial role in shaping the distribution of zooplankton in the Ganga River.

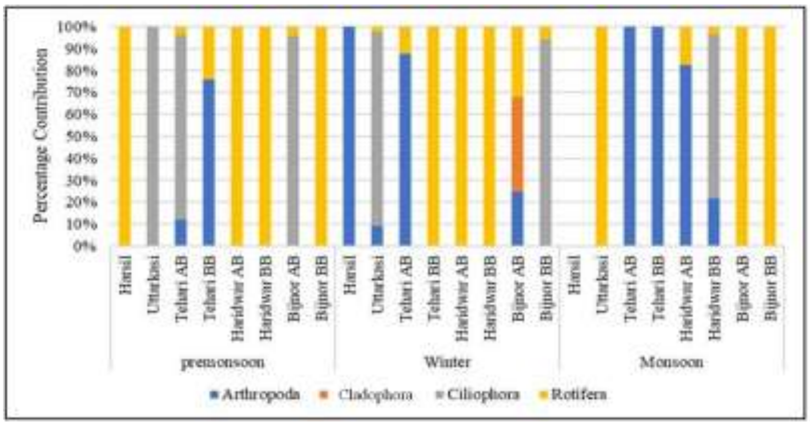


Figure 40: Percentage contribution of zooplankton community in upper stretch of River Ganga

2.3.11.2. Lower and estuarine zone

A total of 91 genera of plankton, belonging to 13 groups, were recorded from the lower and estuarine regions of the Ganga River. Cyanophyceae was observed as the dominant group among the phytoplankton, while Rotifera was the predominant group among the zooplankton. During the pre-monsoon season, significant taxa such as Cyanophyceae and Chlorophyceae were the most abundant, with Cyanophyceae being the most dominant in Patna (2,401,500 cells/L) and Chlorophyceae showing the highest count (385,800 cells/L) at Bhagalpur (Fig. 41). Coscinodiscophyceae and Bacillariophyceae were dominant across most stations, with maximum abundance observed in Buxar (120,000 cells/L and 15,000 cells/L, respectively). Trebouxiophyceae was found in the highest number at Buxar (29,100 cells/L), and Zygnematophyceae showed high density at Jangipur (94,440 cells/L). Among zooplankton, Rotifera (4,200 ind/l) and Arthropoda (600 ind/l) were most abundant at Patna. During the monsoon season, a noticeable presence of Cyanophyceae was recorded at Godakhali, with 14,960 cells/L. Bacillariophyceae and Coscinodiscophyceae showed moderate abundance, with the highest count of Bacillariophyceae recorded at Fraserganj (6,440 cells/L) and Coscinodiscophyceae at Godakhali (6,080 cells/L). Chlorophyceae were found in high numbers at Godakhali (3,860 cells/L), while Euglenophyceae reached 1,440 cells/L at Fraserganj. Among zooplankton, Arthropoda (5,360 ind/l) and Rotifera (2,520 ind/l) were most abundant at Godakhali. In the post-monsoon season, Bacillariophyceae dominated, with the highest concentration found at Buxar (10,240 cells/L), and Coscinodiscophyceae peaked at Godakhali (2,120 cells/L). Chlorophyceae and Trebouxiophyceae showed moderate abundance, with maximum values recorded at Godakhali (480 cells/L and 400 cells/L, respectively). Cyanophyceae remained prominent at Buxar (1,560 cells/L). Dinophyceae were found in the highest density at Diamond Harbour and Fraserganj. The maximum density of total plankton was observed during the pre-monsoon season (3,801,120 cells/L), due to stable environmental conditions, ample nutrient concentration, and adequate light availability, which promoted the growth of planktonic groups. The minimum density was recorded in the post-monsoon season (25,800 cells/L) due to the dilution effect caused by monsoon rains, which may further reduce nutrient concentrations.

Cyanophyceae (2,697,125 cells/L) was the dominant group, followed by Coscinodiscophyceae (450,890 cells/L). The predominance of Cyanophyceae in the Patna and Farakka stretch of the river indicated relatively poor water quality due to several anthropogenic nutrient loadings, agricultural runoff, sewage discharge, and barrage construction. This high dominance was attributed to low water velocity, sufficient light availability, and rich nutrient concentrations. Additionally, the maximum abundance of Cyanobacteria during the pre-monsoon season was associated with increased temperature, pH, and total alkalinity in the river. The dominance of the Coscinodiscophyceae group, primarily due to *Aulacoseira granulata*, was reflected in its maximum density (437,865 cells/L). This abundance was attributed to the turbid and turbulent conditions of the riverine ecology. The substantial presence of this species during the monsoon season was linked to the overflow of floodplain wetlands, which are rich in *A. granulata*. Rotifera, a class of zooplankton, are also sensitive to water quality and frequently flourish in habitats that are polluted or rich in nutrients. The maximum dominance of this group at Patna, Bhagalpur and Godakhali indicates the anthropogenic stress at these sites.

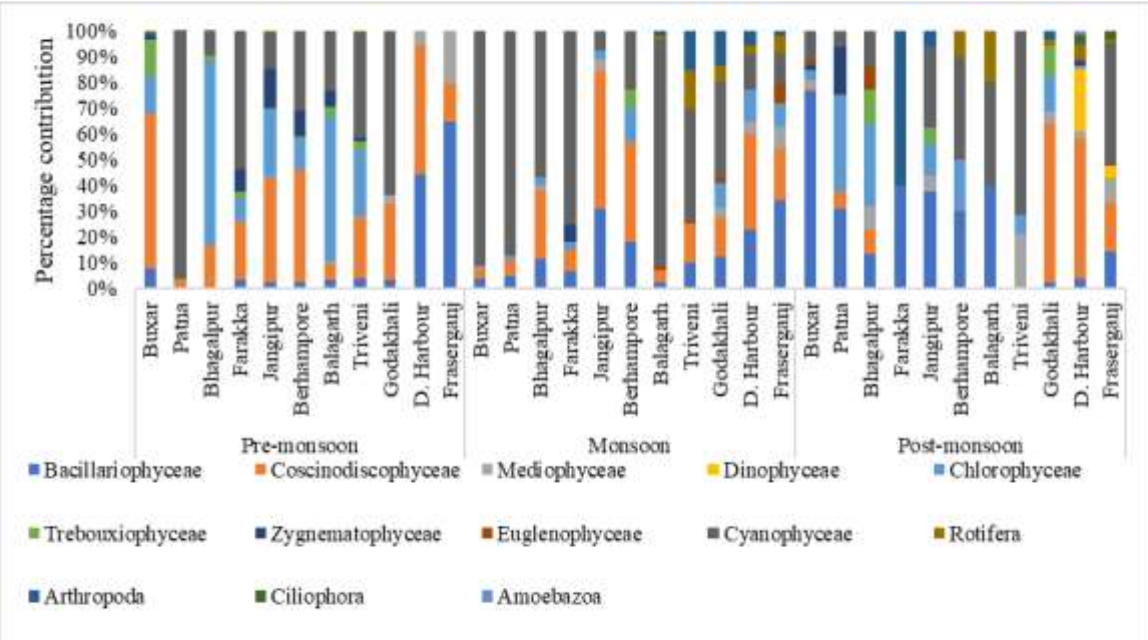


Figure 41: Percentage contribution of plankton community in lower and estuarine stretches of River Ganga

2.3.12. Periphyton status of river Ganga

A total of 63 genera of periphyton belonging to 14 groups were recorded from the Ganga River. During the pre-monsoon season, Chlorophyceae exhibited high densities, with the maximum recorded at Patna (48600 cells/cm^2) and a significant abundance at Triveni (46300 cells/cm^2). Other groups such as Bacillariophyceae Showed the highest concentrations at Triveni (41850 cells/cm^2) and Buxar (25560 cells/cm^2), while Cyanophyceae showed a maximum at Godakhali (21500 cells/cm^2) and Buxar showed the most dominated group Trebouxiophyceae (5760 cells/cm^2); Mediophyceae (5400 cells/cm^2) and Coscinodiscophyceae (5040 cells/cm^2). The Ciliophora group was at Patna (360 ind/cm^2) while Rotifera, and Arthropoda, showed relatively lower abundances, predominantly at Balagarh (100 Ind/$cm^{2)}$ respectively (Fig.42). While specific taxa like Dinophyceae and Xanthophyceae were absent throughout. During the Monsoon season, significant densities of Cyanophyceae were observed at Balagarh (1639360 cells/cm^2) and Patna (1096000 cells/cm^2). Bacillariophyceae (668000 cells/cm^2) and Ulvophyceae (441500 cells/cm^2) showed a high density in Bhagalpur. In contrast, Zygnematophyceae exhibited a maximum at Jangipur (1.526 million cells/cm^2). Coscinodiscophyceae displayed significantly lower densities across all stations, with the highest density recorded in Bhagalpur (20,500 cells/cm^2). While certain taxa like Dinophyceae, Xanthophyceae, Trebouxiophyceae, Rotifera, Arthropoda, and Ciliophora were absent or negligible throughout. Post-monsoon, Bacillariophyceae became dominant, especially at Berhampore (50700 cells/cm^2), while Cyanophyceae was maximum at Triveni (11350 cells/cm^2). Mediophyceae displayed much lower densities across all stations, with the highest density observed in Balagarh (2,250 cells/cm^2). While specific taxa, such as Euglenophyceae, Rotifera, and Arthropoda, were absent during the post-monsoon period. Among the periphyton groups, Cyanophyceae has the most significant overall abundance (6152647 cells/cm^2), followed by Bacillariophyceae (2705007 cells/cm^2), Zygnematophyceae (1566770 cells/cm^2) and Ulvophyceae (654750 cells/cm^2). Ciliophora (360 ind/cm^2) was revealed to be the dominant group among zooplankton, followed by Arthropoda (250 ind/cm^2) and Rotifera (100 ind/cm^2).

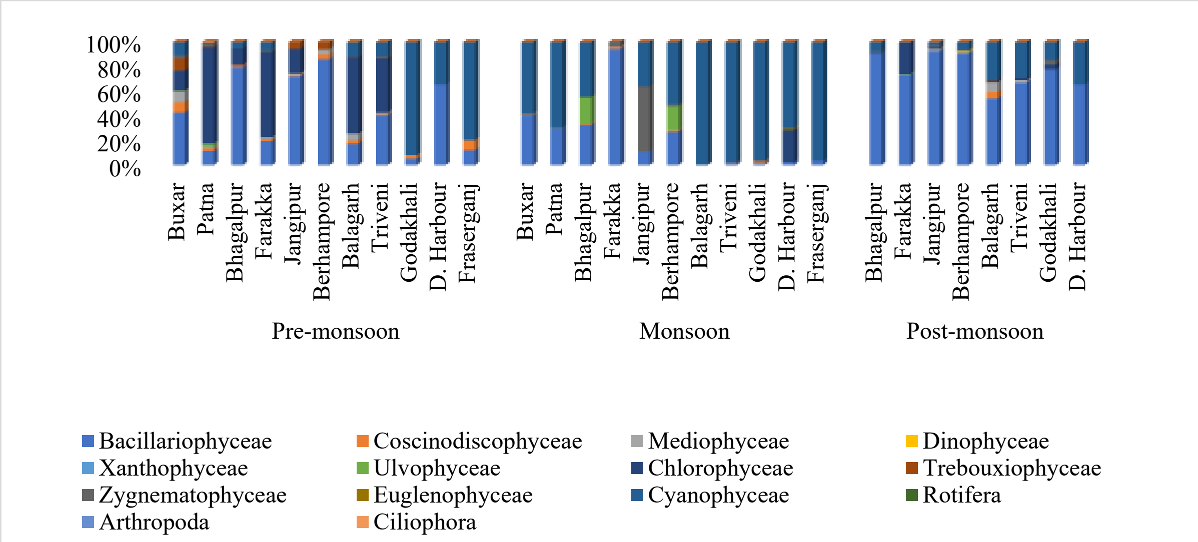


Figure 42: Percentage contribution of periphyton community in lower and estuarine stretches River Ganga

2.3.13. Pollution related to algae in the River Ganga

2.3.13.1 Algal pollution index (API)

In the current study, 18 of the 20 phytoplankton genera identified by Palmar (1969) as indicators of pollution were recorded from the river. These genera provide valuable insights into the pollution levels at various sampling stations along the river. Stations such as Harsil, Uttarkashi, Berhampore, and Balagarh reported an API (Algal Pollution Index) of less than 15, indicating low levels of pollution in these areas (Fig.43). This suggests minimal organic pollution and relatively better water quality in these regions. On the other hand, stations like Tehri, Haridwar, Mirjapur, Patna, Farakka, Jangipur, Triveni, Godakhali, and Fraserganj had API indices ranging from 15 to 19. This range is indicative of probable pollution, suggesting moderate organic pollution levels that may affect water quality and aquatic ecosystems over time. Stations with API values exceeding 20 exhibited high levels of organic pollution, signifying substantial degradation in water quality and posing potential risks to aquatic biodiversity.

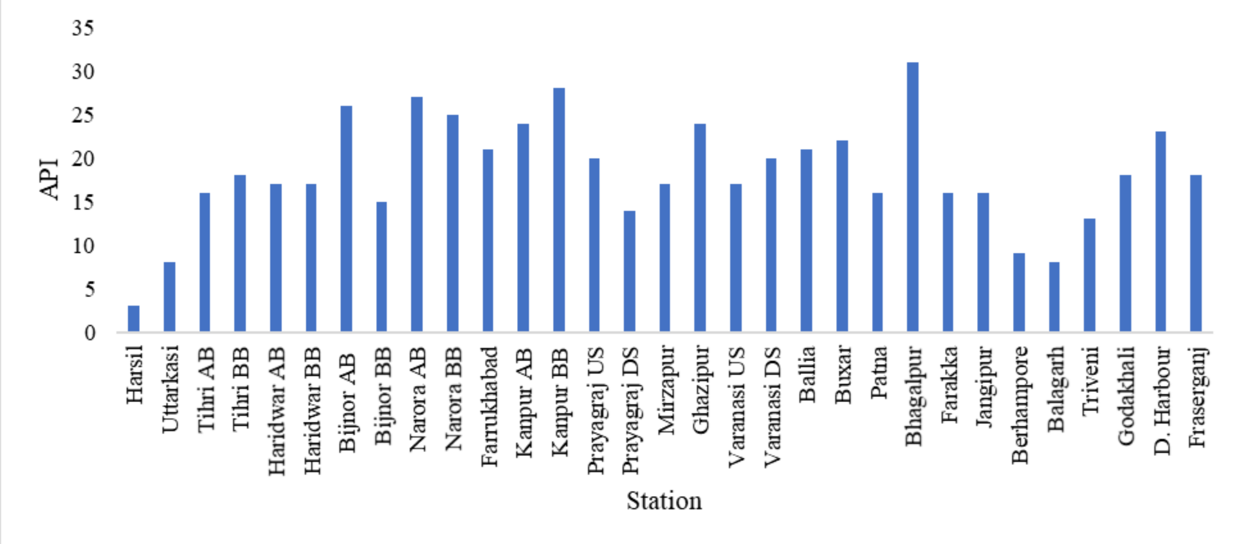


Figure 43: Algal pollution index in different stations of River Ganga

2.3.13.2. Heavy metal analysis of periphytons

The analysis of heavy metal concentrations across various locations reveals significant variations in the levels of Chromium (Cr), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Cadmium (Cd), and Lead (Pb) (Fig. 44). These differences are likely influenced by factors such as industrial activities, agricultural runoff, wastewater discharge, and natural geochemical processes. Chromium concentrations are notably high in Fraserganj (31.98 mg/kg) and D. Harbour (31.23 mg/kg), which may be attributed to industrial effluents or saline conditions in these regions. In contrast, Bhagalpur recorded the lowest levels of chromium (7.57 mg/kg), suggesting minimal industrial influence in this area. Similarly, cobalt levels are the highest in Balagarh (15.77 mg/kg), possibly due to mining activities, industrial discharges, or soil erosion carrying cobalt-rich sediments. Bhagalpur again recorded the lowest cobalt levels (3.14 mg/kg), reflecting a relatively uncontaminated environment. Nickel concentrations follow a similar pattern, with Fraserganj showing the highest levels (31.68 mg/kg), potentially due to industrial pollution or the presence of nickel-based alloys in waste. In comparison, Bhagalpur (7.36 mg/kg) remains the least affected. Copper levels are highest in Berhampore (41.90 mg/kg), which may be attributed to the use of agricultural pesticides or industrial processes involving copper. Bhagalpur (9.30 mg/kg) exhibits the lowest copper levels, further indicating limited industrial or agricultural impact. Zinc concentrations are exceptionally high in Balagarh (162.96 mg/kg), a clear outlier that suggests the use of zinc-based fertilisers. In comparison, Bhagalpur (14.21 mg/kg) recorded the lowest levels of zinc, consistent with its relatively low contamination across other metals. Cadmium, a highly toxic metal even in trace amounts, showed its highest concentration in Buxar (5.01 mg/kg), potentially linked to phosphate fertilisers, battery waste, or sewage sludge. Farakka (0.15 mg/kg) exhibited the lowest cadmium levels, indicating minimal anthropogenic impact. Lead concentrations are alarmingly high in Fraserganj (25.5 mg/kg), which could result from vehicular emissions, lead-based paints, oil discharge from boats, sewage load, etc. This concentration is significantly elevated compared to other regions, such as Bhagalpur (4.37 mg/kg), where the lead levels are the lowest.

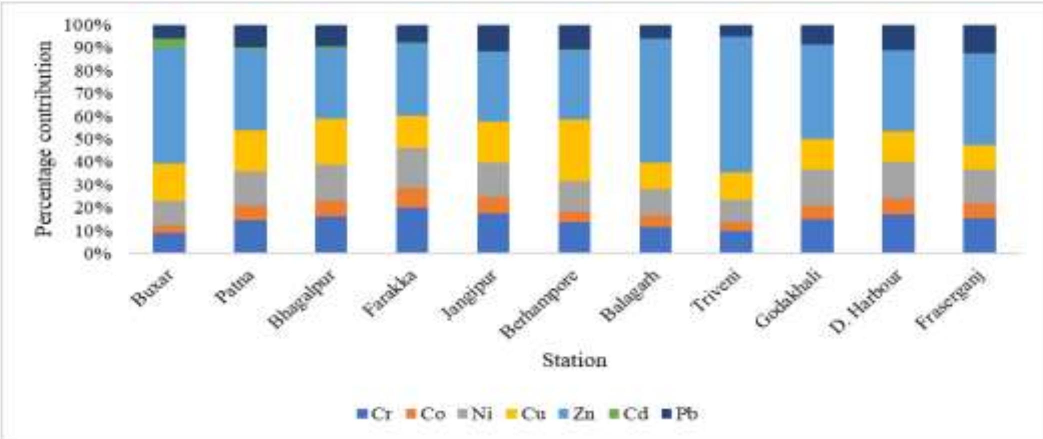


Figure 44: Heavy metal distribution in periphyton community across different stretches River Ganga

2.3.14. Benthic diversity of river Ganga

2.3.14.1. Upper and middle stretch

A total of 34 macro-benthic fauna (Fig. 45A, B) were recorded, belonging to 13 orders and 22 families, comprising 15 Gastropods, 6 Bivalves, 9 Insects, 2 Polychaeta and two Clitella from 13 sampling sites of the river Ganga from Harsil to Ballia. The highest total abundances (ind/m^2) of the macro-benthic species during the year 2024 were recorded 555 from Ghazipur followed by Ballia (530 ind/m^2), AB Narora (417 ind/m^2), Mirzapur (521 ind/m^2), AB Bijnor (391 ind/m2), Harsil and AB Kanpur (363 ind/m^2), Varanasi (361 ind/m^2), Prayagraj (314 ind/m^2), Farrukhabad (312 ind/m^2), BB Bijnor & BB Kanpur (307 ind/m^2), BB Haridwar (273 ind/m^2), BB Narora (263 ind/m^2), AB Haridwar (163 ind/m^2), Uttarkashi (88 ind/m^2), BD Tehri (67 ind/m^2) and AD Tehri (52 ind/m^2) respectively. The dominant benthic species were as follows (Gastropods) *Filopaludina bengalensis*, *Gyraulus convexiusculus*, *Lymnaea acuminata*, *Tarebia granifera*, *Indoplanorbis exustus*, *Physella acuta,* and *Melanoides tuberculata* (Bivalves) *Corbicula striatella*, *Parreysia favidens*, *P. shurtleffiana*, *P. corrugata* etc, (Insects) *Chironomus* sp. mostly dominated in the middle zone, but *Heptagenia* sp, *Hydropsyche* sp, *Baetis* sp. and *Leptophlebia* sp. were recorded in the upper zone of the river Ganga. The pre-monsoon showed the maximum 652 ind/m^2 and minimum 65 ind/m^2 were observed at BB Haridwar and Uttarkashi. On the other hand, in the monsoon season, the maximum 603 ind/m^2 and minimum 20 ind/m2 benthic species were recorded from Ballia and BD Tehri, respectively.

2.3.14.2. Lower and estuarine stretch

The pre-monsoon distribution of various molluscan species across different locations (Fig.45C). Among the recorded species, *Tarebia granifera* exhibited the highest abundance at 649 individuals/m^2 in Tribeni, followed by *Melanoides tuberculata* with 476 individuals/m^2 in the same region. *Mekongia crassa* was found to have a significant presence in Jangipore and Berhampore. Several species, such as *Filopaludina bengalensis*, were observed in multiple locations, including Patna, Buxar, and Balagarh, with abundance reaching up to 173 individuals per square meter. Some species, including *Indothais lacera* and *Indothais sacellus*, were recorded only in Fraserganj, whereas *Gabbia orcula* was found exclusively in Balagarh (433 individuals/m^2). The presence of species like *Lymnaea luteola* and *Corbicula assamensis* in various locations indicates their adaptability to different habitats. *Tarebia granifera* recorded the highest abundance, at 649 individuals/m^2, in Nabadwip, followed by *M. tuberculata*, with 390 individuals/m^2 in the same location. *Filopaludina bengalensis* was widespread, with high densities in Tribeni (216 individuals/m^2), Balagarh (303 individuals/m^2), and Patna (476 individuals/m^2). The presence of *Indoplanorbis exustus* was observed, with the highest abundance in Nabadwip at 260 individuals/m^2. *Corbicula bensoni* and *Corbicula assamensis* were observed in Bhagalpur, Patna, and Buxar, suggesting their preference for those regions. Fraserganj and Godakhali had unique species records, including Telescopium telescopium (216 individuals/m^2 in Godakhali) and Cerithidea obtusa (303 individuals/m^2 in Fraserganj).

In the data observed in the post-monsoon season, *Filopaludina bengalensis* was recorded in multiple stations, with the highest abundance at Jangipore (130 ind/m^2) and the lowest at Buxar (43 ind/m^2). *Melanoides tuberculata* showed a uniform distribution, with 43 individuals recorded in three locations. *Tarebia granifera* was notably abundant at Tribeni (476 ind/m^2) and Balagarh (563 ind/m^2). Some species were found only in specific stations. *Mekongia crassa* was recorded only in Balagarh, with a high abundance of 606 ind/m^2. *Neripteron violaceum* and *Corbicula bensoni* were both exclusively present in Diamond Harbour. *Corbicula assamensis*, *Corbicula striatella*, and *Parreysia cylindrica* were found solely in Buxar.

In Buxar, three different types of larvae Berosus larvae (87 ind/m^2), Chironomid larvae (130 ind/m^2), and Ceratopogonidae larvae (173 ind/m^2) were identified. The distribution of species varies significantly across locations, with some species showing a widespread presence while others are more localized. The data suggest that certain regions offer more favourable conditions for specific species, likely due to variations in water quality, habitat type, and food availability.

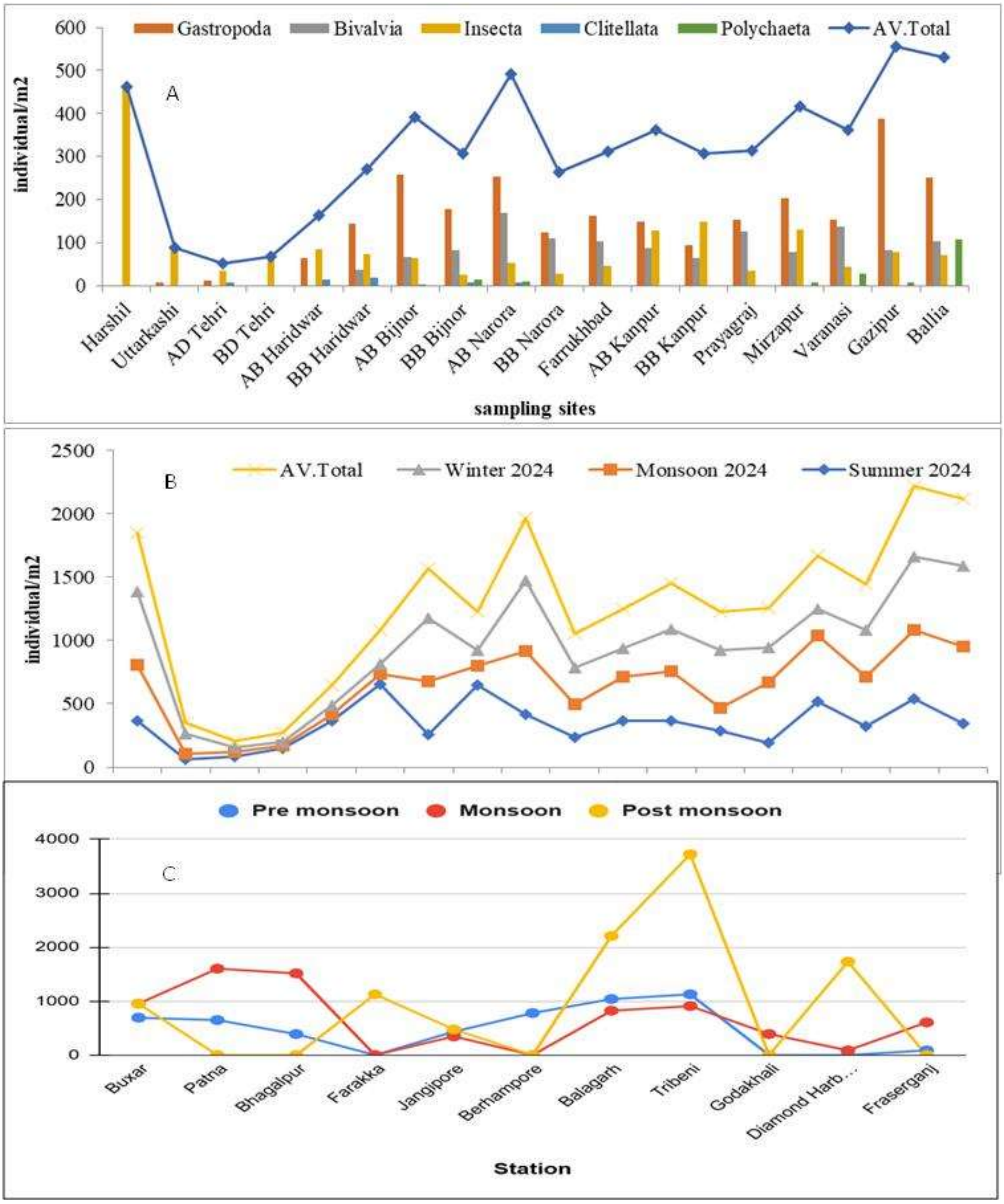


Figure 45: Benthic density in A-B. upper stretch C. middle and estuairne stretch of River Ganga

2.3.15. Microplastic contamination

2.3.15.1. River water

The locations include Buxar, Patna, Bhagalpur, Farakka, Jangipur, Berhampore, Balagarh, Tribeni, Godakhali, Diamond Harbour, and Fraserganj. The data, expressed in units of relative abundance, highlight spatial variation in microplastic pollution (Fig. 46A). Fibres were the most prevalent microplastic type across all locations, with the highest concentration recorded at Buxar (8.00 items/L), followed by Patna (6.00 items/L) and Bhagalpur (5.33 items/L). Downstream locations such as Berhampore, Balagarh, and Tribeni reported significantly lower fibre concentrations (1.33–1.67 items/L), indicating a decreasing trend in fibre pollution. Fragments showed a consistent presence across sites, with the highest abundance at Buxar and Patna. Films exhibited relatively uniform concentrations, typically around 1.00–1.67 items/L, except for Fraserganj, which showed a slightly higher abundance of 2.00 items/L/L. Beads were the least abundant type of microplastic, absent in certain locations, including Jangipur, Berhampore, and Balagarh. They were most abundant at Buxar (2.33 items/L), suggesting localised sources or environmental factors influencing their distribution. Buxar exhibited the highest levels of all microplastic types. Conversely, downstream sites such as Tribeni and Berhampore reported minimal microplastic pollution, except for localised variations in specific types (e.g., fibres at Godakhali and Fraserganj). This pattern highlights the influence of urbanisation, industrial discharges, and hydrodynamic factors on microplastic distribution. Upstream regions likely contribute the majority of pollutants, while dilution, sedimentation, and biodegradation may reduce microplastic concentrations further downstream. This assessment highlights the need for targeted pollution mitigation strategies, particularly in upstream areas with high microplastic loads.

2.3.15.2. River sediment

Microplastic contamination in aquatic ecosystems has become a global environmental concern due to its pervasive presence and potential ecological impacts. This study evaluates the distribution and types of microplastics present in sediment samples collected from various sites along the Ganges River (Fig. 46 B), ranging from Buxar to Fraserganj. The analysis identifies five categories of microplastics: fibres, fragments, films, foam, and beads. Results reveal significant spatial variation in microplastic abundance, with fibres being the most prevalent type across all sites. These findings highlight the urgent need for effective waste management and pollution mitigation strategies to protect this vital river system. Fibres were the most abundant type of microplastic observed, with their presence recorded at all sites. The highest concentrations were observed at Buxar (23 items/kg) and Godakhali (18 items/kg). These results suggest that textile wastewater and untreated domestic effluents are significant sources of fibre pollution. Fragments were widely distributed, with the highest occurrence at Fraserganj (19 items/kg) and Buxar (14 items/kg). Their irregular shapes indicate the degradation of larger plastic items such as packaging and household products. Films were relatively less common, with Bhagalpur and Fraserganj reporting the highest numbers (4 items per kilogram). These plastics likely originate from single-use packaging materials and agricultural mulch films. Foam particles were most prevalent at Fraserganj (21 items/kg) and Diamond Harbour (14 items/kg), indicative of urban runoff and improper disposal of polystyrene products. Upstream sites such as Balagarh and Tribeni exhibited minimal foam contamination. Beads were the least common type, found at only a few locations, including Buxar (3 items/kg), Godakhali (2 items/kg), and Fraserganj (3 items/kg). These beads are likely sourced from personal care products and industrial applications.

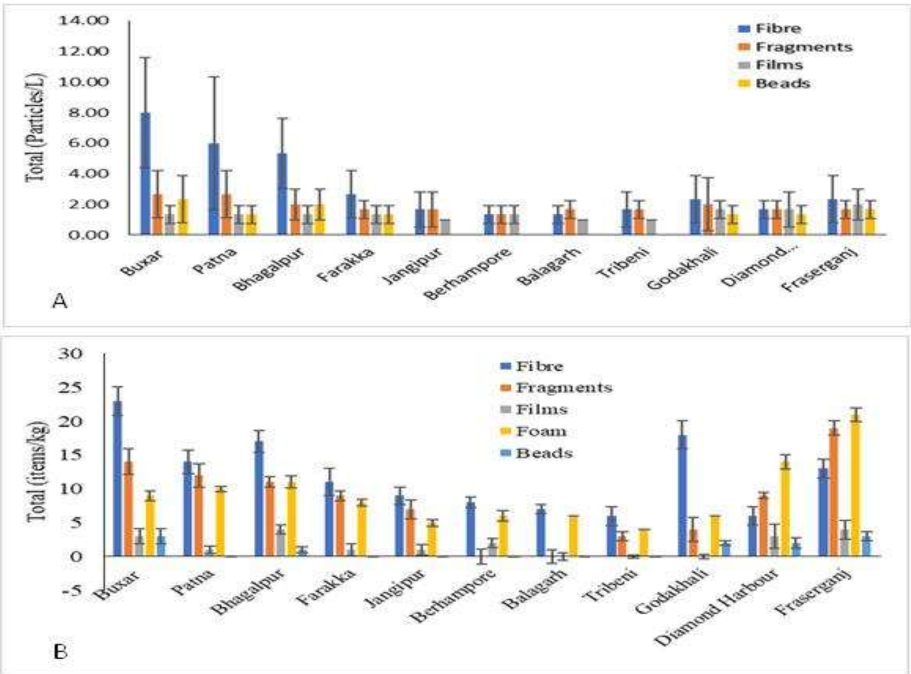


Figure 46: A. Site-wise microplastic contamination in waters of the river Ganga, B. Site-wise microplastic contamination in sediment of the River Ganga

2.3.16. Sediment status of the river Ganga

2.3.16.1. Upper and middle stretch

The sediment pH of the river Ganga during PRM was found mostly alkaline, with a highest value of 9.11 at Narora AB and a lowest of 7.6 at Uttarkashi and Haridwar BB. During MON, a slightly alkaline to alkaline pH range of 7.19 to 8.95 was obtained at Harsil and Farrukhabad, respectively (Fig. 47). During POM somewhat acidic to alkaline pH range of 6.73 (Harsil) – 8.97 (Bijnor BB) was observed. In most of the stations, MON values of pH were found to be higher than POM and PRM.

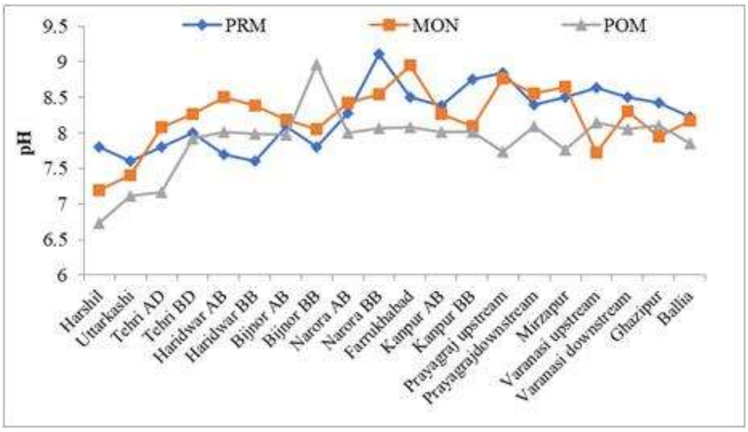


Figure 47: Variation of sediment pH in the upper & middle stretches of the River Ganga

2.3.16.2. *Specific conductance (mS/cm)*

The specific conductance (SC) of the river sediment during PRM was estimated to be 0.037 mS/cm at Tehri BD and 1.036 mS/cm at Kanpur BB. During the MON, conductance was found to be 0.06 mS/cm at Farrukhabad and 0.496 mS/cm at Varanasi upstream. POM values of SC were recorded as highest (0.77 mS/cm) at Kanpur BB and lowest (0.097 mS/cm) at Haridwar AB (Fig. 48A). Higher SC values at Kanpur BB during PRM and POM indicate contamination of the sediment.

2.3.16.3. *Sediment texture (%)*

The content of sand, silt, and clay primarily represents the sediment texture. During the pre-monsoon period (PRM), the highest sand percentage (94%) was reported at Harsil, and the lowest (53.34%) at Narora AB (Fig. 48 B). In the monsoon (MON), the highest sand percentage was found to be 89.49% at Tehri BD, and the lowest was 58.38% at Ghazhipur. The highest percentage of sand, 88.76, was reported at Haridwar AB, and the lowest, 60.76, was at Prayagraj upstream during the post-monsoon (POM) season. High sand content was observed from Harsil to Haridwar during PRM; however, it was absent from Bijnor to Ballia during POM, except in a few cases. The irregular trend in sand content may be due to illegal sand mining, primarily occurring at the middle stretch of the River Ganga. The lowest silt% % (0.036) was recorded from Varanasi to Ballia, and the Highest (31.35) was at Narora AB during PRM. The maximum silt percentage was found at 21.74% at Varanasi downstream, and the minimum was 0.28% during the month. During the POM, silt percentages with values of 0.28 were reported at Haridwar AB, Prayagraj downstream, and 24.28 at Tehri BD. From Harsil to Kanpur, the highest silt content was observed during the PRM and POM seasons, whereas from Prayagraj to Ballia, it occurred during the MON season. It may be due to the presence of four barrages at Haridwar, Bijnor, Narora and Kanpur.

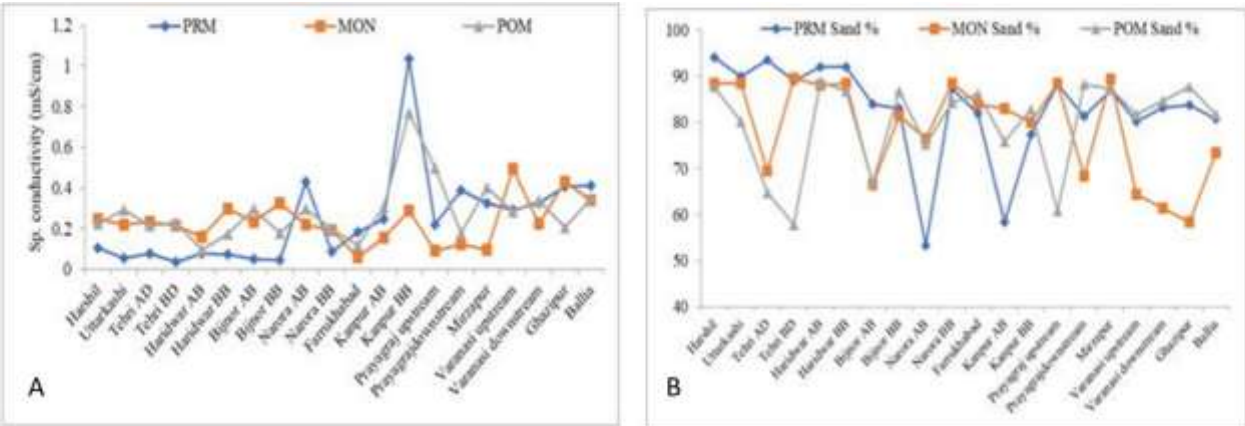


Figure 48 (A-B): Variation of sediment specific conductivity (A) and texture (B) in upper & middle stretch of River Ganga

2.3.16.4. *Available Nitrogen (mg/100g)*

In pre-monsoon (PRM), the lowest available nitrogen (AN) content was noticed at Ghazhipur, 2.24 mg/100g, and the highest was at Uttarkashi, 13.72 mg/100g. During MON values of AN, 1.96 mg/100g (Tehri BD) and 24.64 mg/100g (Ghazhipur) were recorded. The maximum value of AN during POM was recorded as 27.72 mg/100g at Narora AB, and the minimum was 1.68 mg/100g at Haridwar AB. The AN content during MON was higher than that of PRM and POM at most stations. This may be due to monsoonal deposition of silt and clay content in river-bed sediment.

2.3.16.5. ***Available and total phosphorus (mg/100g)***

The available phosphorus (AP) ranged from 2.54 mg/100g (Farrukhabad) to 20.92 mg/100g (Tehri AD) during the PRM (Fig. 49A). In the MON available phosphorus was observed 0.08 mg/100 g at Bijnor BB and 33.58 mg/100g at Tehri AD. A minimum value of 1.02 mg/100g was observed at Narora AB and a maximum of 37.16 mg/100g at Uttarkashi during POM. Upper stretch (from Harsil to Tehri) shows higher AP content during all the seasons. Total phosphorus (TP) levels during PRM were found to range from a minimum of 5.55 mg/100g at Bijnor AB to a maximum of 69.99 mg/100g at Varanasi downstream (Fig. 49B). In the MON total phosphorus value was reported 0.88 mg/100g at Tehri BD and 45.77 mg/100g at Narora BB. A higher value of 55.56 mg/100g was observed at Bijnor AB, and a lower value of 2.30 mg/100g at Narora AB. In comparison to AP maximum values of TP were observed during PRM season.

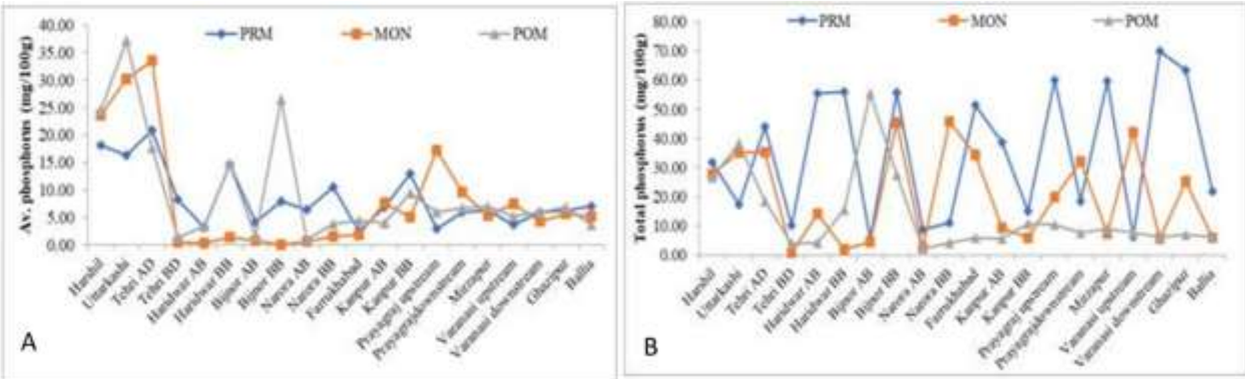


Figure 49 (A-B): Variation of sediment Avl. P (A) and Total P.(B) and texture in upper & middle stretch of River Ganga

2.3.16.6. ***Calcium carbonate (%)***

In pre-monsoon (PRM), the maximum and minimum value of calcium carbonate ($CaCO_3$) was reported as 2 and 15%, respectively, at Farrukhabad and Bijnor BB. During MON $CaCO_3$ ranges from 0.5% to 16% (Ghazipur). The minimum and maximum values of 8 and 16% were recorded at Tehri BD and Bijnor AB, respectively, during POM (Fig. 50A). The value of $CaCO_3$ was higher during POM at most of the sampling stations of the river Ganga.

2.3.16.7. ***Organic Carbon (%)***

In the pre-monsoon (PRM) season, the organic carbon (OC) concentration was found to be very low (0.03%) at Bijnor AB and Ballia, and high (0.67%) at Ghazipur. During MON, the lowest value of OC, 0.03%, was obtained at many sites, and a maximum of 0.85% at Tehri AD (Fig.

50B). The highest value of 1.73% was obtained at Tehri AD, and the lowest was 0.06% during POM. Higher OC content of Tehri AD during PRM and POM may be due to the presence of high silt content. River Ganga gets converted into a lake due to the presence of the Tehri dam, where higher siltation occurs.

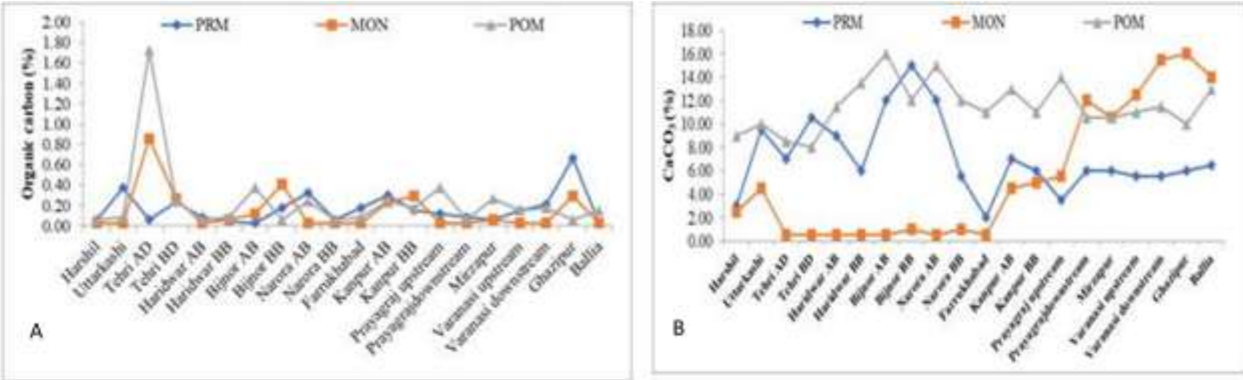


Figure 50 (A-B): Variation of sediment $CaCO_3$ (A) and organic C (B) in the upper & middle stretch of the river Ganga

2.3.17. Lower and estuarine stretch

2.3.17.1. *Sediment pH*

An analysis of pH levels at eleven key locations along the Ganga River during the monsoon (MON) and post-monsoon (POM) periods revealed notable seasonal variations (Fig. 51A). Most locations exhibited a decrease in pH, suggesting a trend toward increased acidity following the monsoon. For instance, Buxar showed a decline from 8.33 to 8.04, and Patna experienced a marginal drop from 8.32 to 8.03, indicating relatively stable but slightly more acidic conditions. Bhagalpur and Farraka recorded more pronounced reductions from 8.54 to 8.24 and 8.64 to 8.07, respectively, with Farraka showing a significant shift. Jangipur also saw a notable drop from 8.32 to 8.01, while Baharampore's pH reduced from 8.45 to 8.05, maintaining moderately alkaline waters. Balagarh experienced one of the most significant reductions, from 8.67 to 7.95, indicating substantial post-monsoon neutral pH. Tribeni (8.14 to 7.93) and Diamond Harbour (8.13 to 7.97) reflected consistent seasonal decreases. Godakhali remained largely unchanged, with a minimal shift from 7.95 to 7.93. In contrast, Faserganj was the only location to record an increase in pH, rising from 8.45 to 8.98, suggesting enhanced alkalinity in post-monsoon. This overall trend highlights the influence of seasonal changes on the river's pH dynamics. Overall, most sites exhibited a reduction in pH during the post-monsoon period, reflecting the influence of runoff, dilution, and other seasonal factors. Faserganj, however, demonstrated an anomalous increase in pH post-monsoon, warranting further investigation.

2.3.17.2. ***Specific conductivity (µS/cm)***

An analysis of conductivity levels along the Ganga River during the monsoon and post-monsoon periods reveals distinct spatial and seasonal variations influenced by hydrological and anthropogenic factors. In upstream regions such as Buxar and Patna, conductivity increased significantly post-monsoon from 123.5 to 393 µS/cm. From 111 to 272 µS/cm, respectively, likely due to reduced freshwater inflow and subsequent concentration of dissolved ions (Fig. 51B). Bhagalpur exhibited the lowest conductivity during the monsoon (98 µS/cm), reflecting substantial freshwater input, with only a modest post-monsoon rise to 130.33 µS/cm. Farakka followed a similar trend, with low monsoon conductivity (100 µS/cm) increasing to 201 µS/cm post-monsoon, possibly due to regulated water release and diminished dilution. In contrast, Jangipur maintained relatively high conductivity during both seasons (230 µS/cm in monsoon and 222 µS/cm post-monsoon), suggesting a stable ionic environment. Beharampore exhibited a moderate increase from 196.5 to 222 µS/cm, likely due to sediment resuspension and human activities. A sharp increase was observed in Balagarh, where conductivity nearly doubled from 106 to 210 µS/cm, indicating a significant concentration of dissolved ions after the monsoon. Interestingly, Tribeni experienced an atypical decline from 292 µS/cm to 197 µS/cm, potentially reflecting dilution from downstream freshwater influx. In the lower reaches, Godakhali's high monsoon conductivity (337 µS/cm) decreased to 187 µS/cm post-monsoon, likely influenced by seasonal hydrodynamics. Diamond Harbour showed persistently high conductivity (434 µS/cm rising to 477 µS/cm), reflecting the influence of brackish water and tidal mixing. Faserganj, at the river's estuarine end, recorded the highest monsoon conductivity (2950 µS/cm), indicative of strong estuarine influence, which dramatically declined to 491 µS/cm post-monsoon, suggesting tidal dilution and altered saline intrusion. Overall, these patterns highlight the complex interplay of freshwater inflow, tidal forces, and human activities in shaping the river's conductivity profile across seasons.

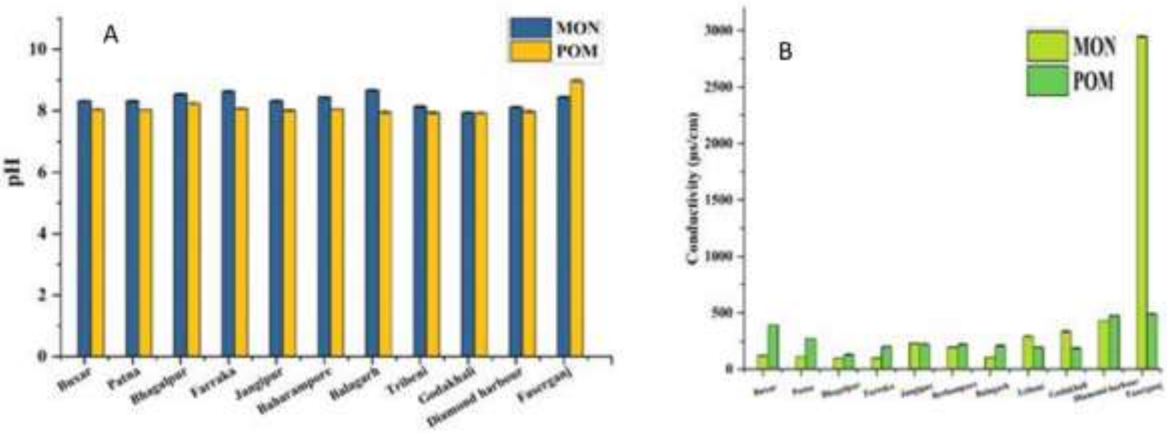


Figure 51 (A-B): Variation of sediment pH (A) and Sp. Conductivity, (B) in the middle & estuarine stretch of the river Ganga

2.3.17.3. *Sediment texture (%)*

The analysis of sediment texture across key locations along the Ganga River during the monsoon and post-monsoon periods reveals distinct spatial variations driven by hydrodynamic conditions and estuarine influences. Upstream sites such as Buxar, Patna, and Bhagalpur are characterized by a predominantly sandy texture, with sand content exceeding 90% and minimal silt and clay fractions (Fig. 52A). This composition reflects high-energy fluvial conditions that favour the deposition of coarser materials while inhibiting the accumulation of finer sediments. In contrast, sites like Farakka and Jangipur display relatively higher proportions of silt and clay. Midstream sites including Baharampore, Balagarh, and Tribeni exhibit intermediate sediment compositions. While sand remains the dominant fraction, these sites show a noticeable presence of silt and clay, likely due to localized variations in flow velocity and sediment input. In the lower reaches, Godakhali and Diamond Harbour exhibit variable silt and clay percentages, indicating fluctuating depositional conditions influenced by tidal mixing and estuarine dynamics. Faserganj, located in the estuarine zone, records the highest proportion of silt and clay at 28%, highlighting its low-energy environment that favours the deposition of finer materials. Collectively, these sediment texture variations highlight the intricate relationships between riverine flow, tidal influence, and site-specific hydrodynamics that govern sediment transport and deposition along the Ganga River.

2.3.17.4. *Calcium Carbonate (%)*

The distribution of calcium carbonate ($CaCO_3$) content along the sediments of Ganga River during the monsoon (MON) and post-monsoon (POM) periods reveals distinct spatial and temporal trends (Fig. 52B). In the Buxar and Patna regions, a moderate increase in $CaCO_3$ concentrations from MON to POM was noted suggesting enhanced carbonate deposition during the post-monsoon period, possibly due to reduced dilution and increased sedimentation of carbonate-rich material. Bhagalpur, Farraka, and Jangipur consistently exhibited relatively high $CaCO_3$ concentrations in both periods, with only minor fluctuations, indicating stable carbonate dynamics in these midstream zones. Baharampore, however, recorded the highest $CaCO_3$ levels during the monsoon, followed by a noticeable decline in the post-monsoon period, likely reflecting seasonal changes in sediment input and hydrological flow.

In Balagarh and Tribeni, $CaCO_3$ levels remained moderate, with slight variations between the two seasons, indicating a relatively steady carbonate supply. In the lower reaches, Godakhali and Diamond Harbour displayed a decreasing trend in $CaCO_3$ concentrations during POM, which may be attributed to dilution effects from increased freshwater influx post-monsoon. Faserganj presented an interesting pattern, with the lowest $CaCO_3$ concentration during MON but the highest in POM, indicating estuarine influences that enhance carbonate deposition as tidal dynamics shift. Overall, these patterns highlight how a complex interplay of seasonal hydrology, sediment source variation, and estuarine mixing processes influences carbonate content in river sediments.

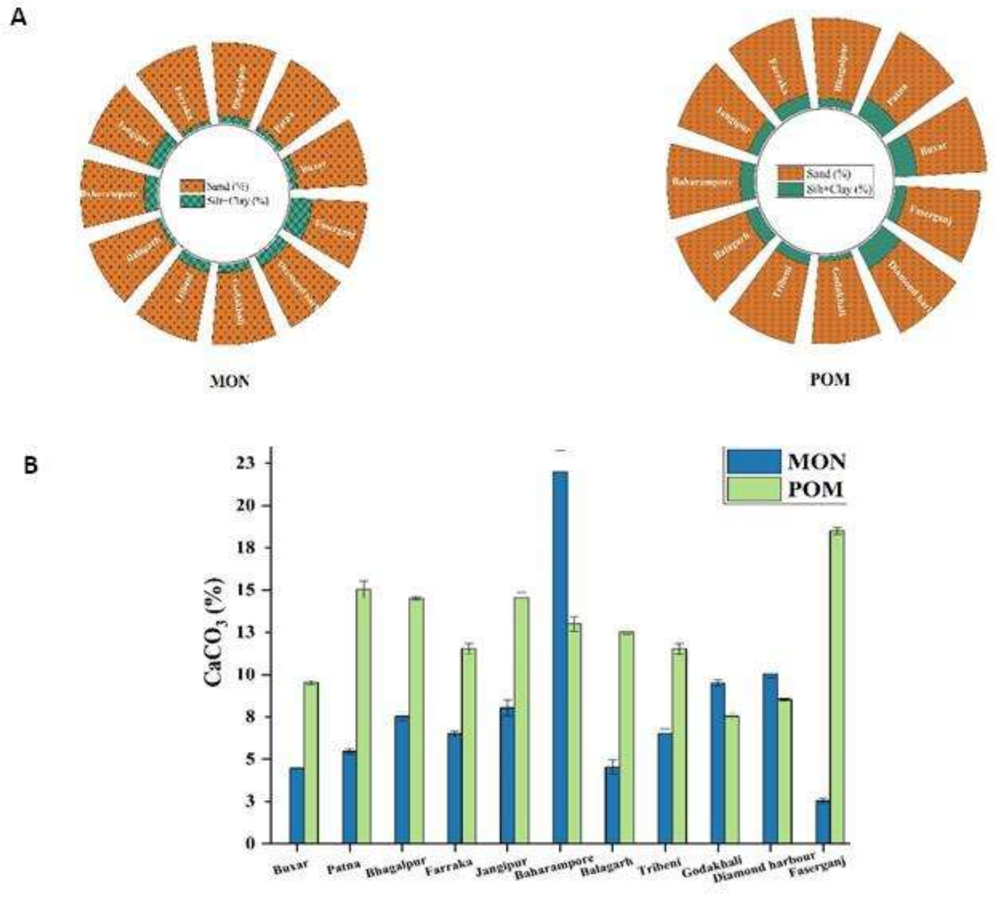


Figure 52 (A-B): Variation of A. sediment texture and B. sediment $CaCO_3$% % in the middle & estuarine stretch of the River Ganga

2.3.17.5. *Total phosphate (mg/100g)*

The variations in Total Phosphorus (TP) concentrations across the study locations highlight the complex and dynamic nature of phosphorus cycling in the river system, influenced by hydrological conditions, anthropogenic inputs, and sediment interactions (Fig. 53A). Buxar and Patna showed a significant decrease in TP from the monsoon (MON) to the post-monsoon (POM) period, likely due to dilution effects from increased water flow during POM. In contrast, Bhagalpur, Jangipur, and Tribeni exhibited a notable increase in TP during POM, indicating potential phosphorus inputs from upstream sources or intensified anthropogenic activities. Farraka and Balagarh maintained relatively stable TP levels between the two periods, suggesting a consistent phosphorus load in these areas. Baharampore consistently recorded lower TP values in both MON and POM, reflecting limited phosphorus enrichment. The estuarine regions of Godakhali and Diamond Harbour experienced the highest TP levels during

POM, likely driven by estuarine influences such as tidal mixing and sediment resuspension. Faserganj displayed moderate TP concentrations with a slight decrease in POM, possibly attributed to tidal flushing. These spatial and temporal patterns highlight the interplay between natural processes and human activities in shaping phosphorus dynamics within the river-estuary continuum.

2.3.17.6. *Total nitrogen (mg/100g)*

The spatial and temporal patterns of Total Nitrogen (TN) across the study sites reveal the varying influences of external inputs, hydrological processes, and biogeochemical mechanisms (Fig. 53B). Buxar, Patna, and Godakhali showed an increase in TN levels during the post-monsoon (POM) period, indicating possible external nitrogen inputs from sources such as agricultural runoff or wastewater discharge. In contrast, Bhagalpur, Jangipur, and Baharampore exhibited relatively stable TN concentrations between the monsoon (MON) and POM periods, suggesting a steady and consistent nitrogen source in these regions. Farraka and Balagarh exhibited a decline in TN during POM, likely due to dilution from increased water volume or reduced upstream inputs. Notably, Tribeni and Diamond Harbour experienced a substantial decrease in TN levels during POM, which could be attributed to nitrogen removal processes such as denitrification or sedimentation. On the other hand, Faserganj recorded a significant increase in TN in the POM period, possibly due to estuarine influences and the accumulation of nutrients in this tidal zone. These observations underscore the complex nitrogen dynamics shaped by both natural processes and anthropogenic pressures across the river-estuary continuum.

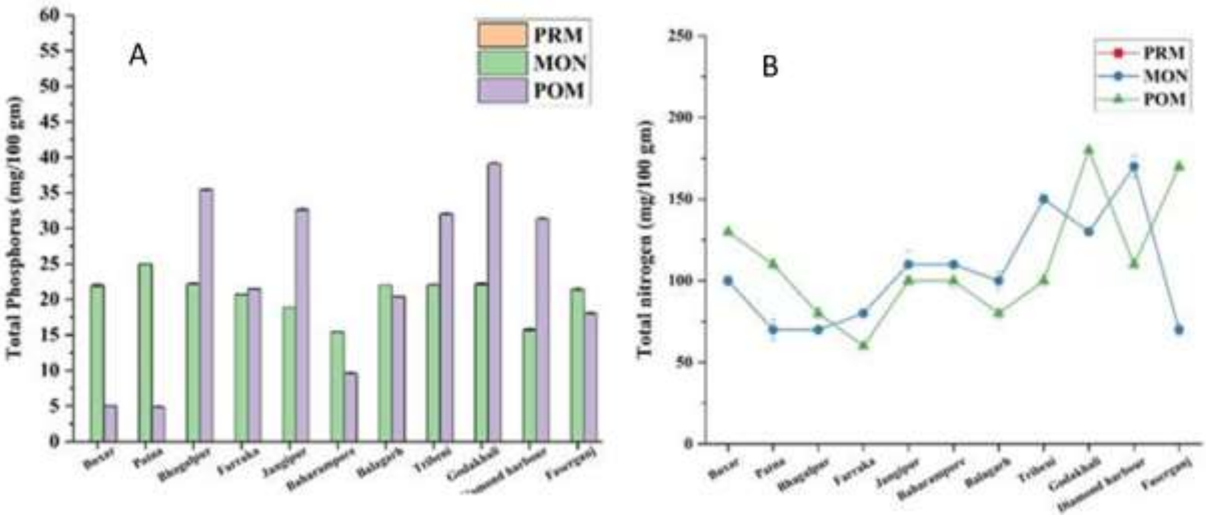


Figure 53 (A-B): Variation of total P. (A) and total N.(B) in middle & estuarine stretch of River Ganga

2.3.17.7. *Organic Carbon (%)*

The distribution of Organic Carbon (OC) across the study sites highlights the influence of seasonal changes, upstream inputs, and local environmental conditions on organic matter dynamics (Fig.54). Site like Buxar and Farraka recorded a significant increase in OC from the pre-monsoon (PRM) to the monsoon (MON) period, likely driven by enhanced input of organic matter from upstream sources or increased decomposition due to higher water flow and temperature. However, sites like Patna, Jangipur, Tribeni, and Diamond Harbour exhibited a moderate increase in OC, suggesting a steady influx of organic material from both natural processes and anthropogenic activities. In contrast, Bhagalpur, Baharampore, and Godakhali showed relatively stable OC concentrations between PRM and MON, indicating limited seasonal variability in organic matter input or processing. Balagarh displayed a noticeable increase in OC, potentially due to sediment resuspension or localized contributions of organic material.

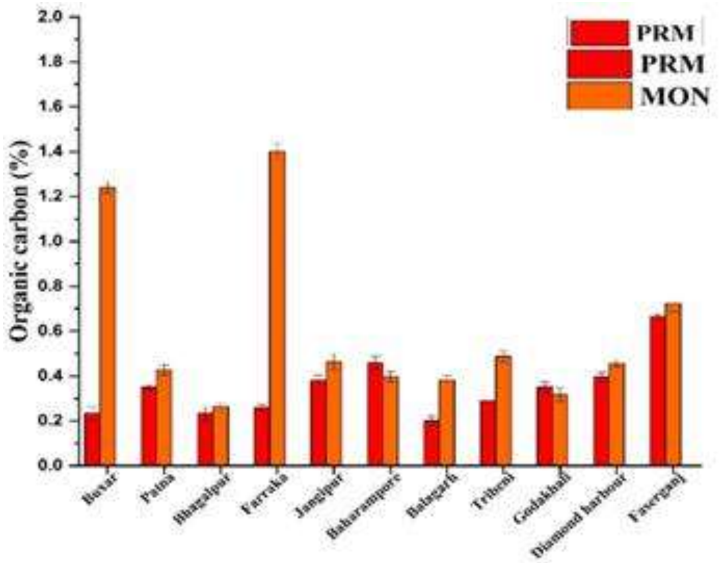


Figure 54: Variation of sediment Organic C in the middle & estuarine stretch of River Ganga

2.3.17.8. Geochemical partitioning of sediment-bound phosphorus in River Ganga: Status of bioavailability, pollution sources, and eutrophication implications

Despite continuous efforts, eutrophication continues to occur in freshwater, and phosphorus (P) is the most essential nutrient that drives eutrophication in rivers and streams. The geochemical fractions, bioavailability, and ecological risk of phosphorus in the surface sediments of the River Ganga were investigated (Fig. 55). To better understand the P dynamics, sequential chemical extraction techniques were used to study sediment P pool distribution, such as exchangeable (Ex-P), aluminium-bound (Al-P), iron-bound (Fe-P), calcium-bound (Ca-P), and organically bound phosphorus (Org-P). Significantly higher level of total P was recorded in pre-monsoon season (438.49±95.76 mg/kg), than other [winter (345.68 ± 110.62 mg/kg), post-monsoon (319.20± 136.30 mg/kg), and monsoon (288.63 ± 77.32 mg/kg)] seasons and was primarily composed of inorganic P. Ca-bound P was the dominant fractions of P in sediments. Sources such as agricultural activities, along with sewage from both industry and domestic activities, all have an impact on the P dynamics in the river Ganga. Bioavailable phosphorus (BAP) suggests the availability of an ample amount of bioavailable P fractions (37.8-46.0%) in sediments. However, an estimated phosphorus pollution index based on sediment total P content showed no ecological risk of phosphorus to the Ganga River sediment. This information will be helpful in applying various mitigation techniques to reduce the phosphorus load in river ecosystems.

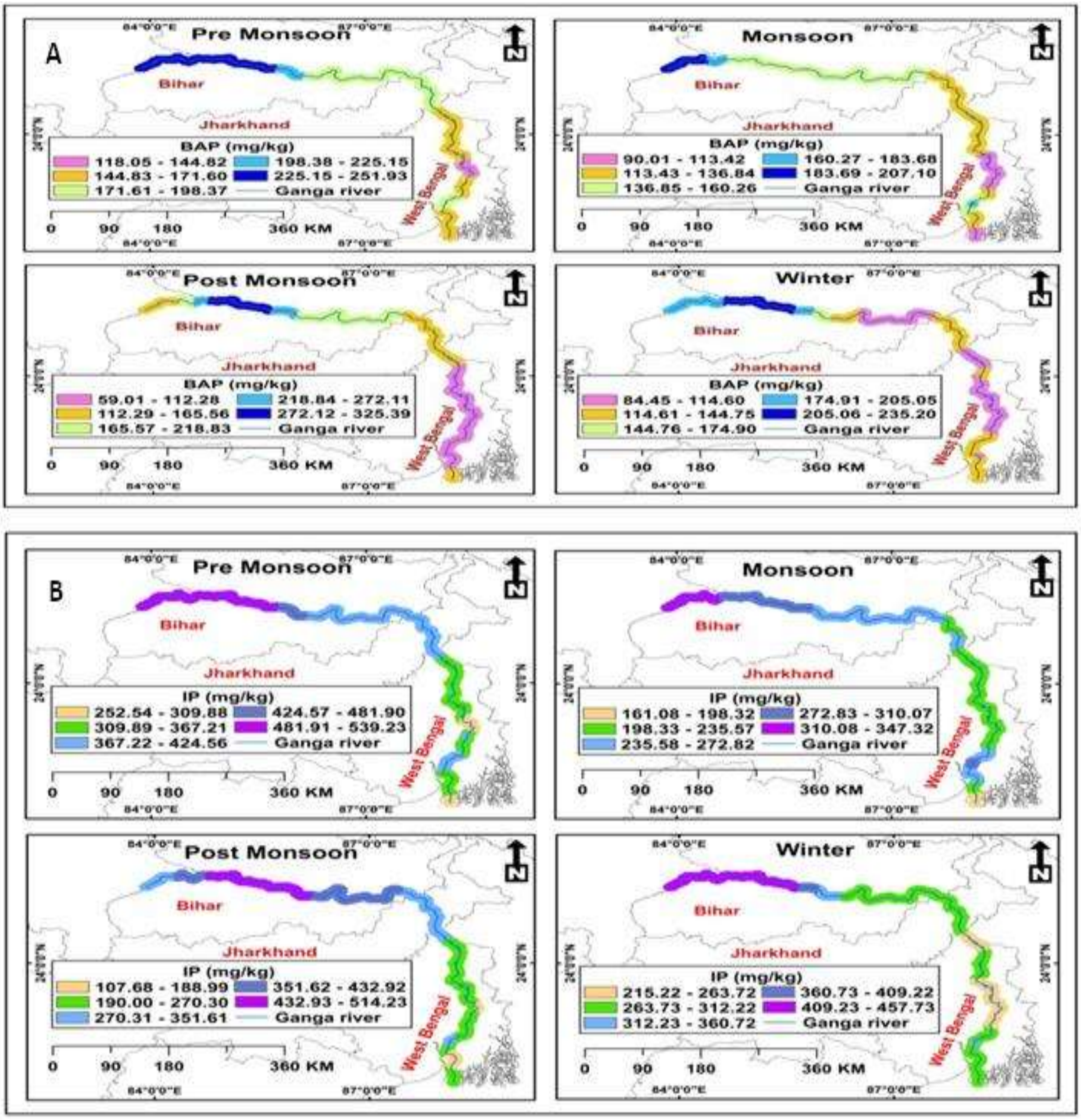


Figure 55: Sediment bound Phosphorus dynamics in different seasons of the river Ganga

2.4 OBJECTIVE IV: NUTRIENT PROFILING OF COMMERCIALY IMPORTANT FISH SPECIES OF THE RIVER GANGA

2.4.1. Gross chemical composition of food fishes of the River Ganga

- Gross chemical composition of fish is generally the percentage composition of the four basic constituents' viz., water, protein, fat and ash (mainly minerals). The chemical composition of fish varies widely between species and among the individual fishes within the same species (Table 4.), depending on age, sex, environment and season. Protein and ash content exhibit minimal variation. Lipid content shows remarkable variation and shows an inverse relationship with water content. The water or moisture content is essentially the difference in weight after heating finely minced meat or ground fish at a specific temperature for a defined duration.
- The crude protein is measured in terms of nitrogenous compounds present in the sample, which are converted to ammonium sulfate by boiling with concentrated sulfuric acid. Upon distillation with excess alkali, the ammonia is liberated, which is estimated by titration with standardised sulfuric acid. Similarly, fat, which is soluble in organic solvents, can be extracted from moisture-free samples using solvents such as petroleum ether and ethyl ether. The solvent is evaporated, and fat is estimated gravimetrically, and ash is the residue obtained after incineration of the dry material at high temperature and appears as grey-white colored powder (Mohanty et al., 2019).
- Thirty food fishes, especially the small indigenous fishes (SIFs), were collected from different sampling sites of the lower stretch of the River Ganga (Farakka, Sheoraphuli, Nawabganj, Mangal Pandey Ghat, Faserganj) and gross chemical composition in terms of moisture, crude fat, crude protein and ash content was analysed. The analysis showed that among the fish studies, the top three fat-rich fishes were *Anondontostoma chacunda* (Chacunda gizzard shad), *Cynoglossus cynoglossus* (Bengal tongue sole), and *Crossocheilus latius* (Gangetic latia) and the fishes which can be utilised as a good source of lean meat, being rich in protein, were *Eutropiichthys vacha* (Batchwa vacha), *Clupisoma garua* (Garua bachcha), and *Macrognathus pancalus* (Barred spiny eel).

Table 4: Gross chemical composition analysis of thirty food fishes from River Ganga

Sl no.	Fish species	Common name	Moisture (%)	Crude protein (%)	Crude Fat (%)	Ash (%)
1.	*Eutropiichthys vacha*	Bacha	78.66±0.73	19.75±1.31	02.39±0.04	2.49±0.10
2.	*Lepidocephalichthys guntea*	Gunte, Gutum	75.63±1.14	15.80±1.42	04.55±0.22	3.38±0.50
3.	*Clupisoma garua*	Ghero, Ghauro	72.37±1.45	18.76±1.71	10.20±0.95	2.53±0.02
4.	*Macrognathus pancalus*	Pankaal	77.15±1.27	18.35±1.31	09.57±0.85	3.44±0.60
5.	*Gonialosa manmina*	Chapra, kurti	70.26±0.78	17.35±0.92	15.11±1.11	6.23±0.90
6.	*Gagata cenia*	Kukri	70.34±0.98	13.52±1.32	11.73±0.86	6.76±1.01
7.	*Silonia silondia*	Silon	73.59±1.13	16.90±1.32	10.25±0.85	1.96±0.01
8.	*Rhinomugil corsula*	Korshula	74.43±0.97	17.28±1.75	07.59±0.62	4.01±0.05
9.	*Channa marulius*	Gogol, Sal	81.70±2.03	17.05±1.25	01.06±0.08	1.52±0.01
10.	*Chanda nama*	Chanda	79.57±0.94	14.99±1.26	2.95±0.09	4.46±0.07
11.	*Apocryptes bato*	Pituli bele	81.44±2.01	15.80±1.42	1.8±0.08	2.87±0.02
12.	*Setipinna phasa*	Phasa	79.33±1.06	14.99±1.25	2.37±0.11	3.21±0.04
13.	*Nandus nandus*	Nadosh, Bheda	77.25±0.86	15.07±1.22	5.01±0.21	4.17±0.02
14.	*Cirrhinus reba*	Reba bata, Rai	77.17±1.05	16.50±1.42	5.34±0.25	3.44±0.02
15.	*Parambassis ranga*	Chanda	78.63±0.88	11.76±0.90	3.88±0.16	5.13±0.05
16.	*Salmostoma bacaila*	Chela	77.59±1.08	15.05±1.33	4.77±0.28	4.10±0.09
17.	*Glossogobius guiris*	Aash Bhele	80.22±1.22	17.53±1.68	1.14±0.15	3.05±0.03
18.	*Cabdio morar*	Piyali	77.89±0.98	15.60±1.31	5.28±0.22	3.49±0.02
19.	*Crossocheilus latius*	Kalo	67.47±0.77	13.19±1.15	17.3±0.98	3.67±0.03
20.	*Eleotris fusca*	Kalo bele	79.96±1.43	14.45±1.22	4.72±0.22	3.20±0.04
21.	*Acanthocobitis botia*	Chitai	72.55±0.99	16.17±1.14	8.29±0.75	4.42±0.04
22.	*Anondontostoma chacunda*	Nona khoira	58.76±0.55	15.62±1.50	24.15±2.1	1.98±0.01
23.	*Cynoglossus cynoglossus*	Banspata	72.22±0.91	06.34±0.42	17.36±1.21	4.08±0.04
24.	*Glyptothorax telchitta*	Kukri	64.50±0.97	16.00±1.52	15.44±1.11	6.24±0.05
25.	*Corica soborna*	Sona karke	81.63±0.82	05.66±0.33	13.35±0.96	2.26±0.01
26.	*Mystus cavasius*	Tengra	75.26±1.18	16.65±1.61	7.65±0.82	2.83±0.01
27.	*Colia dussumieri*	Amodi	74.60±0.76	15.72±1.44	5.95±0.55	5.10±0.05
28.	*Mystus bleekeri*	Golsha-tengra	74.93±0.91	14.20±0.93	4.79±0.34	4.05±0.13
29.	*Systomus sarana*	Sar puti	78.65±0.42	15.64±0.49	2.50±0.37	1.56±0.21
30.	*Sardinella melanura*	Chandana ilish	72.78±0.26	16.66±0.23	5.66±0.51	3.70±034

2.4.2 Amino acid composition of food fishes of the River Ganga

- The amino acids are separated in an HPLC equipped with a C18 reverse phase column and a fluorescence detector (2475, Waters). Protein is hydrolyzed to constituent amino acids by 6N hydrochloric acid. The amino acids were identified and quantified by comparing the retention times and peak areas with those of the amino acid standard (WAT088122, Waters) (Das et al., 2024).

- The amino acid composition of thirty food fishes was generated and collected from different stretches of the river Ganga (Table 5). Among the fish species studied, the essential amino acids lysine (LYS), leucine (LEU), and arginine (ARG) were found to be the dominant amino acids. The fish species *Eleotris fusca*, *Sardinella melanura*, and *Mystus cavasius* were identified as rich sources of these essential amino acids, respectively. Similarly, the non-essential amino acids glutamic acid, glycine, and aspartic acid were the dominant amino acids found in the fishes *Eleotris fusca*, *Mystus cavasius*, and *Cynoglossus cynoglossus*, respectively.

Table 5: Amino acid composition of food fishes from River Ganga

Food Fishes	Amino Acids (g/100g)																
	ARG	**VAL**	**HIS**	**ILE**	**LEU**	**LYS**	**MET**	**PHE**	**THR**	**CYS**	**GLU**	**GLY**	**PRO**	**TYR**	**ALA**	**ASP**	**SER**
L. guntea	1.10±0.14	0.46±0.02	0.19±0.01	0.43±0.01	0.71±0.04	0.95±0.03	0.02±0.00	0.40±0.01	0.47±0.05	-	1.91±0.21	1.01±0.11	0.55±0.02	0.29±0.01	0.74±0.06	1.16±0.12	0.51±0.05
M. bleekeri	2.9 ± 0.2	1.8 ± 0.6	0.8 ± 0.5	1.8 ± 0.5	3.3 ± 0.3	3.9 ± 0.7	0.9 ± 0.4	1.7 ± 0.7	1.9 ± 0.3	0.4 ± 0.1	7.3 ± 1.5	1.8 ± 0.6	1.3 ± 0.3	1.5 ± 0.5	2.6 ± 0.6	4.6 ± 0.3	1.8 ± 0.4
G. cenia	0.16±0.01	0.51±0.04	0.23±0.01	0.49±0.02	0.80±0.06	0.91±0.08	0.04±0.0	0.46±0.02	0.45±0.04	1.90±0.11	1.83±0.14	0.48±0.02	0.36±0.02	-	0.59±0.03	1.14±0.20	0.47±0.02
C. morar	1.62±0.14	0.84±0.09	1.21±0.11	0.41±0.02	0.78±0.12	0.93±0.06	0.08±0.0	0.40±0.01	0.06±0.0	-	1.16±0.12	0.11±0.01	0.39±0.01	-	0.59±0.03	0.53±0.02	1.08±0.09
S. sarana	3.6 ± 0.2	2.7 ± 0.3	1.4 ± 0.5	2.4 ± 0.4	4.6 ± 0.5	5.1 ± 1.2	1.6 ± 0.6	2.5 ± 0.2	2.8 ± 0.4	0.1 ± 0.6	9.3 ± 1.2	3.0 ± 0.4	2.4 ± 0.2	2.2 ± 0.4	3.9 ± 0.6	6.5 ± 1.4	2.5 ± 0.2
R. corsula	0.09±0.0	0.51±0.4	0.28±0.02	0.46±0.06	0.85±0.12	0.92±0.11	0.16±0.01	0.45±0.06	0.58±0.09	-	1.62±0.14	0.34±0.02	0.38±0.06	0.38±0.01	0.65±0.11	0.88±0.09	0.56±0.08
C. marulius	0.99±0.22	0.47±0.03	0.24±0.01	0.42±0.03	0.75±0.08	0.74±0.09	0.04±0.00	0.42±0.03	0.42±0.01	-	1.52±0.22	0.54±0.06	0.44±0.02	0.28±0.01	0.53±0.95	0.91±0.1	0.41±0.04
A. bato	0.07±0.00	0.40±0.03	0.70±0.08	0.02±0	0.73±0.08	0.93±0.09	0.12±0.01	0.38±0.04	0.87±0.10	0.21±0.01	0.75±0.09	0.76±0.10	0.37±0.02	0.34±0.02	0.63±0.06	0.08±0.01	0.66±0.08
M. pancalus	1.94±0.25	0.88±0.09	0.45±0.04	0.84±0.10	1.45±0.14	1.46±0.11	0.25±0.02	0.79±0.08	0.83±0.10	-	3.22±0.33	1.65±0.14	0.97±0.12	0.63±0.08	1.32±0.15	1.88±0.14	0.85±0.09
C. cynoglossus	1.80±0.12	1.04±0.08	0.51±0.04	0.99±0.08	1.65±0.14	1.92±0.21	0.33±0.01	0.90±0.09	0.86±0.10	-	3.36±0.31	1.04±0.09	3.24±0.24	0.64±0.04	1.18±0.11	2.09±0.21	0.89±0.09
S. phasa	0.69±0.06	0.35±0.02	0.17±0.01	0.29±0.01	0.58±0.03	0.66±0.04	0.14±0.01	0.31±0.01	0.40±0.01	-	1.45±0.11	0.47±0.02	0.41±0.02	0.27±0.01	0.49±0.02	0.85±0.08	0.35±0.01
P. ranga	0.91±0.07	0.38±0.02	0.18±0.01	0.34±0.01	0.66±0.03	0.32±0.01	0.14±0.11	0.34±0.01	0.39±0.01	-	1.56±0.11	0.63±0.02	0.55±0.04	0.31±0.02	0.58±0.03	0.93±0.03	0.41±0.02
S. silondia	2.00±0.21	0.92±0.10	0.46±0.02	0.93±0.10	1.67±0.11	1.66±0.12	0.31±0.01	0.83±0.07	0.89±0.07	-	0.95±0.09	0.74±0.04	0.66±0.04	0.73±0.06	1.12±0.11	0.59±0.03	0.91±0.09
S. bacaila	0.93±0.04	0.480.03	0.25±0.01	0.45±0.02	0.85±0.07	0.86±0.07	0.16±0.01	0.44±0.02	0.45±0.01	0.11±0.01	1.77±0.14	0.46±0.02	0.39±0.01	0.40±0.02	0.63±0.02	1.07±0.11	0.44±0.02
C. dussumeri	0.88±0.05	0.47±0.02	0.18±0.01	0.43±0.02	0.80±0.05	0.82±0.08	0.14±0.01	0.42±0.01	0.40±0.03	-	1.66±0.12	0.49±0.02	0.39±0.01	0.36±0.02	0.57±0.03	0.96±0.05	0.40±0.02

A. chacunda	1.00± 0.08	0.59± 0.03	0.34±0.01	0.53± 0.04	0.97±0.08	1.04± 0.10	0.19± 0.01	0.52± 0.04	0.53± 0.04	-	1.92± 0.18	0.56± 0.02	0.46± 0.02	0.44± 0.02	0.69± 0.05	1.14±0.11	0.51± 0.04
G. telchitta	0.96± 0.08	0.53± 0.04	0.21±0.02	0.53± 0.03	0.95±0.05	0.93± 0.05	0.13± 0.01	0.52± 0.02	0.48± 0.04	-	1.79± 0.14	0.48± 0.02	0.55± 0.02	0.41± 0.02	0.65± 0.04	1.09±0.08	0.47± 0.02
G. giuris	0.93± 0.06	0.48± 0.04	0.25±0.01	0.45± 0.03	0.81±0. 06	1.13± 0.11	0.16± 0.01	0.46± 0.02	0.44± 0.03	-	1.81± 0.18	0.47± 0.03	1.64± 0.12	0.37± 0.03	0.62± 0.04	1.13±0.11	0.47± 0.02
E. fusca	4.90± 0.36	3.12± 0.34	1.77±0.021	3.10± 0.24	5.24±0.41	4.06± 0.33	1.92± 0.18	3.62± 0.28	2.56± 0.22	0.62± 0.06	7.61± 0.63	3.10± 0.28	2.35± 0.22	2.92± 0.24	3.18± 0.32	4.55±0.045	2.51± 0.22
C. garua	0.58± 0.04	0.33± 0.02	0.89±0.06	0.30± 0.01	0.64±0.09	0.57± 0.06	0.14± 0.01	0.34± 0.02	0.37± 0.02	-	1.38± 0.11	0.52± 0.04	0.34± 0.02	0.24± 0.01	0.43± 0.01	0.84±0.06	0.36± 0.01
C. soborna	0.99± 0.11	0.47± 0.04	0.24±0.01	0.42± 0.06	0.75±0.08	0.74± 0.11	0.04± 0.01	0.42± 0.06	0.42± 0.06	-	1.52± 0.08	0.54± 0.03	0.46± 0.04	0.28± 0.01	0.53± 0.08	0.91±0.06	0.41± 0.02
G. manmina	1.02± 0.09	0.54± 0.02	0.25±0.03	0.50± 0.06	0.88±0.09	0.94± 0.06	0.17± 0.09	0.46± 0.02	0.50± 0.03	-	1.84± 0.11	0.48± 0.03	0.38± 0.02	0.42± 0.02	0.57± 0.05	1.04±0.11	0.47± 0.02
E. vacha	0.64± 0.08	0.32± 0.03	0.15±0.01	0.86± 0.08	0.57±0.05	0.26± 0.01	0.09± 0.01	0.29± 0.01	0.30± 0.02	-	1.25± 0.14	0.28± 0.04	0.24± 0.01	0.25± 0.04	0.39± 0.04	0.75±0.08	0.31± 0.02
C. nama	1.07± 0.05	0.69± 0.05	0.27±0.01	0.55± 0.07	0.96±0.11	1.08± 0.09	0.16± 0.01	0.50± 0.05	0.49± 0.02	-	1.97± 0.13	0.02± 0.0	0.41± 0.02	0.44± 0.03	0.68± 0.05	1.45±0.14	0.53± 0.02
C. latius	0.13± 0.10	0.41± 0.02	0.95±0.01	0.34± 0.02	0.74±0.07	0.61± 0.05	0.05± 0.01	0.45± 0.04	0.64± 0.06	-	1.50± 0.11	0.80± 0.07	0.43± 0.01	0.32± 0.01	0.52± 0.04	0.92±0.07	0.45± 0.03
N. nandus	0.15± 0.01	0.35± 0.02	0.18±0.02	0.01± 0.0	0.66±0.05	0.80± 0.07	0.15± 0.01	0.35± 0.01	0.35± 0.01	-	1.43± 0.11	0.37± 0.04	0.28± 0.02	0.30± 0.01	0.50± 0.04	0.85±0.05	0.36± 0.03
C. reba	1.03± 0.04	0.57± 0.06	0.31±0.02	0.53± 0.08	0.91±0.07	1.26± 0.14	0.16± 0.01	0.50± 0.04	0.50± 0.04	-	2.01± 0.18	0.51± 0.04	1.57± 0.14	0.42± 0.02	0.69± 0.05	1.26±0.11	0.51± 0.06
M. cavasius	2.28± 018	1.29± 0.09	0.59±0.04	1.33± 0.14	2.34±0.23	2.34± 0.23	0.50± 0.04	1.28± 0.11	1.20± 0.12	-	4.62± 0.31	1.08± 0.09	0.98± 0.07	1.00± 0.08	1.55± 0.11	2.77±0.18	1.20± 0.02
S. melanura	3.5 ± 0.4	2.7 ± 0.5	1.3 ± 0.2	2.3 ± 0.6	4.3 ± 0.4	5.4 ± 1.1	1.9 ± 0.7	2.3 ± 0.6	2.6 ± 0.6	0.5 ± 0.3	9.8 ± 1.7	2.08 ± 0.5	2.0 ± 0.4	2.1 ± 0.4	3.6 ± 0.5	6.4 ± 1.5	2.4 ± 0.6
A. botia	2.22± 0.11	0.97± 0.08	0.43±0.02	0.87± 0.09	1.53±0.16	1.46± 0.12	0.24± 0.01	0.85± 0.10	0.93± 0.10	-	3.36± 0.22	1.04± 0.09	0.74± 0.08	0.68± 0.07	1.25± 0.16	1.99±0.08	0.86± 0.06

Abbreviations: ARG: arginine; VAL: valine; HIS: histidine; ILE: isoleucine; LEU: leucine; LYS: lysine; MET: methionine; PHE: phenylalanine; THR: threonine; CYS: cysteine; GLU: glutamic acid; GLY: glycine; PRO: proline; TYR: tyrosine; ALA: alanine; ASP: aspartic acid; SER: serine

2.4.3. Fatty acid composition of food fishes of River Ganga

- The fatty acids were identified and quantified using a GC (Trace GC Ultra, Thermo Scientific) equipped with a capillary column (TR-FAME, 30m × 0.25mm, 0.25µm film thickness) and an MS (ITQ 900, Thermo Scientific) attached to it. The fat is extracted using a 2:1 chloroform: methanol mixture, and subsequently, fatty acid methyl esters (FAMEs) are prepared and analysed by GC/MS (Mohanty et al., 2016).
- Thirty food fishes from the river Ganga were collected from different sampling sites along the river Ganga, and fatty acid composition was determined (Table 6). The saturated fatty acid palmitic acid (C16:0) was the dominant fatty acid, followed by stearic acid (C18:0), and the fishes *Lepidocephalichthys guntea*, *Clupisoma garua* and *Crossocheilus latius* were rich in these fatty acids. Considering the monounsaturated fatty acids, palmitoleic acid (C16:1) and oleic acid (C18:1) were the dominant fatty acids and the fishes *Anodontostoma chacunda*, *Clupisoma garua* and *Colia dussumeri* were rich in these fatty acids. Similarly, the omega (ω) -3 polyunsaturated fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) were present in higher quantities in the fishes *Anodontostoma chacunda*, *Colia dussumeri*, and *Crossocheilus latius*.

Table 6: Fatty acid composition of food fishes from River Ganga (mg/100g)

Fatty acids	*C. garua*	*R. corsula*	*C. morar*	*M. pancalus*	*C. reba*	*S. melaura*	*S. phasa*	*E. vacha*	*S. bacaila*	*G. cenia*	*C. nama*	*S. sarana*	*A. bato*	*N. nandus*	*C. marulius*
C12:0	40.18±4.26	-	-	-	-	2.32±0.92	-	-	-	-	-	0.22±0.10	0.29±0.01	-	-
C14:0	547.38±10.21	104.20±1.24	42.27±1.33	19.04±0.89	76.13±0.98	1.86±0.97	4.37±0.82	45.69±1.02	14.43±0.39	66.68±1.33	10.42±0.56	0.80±0.01	3.24±0.41	30.41±1.44	1.56±0.06
C15:0	252.35±8.51	81.21±1.21	19.34±1.01	25.01±0.51	119.56±1.23	0.36±0.18	4.45±0.79	69.17±0.79	8.22±0.21	64.60±1.41	4.44±0.31	0.06±0.00	3.08±0.36	32.17±1.36	1.45±0.09
C16:0	1434.76±13.4	448.72±3.33	166.58±1.99	153.39±1.21	287.53±2.33	4.70±0.99	21.52±0.41	323.33±3.24	71.63±0.69	185.87±1.95	51.40±0.07	0.81±0.01	16.11±0.98	188.95±1.99	11.67±0.12
C17:0	308.88±9.51	74.66±1.41	73.52±1.03	38.13±0.50	72.04±0.69	1.63±0.84	7.99±0.56	64.52±0.79	10.25±0.12	131.94±1.21	6.45±0.02	0.13±0.01	26.43±1.26	42.33±0.42	2.97±0.03
C18:0	870.67±10.4	106.15±1.44	62.04±1.01	71.90±0.94	83.04±0.71	1.57±0.23	13.10±1.21	203.91±2.10	31.78±0.39	164.11±1.33	20.74±0.01	0.38±0.01	4.84±1.33	93.15±0.9	12.77±0.12
C20:0	-	-	-	6.35±0.79	-	-	0.79±0.07	-	-	-	-	-	-	-	-
C21:0	89.43±6.21	-	-	-	-	0.53±0.12	-	-	-	-	-	0.08±0.00	-	-	-
C24:0	-	20.09±1.01	-	-	-	-	-	-	-	-	-		-		-
C14:1	13.19±2.1	4.83±0.99	3.56±0.89	3.48±0.49	15.47±0.02	0.58±0.12	2.27±0.09	13.38±0.49	4.72±0.92	72.96±1.03	2.34±0.04	0.02±0.00	1.37±0.03	14.54±0.05	0.52±0.01
C16:1	847.37±9.42	941.40±8.21	419.06±4.33	210.85±2.01	532.74±4.89	8.56±1.43	16.83±1.01	162.85±1.09	83.71±1.01	161.85±1.71	76.55±1.05	0.62±0.01	4.21±0.31	231.60±2.22	4.57±0.98
C18:1	881.45±8.91	271.98±8.91	100.31±1.09	253.15±2.63	289.75±2.26	10.08±1.08	25.49±0.89	634.65±3.24	126.36±1.33	543.13±3.66	70.84±1.71	1.99±0.05	25.78±0.79	315.13±3.23	23.50±0.89
C20:1	864.74±9.42	-	-	18.64±0.63	-	2.0±0.71	7.48±1.21	53.16±0.77	-	228.56±2.53	-	0.29±0.01	8.15±0.11	28.81±0.89	-

C18:2	284.63±2.31	137.69±1.41	35.87±0.07	183.12±1.52	139.95±1.41	4.39±1.64	14.48±0.98	270.20±2.51	100.84±1.02	602.46±6.36	20.96±1.01	1.63±0.06	24.82±0.99	184.93±1.99	9.25±0.79
C18:3	169.49±1.90	303.47±3.43	28.43±0.06	62.18±0.89	190.59±1.89	2.46±0.41	5.69±1.0	195.77±1.23	77.77±0.75	95.99±1.02	25.28±0.98	0.31±0.01	5.54±0.66	204.16±2.22	3.56±0.66
C20:4	281.90±3.30	202.61±2.36	135.54±1.23	102.59±1.53	149.74±1.23	5.12±0.81	38.37±0.79	236.56±2.02	59.54±0.69	270.72±2.60	32.73±0.36	1.51±0.50	35.31±1.24	162.08±1.36	45.89±0.97
C20:5	287.06±3.55	141.98±1.05	239.35±2.03	68.44±0.95	135.76±1.21	5.67±1.11	7.90±1.01	43.09±0.75	40.35±0.69	64.95±0.69	9.66±0.34	0.57±0.01	6.78±0.99	-	1.29±0.06
C22:6	698.36±7.84	416.33±1.55	379.86±3.34	18.59±0.39	207.63±2.08	5.52±1.84	41.23±1.24	290.74±±2.21	111.16±1.24	229.64±2.13	41.20±0.27	2.22±0.02	30.33±1.44	299.63±2.89	40.58±0.69

Contd.

Fatty acid	***L. guntea***	***S. silondia***	***C. latius***	***C. soborna***	***C. cynoglossus***	***M. cavasius***	***G. guiris***	***G. telchitta***	***M. bleekeri***	***G. manmina***	***P. ranga***	***E. fusca***	***A. chacunda***	***A. botia***	***C. dussumeri***
C12:0	16.92±1.23	9.04±0.48	-	-	0.72±0.01	-	-	-	3.55±0.98	0.64±0.01	6.66±0.76	-	16.11±1.28	3.63±0.67	7.1±0.29
C13:0	-	-	-	-	-	-	-	-	-	-	6.01±0.55	-	-	-	-
C14:0	10.09±0.79	75.50±1.12	85.71±0.93	9.14±0.99	17.68±0.41	14.42±0.79	2.58±0.05	1.57±0.03	3.57±0.95	9.52±1.43	44.97±3.24	73.6±2.95	757.07±22.95	56.27±1.98	163.39±5.66
C15:0	10.35±0.69	30.66±1.01	31.61±0.42	2.32±0.02	6.33±0.23	5.13±0.36	1.20±0.06	0.61±0.01	1.31±0.58	4.71±0.98	31.65±2.98	36.8±1.85	136.96±8.88	30.41±1.12	46.13±2.82
C16:0	42.87±0.36	288.27±2.99	286.91±2.66	26.12±0.21	46.69±0.89	46.51±0.23	11.18±0.11	6.73±0.89	7.30±1.23	35.7±3.56	214.03±10.95	235.6±5.98	3185.44±175.04	259.79±4.76	768.93±14.08
C17:0	20.42±0.24	35.58±0.42	123.03±1.02	2.59±0.33	13.53±0.03	9.75±0.11	2.53±0.04	1.09±0.56	2.40±0.96	5.78±1.24	35.79±1.69	39.97±1.06	419.03±12.82	55.74±1.16	70.5±2.25
C18:0	33.19±0.30	149.99±1.32	107.08±1.01	13.26±0.43	32.20±0.44	27.50±0.44	9.59±0.43	4.31±0.33	2.71±0.94	3.04±0.99	113.72±6.75	132.76±3.35	1660.54±84.09	161.03±3.98	384.25±11.98

C20:0	-	-	-	-	-	-	-	-	-	2.28±0.65	-	-	190.41±11.01	12.51±0.87	45.85±2.23
C21:0	-	-	-	-	-	-	-	-	0.46±0.01	-	-	-	-	-	-
C14:1	6.63±0.02	15.65±0.09	7.81±0.05	0.79±0.01	3.89±0.04	4.50±0.36	0.84±0.01	1.03±0.23	0.37±0.01	1.58±0.04	11.89±0.95	17.99±0.98	24.96±1.08	17.61±0.88	8.48±0.86
C16:1	535.80±5.89	266.45±1.99	545.29±5.23	21.01±0.33	38.30±0.99	28.52±0.56	5.84±0.36	4.45±0.11	13.24±1.66	31.96±2.44	243.46±8.44	226.79±2.65	3604.21±166.45	307.95±12.65	761.73±22.65
C18:1	103.72±1.02	419.32±4.08	551.41±5.99	35.49±0.33	68.43±1.01	68.38±0.18	20.15±1.01	35.45±1.23	17.00±1.98	62.18±2.85	641.91±9.26	671.05±4.88	4049.52±212.14	465.45±12.98	838.31±34.98
C20:1	17.84±0.23	35.32±0.98	30.94±0.99	2.66±0.02	21.79±0.89	6.80±0.09	4.32±0.76	2.74±1.01	3.47±0.87	13.27±1.66	30.79±2.33	52.21±1.92	844.29±85.05	950.22±117.61	134.04±4.95
C18:2	63.72±0.44	265.42±2.56	87.10±1.01	20.11±0.08	35.26±1.12	25.49±0.99	8.74±0.99	2.19±0.89	7.55±1.74	11.96±1.43	131.88±4.76	128.36±2.55	408.11±33.09	134.75±3.09	119.78±4.68
C18:3	37.51±0.69	171.74±1.53	93.14±1.33	-	20.60±1.33	18.02±0.78	2.60±0.09	2.29±0.49	4.22±0.78	6.92±0.99	105.99±3.98	76.35±1.94	177.69±8.77	85.02±2.98	28.66±1.18
C20:4	65.28±0.78	124.29±1.01	107.21±1.23	10.42±0.01	46.41±0.89	20.85±0.66	20.21±0.77	2.66±0.36	1.67±0.24	20.83±1.12	141.11±4.99	115.12±3.54	118.99±4.59	121.04±9.01	193.47±5.02
C20:5	12.78±0.41	29.26±0.71	305.87±3.04	13.16±0.02	44.19±0.77	4.76±0.02	6.80±1.01	1.49±0.79	2.96±0.77	21.61±1.84	64.4±1.54	69.9±2.42	2106.68±95.22	89.75±2.06	482.07±12.44
C22:6	55.11±0.23	217.19±2.14	326.57±3.44	58.76±0.99	139.18±1.23	77.63±1.11	18.59±0.66	5.95±1.01	22.38±0.58	81.78±3.22	318.61±7.55	373.73±6.74	1820.72±67.95	189.71±8.97	844.03±33.54

Abbreviations: C12:0- Lauric acid; C14:0- Myristic acid; C15:0-Pentadecylic acid; C16:0- Palmitic acid; C17:0- Margaric acid; C18:0-Stearic acid; C20:0- Arachidic acid; C21:0-Heneicosylic acid; C14:1- Myristoleic acid; C16:1- Palmitoleic acid; C18:1- Oleic acid; C20:1- Eicosenoic acid; C18:2- Linoleic acid; C18:3- Linolenic acid; C20:4- Arachidonic acid; C20:5- Eicospentaenoic acid; C22:6- Docosapentaenoic acid

2.4.4. Mineral composition of food fishes of River Ganga

- Micronutrients are needed only in minuscule amounts but are essential for proper growth and development. And the consequences of their absence are severe. Therefore, the current practice of evaluating nutritive value of diets should include not only energy and protein adequacy but also the micronutrient (mineral and vitamin) density of the diet (Mohanty et al., 2016).

- Macrominerals (Na, K, Ca, Mg) and trace elements (Fe, Mn, Se) were determined by inductively coupled plasma mass spectrometry (ICP-MS) of the fishes collected from different sampling sites of river Ganga (Table 7.). Among the fishes studied, *Colia dussumieri*, *Mystus cavasius,* and *Corica soborna* were rich in the minerals analysed.

Table 7: Mineral composition (mg/kg) of the thirty food fishes from River Ganga

Fish species	Na	K	Ca	Mg	Fe	Mn	Se
Eutropiichthys vacha	1.61±0.20	6.16±0.49	1.35±0.06	0.85±0.04	0.01±0.0	-	-
Lepidocephalichthys guntea	1.93±0.31	1.91±0.30	0.85±0.10	1.84±0.20	0.04±0.0	-	-
Clupisoma garua	2.77±0.40	6.04±0.20	2.04±0.19	1.06±0.10	0.15±0.01	-	-
Macrognathus pancalus	2.66±0.80	8.80±0.90	3.97±0.30	2.25±0.18	0.10±0.01	0.04±0.1	-
Goniolosa manmina	-	11.70±0.6	3.53±0.60	5.39±0.01	0.31±0.02	0.02±0.0	-
Gagata cenia	-	13.30±0.60	2.19±0.20	3.15±0.01	0.22±0.09	0.01±0.0	-
Silonia silondia	-	0.06±0.02	4.69±0.59	3.55±0.30	0.36±0.01	0.01±0.0	-
Rhinomugil corsula		0.07±0.02	1.43±0.12	4.01±.32	0.36±0.01	0.02±0.0	-
Channa marulius	6.22±0.11	39.31±0.6	3.32±0.94	3.76±0.07	0.30±0.01	0.02±0.0	-
Chanda nama	-	20.0±0.60	19.30±0.50	11.51±0.40	0.62±0.07	0.10±0.0	-
Apocryptes bato	-	0.18±0.04	21.07±0.61	9.43±0.10	0.32±0.04	-	-
Setipinna phasa	-	0.10±0.05	23.67±0.70	10.61±0.50	0.38±0.03	0.06±0.0	0.02±0.0
Nandus nandus	-	-	1079.01±15.63	64.03± 2.04	17.56±1.95	-	0.14±0.1
Cirrhinus reba	27.77±0.66	636.4±1.2	1104.04±32.	24.63±0.89	1.47±0.24	-	0.04±0.0
Parambassis ranga	-	846.9±6.1	2059.36±92.11	85.50±2.5	36.94±1.02	-	0.34±0.0
Salmophasia bacaila	-	-	1781.6±12.5	61.35±1.18	7.82±0.75	-	0.44±0.3
Glossogobius guiris	-	-	2395.30±10.2	97.58±3.12	19.47±1.62	-	0.60±0.1
Cabdio morar	3.09±0.16	8.57±0.62	2700.29±10.8	6.12± 0.05	165.43±12	-	0.28±0.0
Crossocheilus latius	3.09±0.42	8.57±0.86	2043.37±18.2	6.12± 0.04	161.54±2.75	-	0.35±0.0
Eleotris fusca	3.09± 0.20	8.57± 0.90	9572.31±45.2	6.12± 0.04	375.72±9.96	-	0.52±0.1

Acanthocobitis botia	1339.04±32.2	1077.47±55.12	182.95±5.3	284.74±9.3	85.32±9.5	0.90±0.0	-
Anondostoma chacunda	1854.79±52.2	2017.65±32.56	187.64±2.1	185.89±16.5	109.97±5.2	-	-
Cynoglossus cynoglossus	3323.66±20.1	3915.23±16.23	312.84±4.6	431.6±35.9	639.99±6.3	-	-
Glyptothorax telchitta	3293.81±15.06	2097.38±26.23	431.1±6.25	407.88±30.6	603.37±56.4	-	-
Corica soborna	4160.54±26.32	8273.65±22.46	380.58±4.92	798.94±109.75	832.65±6.98	-	-
Mystus cavasius	8813.03±29.1	7280.94±18.1	871.68±6.22	852.35±126.3	832.62±12.9	-	-
Colia dussumieri	17022.65±45.1	8912.37±46.3	106.6±2.36	932.24±168.3	1401.79±25.3	-	-

Abbreviations: Na: sodium; K: potassium; Ca: calcium; Mg: magnesium; Fe: iron; Mn: manganese; Se: selenium

3. COMPONENT: II

Establishment of Hilsa Stock in Middle Stretch of River Ganga through Ranching of Hilsa seed bred through Captive and wild adults

3.1. OBJECTIVE I: RANCHING OF JUVENILE AND ADULT HILSA COLLECTED FROM WILD AND ARTIFICALLY BRED TO ENHANCE THE NATURAL STOCK OF HILSA IN THE MIDDLE STRETCH FROM PRAYAGRAJ TO FARAKKA IN THE RIVER

The anadromous migration of Hilsa is mainly to fulfil their breeding attributes. In the river Ganga, the upstream migration of Hilsa generally starts in July and continues until November. At the same time, downstream migration occurs from January to March. Furthermore, the peak upstream migration is recorded with the advent of the South-West monsoon, i.e., July, and continues up to November. Although the period of migration is found to be prolonged, a small-scale migratory run is noticed up to March. Since the construction of the Farakka barrage in 1975 and the operational failure of the Farakka fish pass, the Hilsa population has declined significantly in the middle stretches of the River Ganga. Hilsa landings drastically declined (83.1-98.6%) in the middle stretch of the River Ganga (Farakka barrage to Prayagraj), while at the downstream of the barrage, the landings have increased. Therefore, it was planned to release the Hilsa, preferably adult, collected from the downstream and release them in the upstream of the barrage. Ranching of Hilsa has several critical factors, including transportation, to increase the Hilsa population in the upstream of the barrage, particularly in the middle stretch of the river Ganga.

3.1.1 Transportation of live Hilsa

Live Hilsa transportation remains a significant challenge due to their complex behaviour. Extreme sensitivity to environmental stressors, high oxygen requirements, anadromous migratory behaviour necessitating precise salinity conditions, poor tolerance to confinement and handling, and low survival rates in captivity, all contributes to elevated mortality during transport of the fish. Live Hilsa adult and sub-adults were collected from the downstream region of the Farakka Barrage using experimental fishing, using hand nets or customised lift nets, and monofilament gill nets with mesh sizes ranging from 65 to 110 mm (Fig. 56 A to D) as reported previously. Among these, the customized lift net was identified as the most suitable gear for Hilsa capture, as there is minimal physical injury and higher post-capture survivability (Fig. 5E). Our study confirmed that the fish require high dissolve oxygen for prolonged survival; hence, continuous water churning manually and aeration was maintained throughout the transportation period (Fig. 56 F-H). It was observed that individuals weighing between 100–350 g showed higher survival during transportation. Immediately post-capture, the fish were transferred into plastic tubs containing 25–30 litres of river water (Fig. 56 F). Each tub contained 5–6 numbers of Hilsa, with weight varying from 150 to 300 g. These tubs along with live fish were then transported by motorized vehicles from the downstream to the upstream of the barrage. Healthy individuals showed strong swimming behaviour against the current, whereas fish movement along with the current was reported as unhealthy. Open transport system was used in the whole process. Upon arrival at the ICAR-CIFRI Hilsa Ranching Station, the morphometric parameters, such as length and weight, were recorded for each specimen and acclimatised in 1000-litre holding tanks for 1-2 hours to minimize transportation-induced stress. Subsequently, the acclimatized Hilsa were transported further upstream using boats and released (ranched) 5-15 km from the barrage site.

Figure 56 (A – H): Customized lift net or hand net operated for Hilsa capturing; (C-D) Monofilament Gill Net operation for Hilsa capture; (E) Collection of Live Hilsa from the Fishermen; (F) Acclimatisation of the live Hilsa in a plastic tub; (G&H) Manual Transportation

3.1.2. Ranching of Hilsa

River ranching of native fish species is a strategic fisheries management intervention aimed at conserving and restoring indigenous germplasm in natural ecosystems. In recent years, many riverine ecosystems worldwide, including the Ganga River, in India have been subjected to increasing anthropogenic pressures such as excessive water abstraction, construction of hydraulic structures, industrial and domestic pollution, besides the impacts of climate change. In light of these challenges, enhancement of Hilsa populations in the middle stretches of the Ganga River was identified as a key conservation strategy. Consequently, river ranching was adopted as a principal approach to the re-establish of the declining Hilsa stock. To minimise the probability of downstream migration and potential escape through the feeder canal and beneath the Farakka Barrage, ranching activities were strategically conducted at a minimum distance of 5–15 km in the upstream of the barrage. Following transportation, the Hilsa individuals were transferred using an open-water transport system involving specially designed boats equipped to carry fish in aerated tubs. Between December 2023 and October 2024, a total of 47,755 Hilsa were successfully ranched into the river (Table 8) (Fig. 57). The mean total length and body weight of the released individuals were recorded at 25.5 cm and 367 g, respectively.

Table 8: Month-wise Hilsa Ranching Data from December '23 to October'24

Month	Total ranched Hilsa (no.)	Hilsa Stoking Pond (no.)	Tag Hilsa (no.)	Length range (cm) min-max	Weight range (g) min-max
December’23	3468	-	57	14.8-28.1	25.2-275.3
January	3854	-	216	14.4-30.8	30.3-480.1
February	5647	-		14-30	22.2-197
March	8882	-	20	14.1-33.4	18.9-386.3
April	714	-	7	13.1-32.5	18.9-386.3
May	176	-	7	15.4-27.1	22.8-111.6
June	154	-	4	13.8-23.4	28.4-232.6
July	78	-	2	15.8-26.7	40.1-168.2
August	394	46	20	17.8- 28.1	68.3-254.4
September	2059	42	189	15.1-31.2	35.8-370.1
October	3265	20	276	14.3 -32.2	27.2-375
Total	**28,691**	**108**	**798**	--	--

Figure 57: Activities of Hilsa ranching at the upstream of Farakka baragge (10 km radius) in river Ganga

3.2 OBJECTIVE II: DEVELOPMENT OF HILSA BROODSTOCK IN ARTIFICIAL REARING FACILITIES AND LARVAL PRODUCTION

3.2.1 Artificial Breeding of Hilsa to Enhance the Natural Stock in the Middle Stretch from Prayagraj to Farakka in the River Ganga

Artificial breeding has emerged as a vital intervention in addressing the multifaceted challenges threatening the survival and abundance of Hilsa, a fish species of immense commercial and ecological significance in India. Overfishing, rapid habitat degradation, and the steady decline of natural spawning grounds have contributed to a drastic reduction in Hilsa populations. In response to these pressing challanges, artificial breeding techniques offer a promising solution by supporting population recovery, maintaining genetic diversity, and ensuring a steady, sustainable supply of this culturally and economically valued species. However, between 2023 and 2024, a concerted series of artificial breeding programs were conducted across two key locations in West Bengal, Farakka and Godakhali. A total of eight such breeding programs were systematically conducted during this period, each aimed at improving hatchery success rates, and enhancing fry survival under controlled conditions. The detailed methodology, outcomes, and challenges encountered during these attempts are outlined in the sections below.

Dry and wet stripping methods typically follow the process. After stripping, the matured ova were mixed with a sufficient quantity of matured milt, which is collected by the wild oozing out male Hilsa. Then, the eggs were incubated for 45 minutes to 1 hour, until they reached the hardening phase. After this phase, the fertilization process was initiated, followed by cell division of the fertilized eggs. The fertilized eggs were carefully packaged in leak proof polyethylene bags with sufficient oxygen and transported by railway or road to the ICAR-CIFRI Hilsa ranching station hatchery at Farakka, West Bengal. After a period of 18 ± 3.45 hrs, the hatchlings of Hilsa were produced from the fertilized eggs. The unfertilized eggs were opaque and were removed manually folowing utmost care.

3.2.2 Artificial breeding

The artificial breeding trials of Hilsa conducted between December 2023 to October 2024 at Farakka and Godakhali revealed significant differences in brood stock characteristics and reproductive outcomes, with Godakhali demonstrating superior breeding performance. Both sites conducted four breeding programs using a combination of dry and wet methods, with breeding times ranging from late afternoon to early evening. The male-to-female ratio was maintained at 2:1 in Farakka and 4:1 in Godakhali, with 26 males and 13 females at the former and 48 males and 12 females at the latter, indicating a substantially higher male dominance at Godakhali. Notably, the average weight and length of both male and female brood fish were markedly higher in Godakhali, where males weighed 267.6 ± 26.85 g and measured 28.5 ± 1.41 cm, and females weighed 542.4 ± 19.56 g with a length of 32.9 ± 1.08 cm, compared to Farakka's males at 155.98 ± 14.82 g and 25.48 ± 1.02 cm, and females at 182.06 ± 25.25 g and 26.24 ± 1.26 cm. During the hardening phase, filtered Ganga water was initially used to promote better fertilization outcomes (Fig. 58).

Following this, it was gradually mixed with a combination of filtered Ganga water and packaged drinking water to acclimate the developing embryos. The water temperature during the breeding period ranged from 22 to 27.3 °C at Farakka and was slightly higher, at 22.4–28.6 °C, at Godakhali. Throughout the process, the water temperature was carefully maintained within the optimal range, which may have contributed to improved embryonic development and hatching success. The reproductive output at Godakhali far exceeded that of Farakka, yielding approximately 18.07 lakhs eggs compared to 2.02 lakhs eggs, alongside a significantly higher fertilization rate of 81.2% against 59.4% and a hatching success of 74.85% compared to 34.65%, respectively (Table 9). These results suggest that the larger brood stock size, higher male-to-female ratio, and optimised environmental conditions at Godakhali contributed to enhanced reproductive efficiency, emphasizing the importance of brood stock selection, breeding management, and environmental control in successful Hilsa propagation programs.

Table 9: Details of Artificial Breeding of Hilsa during 2024

Details of breeding	Farakka	Godakhali
Total breeding conducted (nos.)	4	4
Breeding Time	4.05 - 6.30 pm	4:15 - 7:30 pm
Male and Female Ratio	2:1	4:1
Total Male (nos.)	28	48
Total Female (nos.)	14	12
Average Male Hilsa Weight (g)	155.98 ± 14.82	267.6 ± 26.85
Average Male Hilsa Total Length (cm)	25.48 ± 1.02	28.5 ± 1.41
Average Female Hilsa Total Weight (g)	182.06 ± 25.25	542.4 ± 19.56
Average Female Hilsa Total Length (cm)	26.24 ± 1.26	32.9 ± 1.08
Method of breeding	Dry/Wet	Dry/Wet
Water used	Filtered River water/ packaged	Filtered River water/ packaged
Average Water Temperature (°C)	26.7± 1.12	27.3± 1.08
Average Dissolved Oxygen (mg/L)	5.6± 0.8	6.2± 1.1
Average pH	8.14± 0.9	8.36± 0.6
Total Approximate Eggs (Lakhs)	2.02	18.07
Average Fertilized Eggs (%)	59.4	81.2
Average Approximate Hatching (%)	34.65	74.85

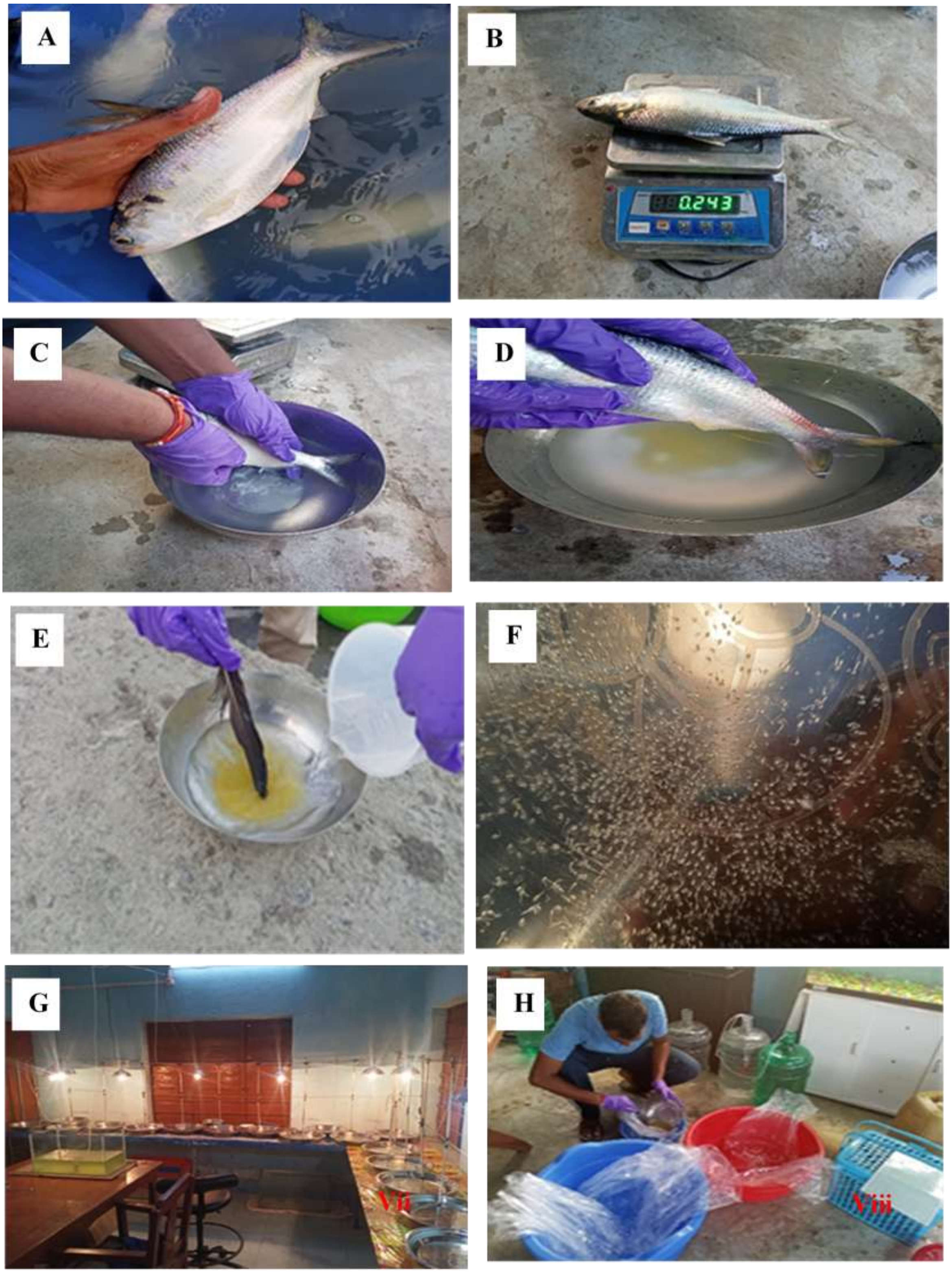


Figure 58 (A-H): (A-F) Steps in Artificial breeding of Hilsa; (G-H) In-house incubation of artificially bred Hilsa's fertilized eggs at Farakka, West Bengal

3.2.3 Ranching of Hilsa fertilized eggs and spawn at the upstream of Farakka Barrage

Ranching of Hilsa involves the judicious release of fertilized eggs and hatchery-reared spawn into river Ganga to enhance wild populations. This process begins with the collection of fertilized eggs from controlled artificial breeding operations. As part of the ranching effort, approximately 20.09 lakh fertilized Hilsa eggs and more than 40,000 Hilsa spawn were released upstream of the Farakka Barrage, particularly in the Rajmahal region of Jharkhand (Fig. 59). This location was chosen for its relatively undisturbed habitat and protected from strong river currents and anthropogenic disturbances, providing a safer environment for early developmental stages of Hilsa. This initiative marks a significant step toward the recovery and sustainable management of Hilsa stocks in the Ganga River basin.

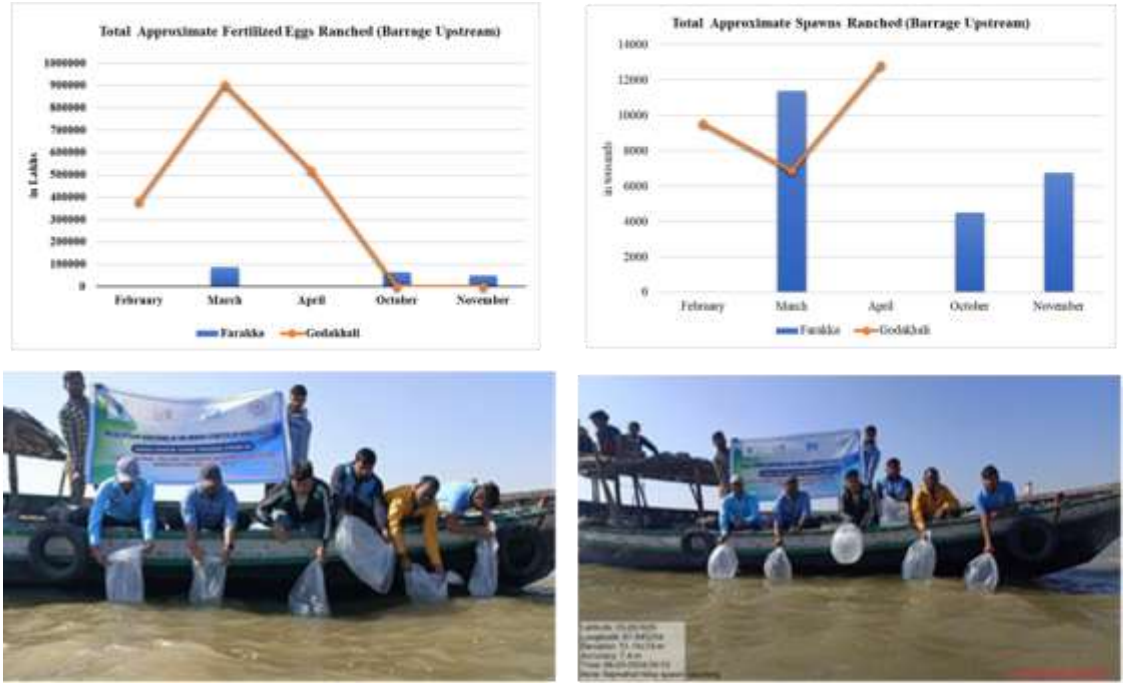


Figure 59: Ranching of Hilsa fertilized eggs and spawn at the upstream of the Farakka Barrage

3.2.4 Artificial rearing facilities of Hilsa

Hilsa, a commercially and culturally significant fish species in South Asia, plays a vital role in regional economies and food security. Found predominantly in the rivers and coastal waters of the Bay of Bengal, the life cycle involves migration between freshwater and marine environments, making it a challenging species for aquaculture. Overfishing, habitat degradation, and climate change have led to significant declines in Hilsa populations, necessitating urgent conservation and sustainable production initiatives.

Developing Hilsa broodstock in artificial rearing facilities offers a promising solution to address these challenges. By replicating the species' natural environment in captivity, researchers aim to produce viable larvae or juveniles for stock enhancement and aquaculture. This approach not only contributes to conserving wild populations but also supports the growing demand for Hilsa. The process involves careful selection of candidates, optimization of water quality, and development of feeding protocols to promote successful spawning and larval survival. This initiative represents a significant step toward sustainable Hilsa management, blending scientific innovation with ecological preservation to ensure the species' long-term viability and its continued contribution to livelihoods and biodiversity.

3.2.4.1 Types of artificial rearing facilities

In our project objective, two types of artificial facilities for the rearing of Hilsa were utilised.

A. Pond aquaculture system

i. *Location of culture system*

A pond with an area of 0.6 ha, adjacent to the main channel of the Ganga River, was selected at Pubarun Township (PTS) in Maldah, NTPC campus (24.817576° N, 87.952019° E), West Bengal.

ii. *Pond Preparation*

In April 2024, a 0.6-hectare pond at the NTPC campus was selected as the site for the project. The pond underwent thorough dredging to remove accumulated silt, debris, and unwanted vegetation, ensuring a clean and conducive environment for aquatic life. Following this, it was systematically manured using a combination of organic and inorganic fertilizers, including urea, single super phosphate (SSP), lime, and an organic nutrient mixture ("organic juice"). These inputs were carefully applied to enhance the pond fertility and promote the growth of plankton, serving as a natural food source for aquatic organisms (Fig. 60). The pond was then filled with a mixture of groundwater and rainwater to achieve optimal water levels and quality. The preparation adhered to the standard protocols for scientific pond preparation as outlined by the ICAR-Central Inland Fisheries Research Institute. These methods ensured the creation of a well-balanced aquatic ecosystem, suitable for supporting the targeted aquaculture activities.

Figure 60 (A-D): Pond construction and preparing the pond procedures at PTS campus, Malda. A. dredging the pond bottom and labelling, B. Liming, C. Sun drying; D. manuring of pond

iii. *Hilsa stocking in the pond*

Live Hilsa adults and sub-adults were carefully collected from the downstream of the Farakka Barrage at the Beniagram site, ensuring minimal stress to the fish during capture. These fish were then manually transported using a specially designed, battery-operated vehicle equipped with hundis (traditional water containers) to maintain water quality and oxygenation throughout the journey. Upon arrival, the fishes were gradually acclimatized to the pond water. This acclimatization process involved slowly mixing pond water with their transport medium to minimise thermal and osmotic stress, thereby ensuring a smooth transition to their new environment. Once acclimated, the fish were gently released into the pond, where conditions closely mimicked their natural habitat.

Post-release, regular monitoring of the Hilsa to track their health, behaviour, and adaptation to the pond environment. Feeding was carried out systematically, with the fish being provided a diet amounting to 1-2% of their body weight twice a day. The feed, formulated by ICAR-CIFRI, contained 28% crude protein to meet the nutritional requirements of the Hilsa and support their growth and reproductive development. This scientific approach ensured optimal care for the broodstock, contributing to the success of the rearing initiative. Hilsa stocking commenced in August 2024, with the process continuing based on availability until October 2024. Over this period, a total of 108 Hilsa were stocked into the prepared earthen pond. While efforts were made to replicate the natural habitat of Hilsa, the new environment posed certain challenges, resulting in a recorded mortality rate of 16.68% over the initial five months (Fig. 61).

At the time of stocking, the average length and body weight of the released Hilsa were 225.2 ± 17.75 mm and 67.28 ± 1.85 g, respectively. These baseline metrics provided valuable insights into the initial condition of the fish and served as reference points for monitoring their growth and adaptation (Table 10). Intermediate netting was conducted in the month of October to monitor the development of the released Hilsa. The assessment revealed a 5-7% increase in body weight of hilsa over the past five months. Since Hilsa are naturally slow-growing species in their native habitat, this level of growth indicates a gradual acclimatization to the artificial ecological niche. This positive development reflects the effectiveness of the pond management practices, including regular monitoring, optimized feeding, and maintaining water quality. While the growth rate remains modest, it is a promising sign that Hilsa are adapting to their new environment, laying the foundation for further improvements in their rearing and management in artificial systems.

Table 10: Monthly Hilsa Stocked in Earthen Pond during August to October 2024

Sl. No.	Months	Total (no.)	Avg Length (mm)	Avg Weight (g)	Mortality (%)
1.	August	46	212.3	70.4	
2.	September	42	203.2	69.2	16.68*
3.	October	20	207.5	69.8	

*Data are aggregated for three months

Figure 61: Hilsa rearing and post-stocking management in pond

B. Cage culture for Hilsa in the natural habitat

Under the National Mission for Clean Ganga (NMCG), ICAR-CIFRI established cage culture facilities for Hilsa to support brood stock development and larval production. Monthly stocking enabled continuous growth monitoring and health management.

i. **Cage Culture Setup and Management**

The cages used for Hilsa rearing were circular, with an inner diameter of 16 meters and an outer diameter of 16 meters and a depth of 8 meters, installed at a designated site in the upstream region of the Farakka Barrage (Fig. 62). The installation site was carefully selected to ensure optimal water flow, oxygen availability, and minimal silt deposition. The cages were made of high-density polyethene (HDPE) frames with reinforced nets to withstand environmental stress. Regular maintenance, including weekly cleaning and net repair, was carried out to prevent biofouling and ensure an optimal rearing environment. The feeding regimen consisted of sinking feed at 3-5% of body weight, administered twice daily to maintain growth and overall health.

3.2.4.2. Monthly Stocking and Mortality Analysis

Hilsa stocking was carried out periodically, with close monitoring of survival rates and growth performance. Mortality was attributed to various environmental and handling factors such as temperature fluctuations, macrophyte infestations, accidental increases in water flow, siltation on the cage net, and injuries sustained during capture using gill nets.

In February 2024, the initial stocking of Hilsa was conducted with 157 individuals in Cage 1 and 462 individuals in Cage 2. Mortality numbers were 85 and 201, respectively. During this period, the average length and weight of Hilsa were 17.95 cm and 61.4 g, respectively. By March 2024, 170 Hilsa were stocked in Cage 1 and 143 in Cage 2. Mortality rates dropped compared to the previous month, with 36 losses in Cage 1 and 92 in Cage 2. Regular netting and sampling were done to monitor surviving individuals. In April 2024, fish stocking was less with only 25 and 23 fish added to Cages 1 and 2, respectively. Mortality was less with only eight mortalities in each cage. Regular feeding and water quality monitoring contributed to the stabilization of survival rates. Disease mitigation techniques, such as potassium permanganate ($KMnO_4$), lime, and salt treatments, were employed using bag treatment to maintain fish health. In June 2024, stocking was increased slightly, with 20 Hilsa stocked in Cage 1 and 19 in Cage 2. Mortality was 11 and 24, in Cage 1 and Cage 2 respectively. Despite some challenges posed by temperature fluctuations and organic load, the average length of Hilsa had increased to 19.36 cm, with an average weight of 62.9 g. However, during the monsoon season, the cages were dismantled due to increased water flow and the accumulation of debris, preventing further stocking. This break allowed for necessary site clearing and maintenance to prepare for reinstallation later in the year.

3.2.4.3. Impact of Environmental Challenges

The major issues were aquatic macrophyte infestations and siltation of the cage nets, which reduced water exchange and occasionally caused mortality. Additionally, monsoonal increases in water flow in July necessitated dismantling the cages due to accumulated debris and heightened structural stress.

Figure 62 : Cage related activities in Farakka, West Bengal

3.3. OBJECTIVE III: DEVELOPING A HILSA NUTRI-PROFILE DATABASE OF DIFFERENT SIZE GROUPS FOR HUMAN HEALTH AND NUTRITIONAL SECURITY

3.3.1. Serum proteome analysis of female Hilsa

The first bioinformatics analysis of the Hilsa serum proteome was conducted using LC-MS/MS, and the genes associated with enriched KEGG pathways (e.g., phagosome, mTOR, Apelin signalling pathways, and herpes simplex virus) were assessed for their role in immune responses. Significant age-dependent differences were found in the expression levels of critical immunological proteins (Alpha2 Macro-globin, Fibulin, mef2, Complement proteins (C3 C4, C5) Albumin, Serum Response Factor (SRF), cd109, non-specific Serine/Threonine protein kinase.), such as those about cellular defence, inflammatory response. A total of 952, 494, 415 and 282 proteins were annotated in the year class IV to class I Hilsa. It was noticed that new proteins appeared from class I to class IV and were more than three-fold (Fig. 63).

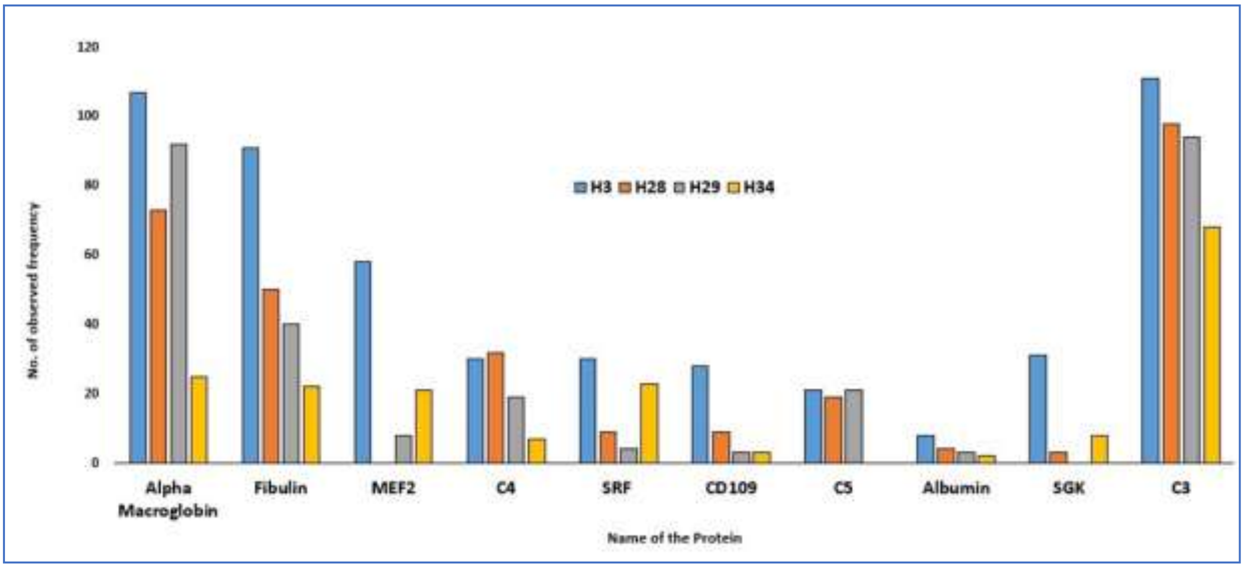


Figure 63: Top 10 frequency of observation of female Hilsa serum proteins

3.4. OBJECTIVE IV: ESTABLISHING THE BREEDING MIGRATORY PATH IN RIVER GANGA BY USING FLOY TAGGING AND OTHER CUTTING-EDGE METHODS

Hilsa tagging is a technique used to monitor the behaviour, population dynamics, and movement patterns of Hilsa fish. Important information about their migrations, spawning locations, and environmental factors influencing their numbers can be obtained by tagging the fish. By improving Hilsa stock management and protection, this knowledge ensures the sustainability of fisheries. The tagging process is crucial for understanding the ecological health of Hilsa and devising strategies to protect this economically and culturally significant species. Before the Farakka Barrage was established in 1975, Hilsa is reported to migrate up to Prayagraj. After the constructionm, it was limited to the downstream of the barrage. This man-made construction brought about a significant change in Hilsa breeding and was a leading cause of decline. With the primary objective of establishing a breeding migratory path in the river Ganga, tagging was a central focus area. More than 100g of Hilsa were selected for tagging to improve their survival. Fishes were caught directly downstream of the Farakka barrage through experimental fishing using a specially designed net operation. After tagging, a 10% (PVP-I) solution is applied as a disinfectant before ranching. A total of 798 fish were tagged to assess the upstream migration of Hilsa during the period between December 2023 and October 2024 (Fig. 64). The average length and weight of the ranched fish were 27.3 cm and 382 g, respectively.

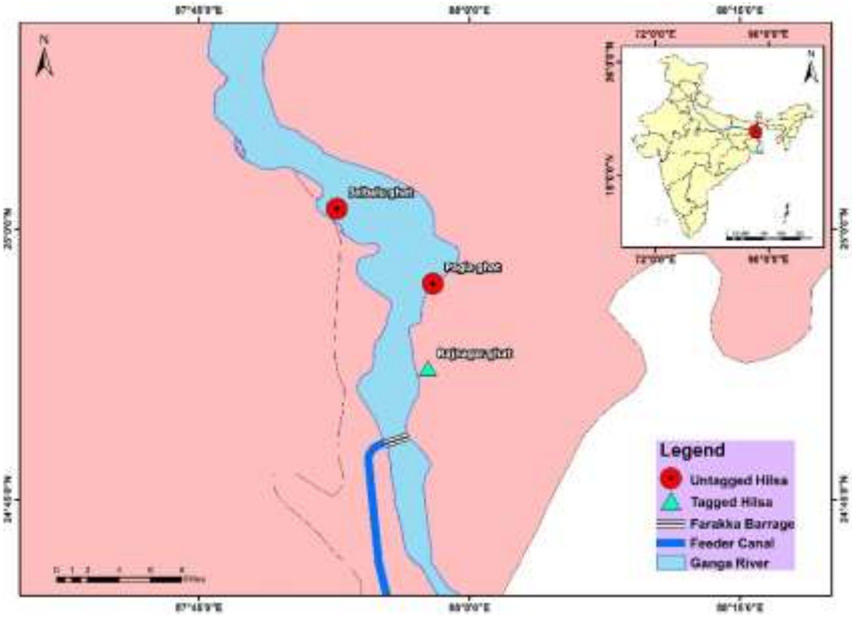


Figure 64 : Hilsa recovery map (Tagged and Untagged)

Figure 65: Juveniles Hilsa recovered from upstream of Farakka barrage

3.4.1. Impact of tagging and ranching

3.4.1.1. Recovery of adult (tagged) and juvenile Hilsa

A single specimen of Hilsa was recovered from upstream of the Farakka barrage by a fisherman on 9th January 2024 at Rajnagar Ghat in Malda Town, West Bengal. The specimen, tagged with Tag number 'CIFRI-2343', was released into the river on 5th January 2024. The specimen measured 261 mm in length and weighed 163 grams. The recovery took place at coordinates Latitude 24.871056 N and Longitude 87.96154 E. This marked the successful return of the specimen after being ranching for four days (Figs. 65 & 66.). The event contributes valuable data to ongoing research efforts on Hilsa populations in the region.

Figure 66 : Handing over of Hilsa tag

3.5. OBJECTIVE VI: SENSITIZING THE FISHERS ON HILSA CONSERVATION AND MANAGEMENT IN THE MIDDLE STRETCHES OF RIVER GANGA FROM PRAYAGRAJ TO FARAKKA BY WAY OF BALLIA, BUXAR, PATNA, BHAGALPUR AND RAJMAHAL

In recent years, following the construction of the Farakka Barrage in 1975, Hilsa fish from downstream have been unable to migrate upstream, leading to a significant decline in Hilsa landings in the middle stretch of the Ganga River above the barrage, particularly at Prayagraj, Buxar, and Bhagalpur. However, landings downstream of the barrage have increased. To address this, ICAR-CIFRI has been working on a project to boost the Hilsa population upstream of the Farakka Barrage, particularly in the middle stretch of the river, with financial support from the National Mission for Clean Ganga (NMCG). Additionally, awareness campaigns on Hilsa conservation were organized by ICAR-CIFRI on regular basis, covering West Bengal, Bihar, and Jharkhand, to educate local fishing communities along the river (Fig. 67).

A total of 95 awareness programmes on Hilsa conservation were conducted, and 2,227 fisherfolk and local communities across the Ganga River ghat and adjacent areas of the river in West Bengal were sensitised (Table 11). The primary goal of these campaigns was to raise awareness among fishermen in the upstream regions of the Farakka Barrage about the importance of Hilsa conservation. Fishermen were informed on how to increase Hilsa populations in their local waters, with advice to release any captured live Hilsa and refrain from catching them for the next year and to allow the fish to grow. They were sensitized to avoid nets with mesh sizes smaller than 100 mm to improve Hilsa survival rates. Fish tagging, a critical tool for studying migration patterns, was emphasised, with fishermen asked to report any tagged Hilsa they encounter during their fishing activities in exchange for a minimum token payment.

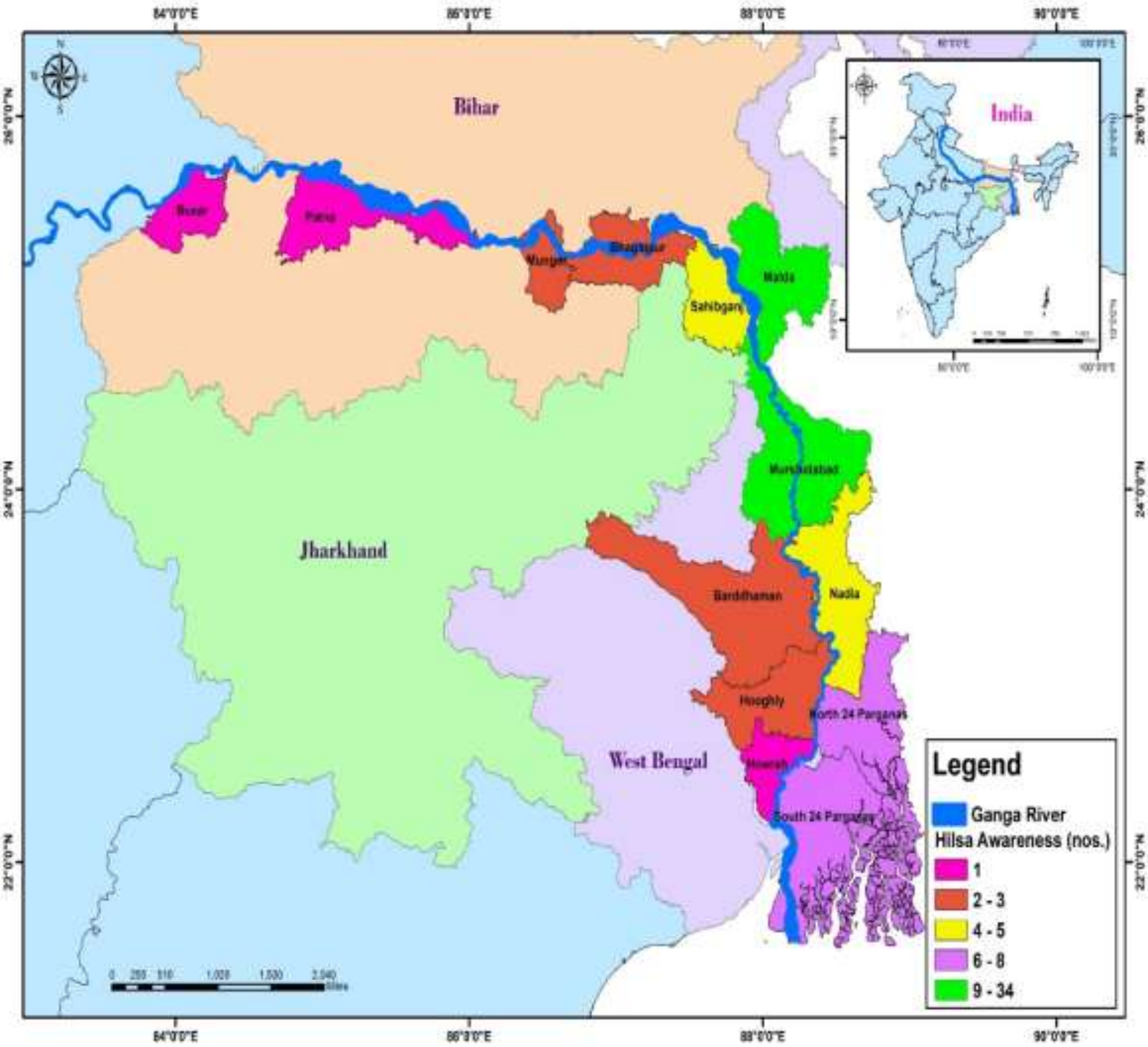


Figure 67: GIS map showing Hilsa sensitization programmes in three different states of West Bengal, Bihar and Jharkhand

Table 11: List of awareness on Hilsa fish held during 2023-2024

Sl no.	Site	Date	No. of participants
1.	Farakka, Taltola Ghat, W.B	02.02.2024	74
2.	Nabadwip, Prabhupada Ghat, W.B	16.02.2024	27
3.	Barrackpore, Monirampore Ghat, W.B		31
4.	Krishnanagar, W.B	22.02.2024	11
5.	Nimtola, Farakka, W.B		24
6.	Birnagar, Farakka, W.B	24.02.2024	13
7.	Bot tola, Farakka, W.B		11
8.	Sikarpur, Farakka, W.B	26.02.2024	11
9.	Bhagalpur, Bihar	13.03.2024	45
10.	Buxar, Ahilya Ghat, Bihar	15.03.2024	48
11.	Patna, Gandhi Ghat, Bihar	14.03.2024	38
12.	Khagaria, Bihar	19.03.2024	8
13.	Supaul, Bihar	21.03.2024	9
14.	Naugachia, Bihar	22.03.2024	16
15.	Rajnagar, Malda, W.B	01.03.2024	10
16.	Rajnagar-2, Malda, W.B		9
17.	Gajipur, Malda, W.B		12
18.	Rajmahal, Jharkhand	06.03.2024	21
19.	Khejurighat, W.B	09.03.2024	17
20.	Khejuri ghat-1, W.B		15
21.	Khejuri ghat-2, W.B		14
22.	Baliara, Fraserganj, W.B	12.03.2024	31
23.	Diamond Harbour, W.B	14.03.2024	41
24.	Godakhali, W.B	15.03.2024	22
25.	Neemsahar, Farakka, W.B	16.03.2024	11
26.	Sikarpur, Jharkhand		17

27.	Radhanagar, Jharkhand		14
28.	Shreeghar, Jharkhand		12
29.	Shreeghar-2, Jharkhand	21.03.2024	10
30.	Shreeghar 8 no, Jharkhand		15
31.	Rajnagar Ghat-2, Malda, W.B	06.04.2024	19
32.	Bin Nagar, Malda, W.B		15
33.	Rajnagar Ghat 1, Malda, W.B	10.04.2024	36
34.	Hilsa ranching station, Farakka, W.B		32
35.	Sikarpur, Malda, W.B	16.04.2024	12
36.	Bin nagar, Malda, W.B	20.04.2024	15
37.	Khejuria Ghat, Malda, W.B		16
38.	Lalutola Ghat, Malda, W.B	27.10.2024	10
39.	Bin nagar, Malda, W.B		13
40.	Rajnagar Ghat ,Malda, W.B	15.05.2024	50
41.	PaglaGhat, Malda, W.B		18
42.	Panchanandapur, Malda, W.B	02.05.2024	11
43.	Deerforest, Farakka, W.B		21
44.	Neemsahar, Farakka, W.B	09.05.2024	35
45.	Rajnagar ghat, Malda, W.B		16
46.	Rajnagar ghat-2, Malda, W.B	18.05.2024	14
47.	Hilsa ranching station, Farakka, W.B		10
48.	Begamganjfutanibazer, Jharkhand	23.05.2024	40
49.	Radhanagar, Jharkhand	29.05.2024	15
50.	Balagarh, W.B		16
51.	Barrackpore, W.B	31.05.2024	120
52.	Rajnagar Ghat, Malda, W.B		18
53.	Khejuria Ghat, Malda, W.B	05.06.2024	9
54.	Kalna, W.B		12

55.	Tribeni, W.B	06.06.2024	32
56.	Mayapur, W.B	07.06.2024	25
57.	Lalbag, W.B	08.06.2024	25
58.	Berhampore, W.B	12.06.2024	40
59.	Bally, W.B	13.06.2024	30
60.	Deerfoest, Farakka, W.B	14.06.2024	63
61.	Nimtola, Farakka, W.B	15.06.2024	09
62.	Nimsahar, Farakka, W.B		18
63.	Nimsahar -2, Farakka, W.B	24.06.2024	16
64.	Nimsahar -2, Farakka, W.B		15
65.	Farakka, Hilsa Ranching Station, W.B	05.07.2024	60
66.	Rajmahal, Jharkhand		44
67.	Kamarganj, Sultanganj, Bihar	12.07.2024	62
68.	Radhnagar, Malda, W.B		16
69.	Radhnagar-1, Malda, W.B		8
70.	Khejuria Ghat, Malda, W.B		13
71.	Khejuria Ghat-2, Malda, W.B		10
72.	Binnagar Ghat, Malda, W.B		23
73.	Sojhi Ghat, Munger, Bihar	21.07.2024	73
74.	Kulideyar Ghat, Murshidabad, W.B	26.07.2024	11
75.	Hossenpore Ghat, Murshidabad, W.B		35
76.	Khejuria Ghat, Malda, W.B	06.08.2024	10
77.	Khejuria Ghat-2, Malda, W.B		11
78.	Nimtala, Farakka, W.B	12.08.2024	13
79.	Nimshahar, Farakka, W.B		13
80.	Adi Krishnanagar Ghat, Ganga Sagar, W.B	14.08.2024	43
81.	Hilsa ranching station, Farakka, W.B	15.08.2024	18
82.	Nimshahar, Farakka, W.B	27.08.2024	14

83.	Khejuria Ghat, Malda, W.B	31.08.2024	12
84.	Khejuria Ghat-2, Malda, W.B	31.08.2024	10
85.	Hilsa conservation workshop, ICAR-CIFRI, Barrackpore	05.09.2024	84
86.	Nimshahar, Farakka, W.B	11.09.2024	12
87.	Deerforest, Farakka, W.B		13
88.	Taltola Ghat, Farakka, W.B	14.09.2024	13
89.	Fraserganj, South 24 Pgs., W.B	24.09.2024	32
90.	Diamond Harbour, South 24 Pgs., W.B	25.09.2024	26
91.	Godakhali, South 24 Pgs, W.B	26.09.2024	15
92.	Mirjapur, Farakka, W.B	04.10.2024	12
93.	Taltola Ghat, Farakka, W.B		13
94.	Khejuriya Ghat, Malda, W.B	14.10.2024	13
95.	Nimsaher, Farakka, W.B	31.10.2024	12
		Total	**2227**

4. COMPONENT: III

Seed Production, Restoration, and Stock Assessment of selected Mahseer Species in upper stretch of River Ganga

4.1. OBJECTIVE I: BROOD STOCK DEVELOPMENT AND SEED PRODUCTION OF SELECTED GOLDEN MAHSEERS OF THE RIVER GANGA USING RIVERINE GERMPLASM

The Golden Mahseer (*Tor putitora*) is a large cyprinid fish, widespread in the upper stretches of the Ganga River. The fish prefer the hilly river with a stony and rocky river bed. This species can live and withstand temperatures between 8 °C and 25 °C and migrates according to climatic conditions for feeding and breeding. Mahseer migrate upstream during the monsoon to find suitable spawning grounds. The golden mahseer can grow to a large size, making it of considerable importance. This fish is a good source of protein and is highly valued, fetching a high market price. The mahseer is responsible for balancing the ecological pyramids. It plays a crucial role in the upper stretch of the Ganga River, occupying a wide range of positions within the food web. However, various anthropogenic activities, such as poisoning and dynamiting in the headwaters and the streams therein, have threatened the mahseer population in natural water bodies and are now considered endangered.

4.1.1. Brooder collections

During 2023-24, a total of 73 Mahseer brooders (length range: 19-47 cm and weight range: 0.3-1.9 kg) were collected from Koteshwar Lake and Tehri Lake (Figs. 68 & 69).

Figure 68: Netting for brooders collection of Mahseer from Tehri dam

Figure 69: Stocking of Mahseer brooders at Koteshwar hatchery

4.1.2. Fingerlings Collections

A total of 6000 live fingerlings of mahseer (*Tor putitora*) (length range: 2-24 cm and weight range: 8-27g) and 800 dark mahseer (*Naziritor chelynoides*) (length range: 3-19 cm and weight range: 3-25g) were collected in this duration and transported to Koteshwar hatchery (Fig. 70). Presently, about 400 of Mahseer fingerlings are available in Koteshwar hatchery.

Figure 70: Collection of Mahseer fingerlings from different tributaries of Ganga River and stocking at Koteshwar Hatchery

4.1.3. Seed production of selected Golden mahseer

Mahseer stocks in hatchery ponds were checked periodically for maturity during the breeding season. There were five female brooders present in the pond, and among these, one female brooder was in fully mature condition. Almost all males were found in mature condition. Therefore, breeding of Mahseer by dry stripping method at Koteswar hatchery in natural conditions was conducted with one mature female (length: 37 cm and weight: 550 g) and two male brooders (length: 42 cm and weight: 1.50 g). During the stripping, a total of 1500 eggs were released by the female brooder, out of which only 820 eggs were fertilised, the fertilisation rate was about 50%. The fertilised eggs were kept in clean water for 25-30 minutes and washed repeatedly before transferring to the hatching unit under flowing conditions. After three days, 180 eggs were found hatched. (Fig. 71).

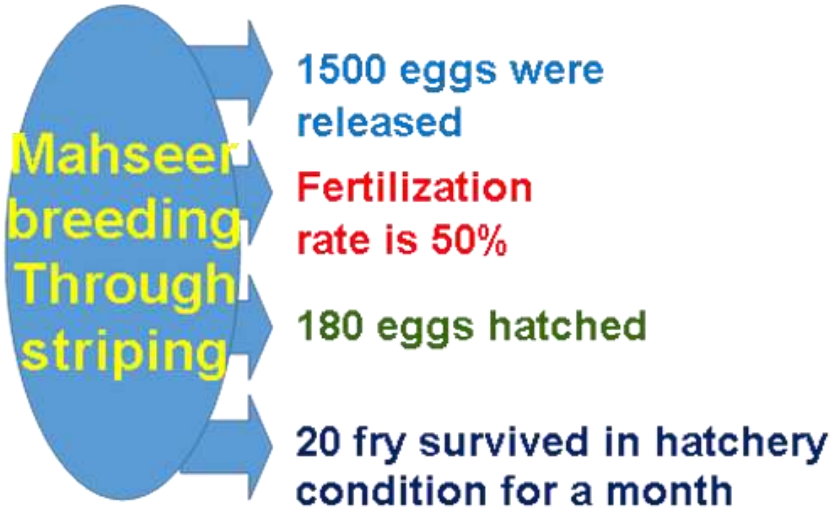


Figure 71: Striping of Mahseer brooders, fertilized eggs into the hatching tray and free-swimming fry after hatching

4.2. OBJECTIVE II: RESTORATION OF GOLDEN MAHSEER (*TOR PUTITORA*) AND CHOCOLATE MAHSEER (*NAZIRITOR CHELYNOIDES*) IN THE UPPER STRETCH OF THE RIVER GANGA THROUGH RANCHING

4.2.1. Ranching program at Haridwar, Uttarakhand

On the occasion of '*Ganga Utsav'*, ICAR-Central Inland Fisheries Research Institute, Barrackpore released about 5500 Mahseer fingerlings and 500 dark Mahseer fingerlings in the River Ganga in the august presence of Shri C. R. Patil, Hon'ble Union Minister of Jal Shakti, Govt. of India at Haridwar (Fig. 72). Fishes were released as a part of the National Ranching program on 4th November 2024 at Chandi Ghat to conserve and restore of these species. The event was also attended by Shri Rajbhushan Chaudhary, Hon'ble Minister of State, Ministry of Jal Shakti, Govt of India, Srimati Rekha Arya, Hon'ble Minister, Govt. of Uttarakhand, Shri Trivendra Singh Rawat, Hon'ble Ex-CM Uttarakhand and Member of Parliament (LS), Haridwar, Shri Rajeev Kumar Mital, IAS, DG NMCG, Dr. Sandeep Behera, Biodiversity Consultant NMCG and Dr. B. K. Das, Director ICAR-CIFRI.

Figure 72: River ranching program at Chandi Ghat, Haridwar, and Uttarakhand during 'Ganga Utsav-2024'

4.3. OBJECTIVE III: STOCK ASSESSMENT OF GOLDEN MAHSEER (*TOR PUTITORA*) AND SNOW TROUT (*SCHIZOTHORAX RICHARDSONII*) IN THE UPPER STRETCH OF THE RIVER GANGA

4.3.1. Golden mahseer (*Tor putitora*)

The Himalayan Mahseer possesses an oblong, compressed body covered with large cycloid scales, which provides a golden orange tinge (as its name suggests) to the body. Head length exceeds that of the body depth. The number of scales along with the lateral line extends from 23 to 28. Two pairs of barbels are present, two each at the extreme corners of the mouth and the lower jaw. Jaws are protrusible with fleshy lips. The dorsal fin is occupied nearly the middle of the back with ventral originating (Fig. 73).

Figure 73: A fresh specimen of *Tor putitora* (Mahseer)

Von Bertalanffy's (1938) equation for growth in length for this species (VBGF) is L_∞ = 435.23 mm and K = 0.20 yr^{-1}. The instantaneous rate of the total mortality coefficient (Z) was estimated to be 0.37 yr^{-1}. Similarly, the natural mortality coefficient (M) estimates were 0.29 yr^{-1}. The fishing mortality (F) estimated was 0.08 yr^{-1}. The estimated exploitation ratio (E) was 0.21. The computed L_{25}, L_{50}, and L_{75} values for the species were 194.8 mm, 250.8 mm, and 306.7 mm, respectively (Fig. 74). The exploitation ratio (E) was observed to be below the optimum level of 0.50, suggesting that the population is being exploited judiciously. Moreover, the fishing mortality was observed to be maximum in the length range of 284.5 to 304.5 mm. The length-based virtual population analysis (VPA) findings indicated a decrease in fishing mortality for the length group of >304 mm onwards. Two peaks were observed in the annual recruitment patterns of *T. putitora*, corresponding to March (early monsoon) and July (monsoon).

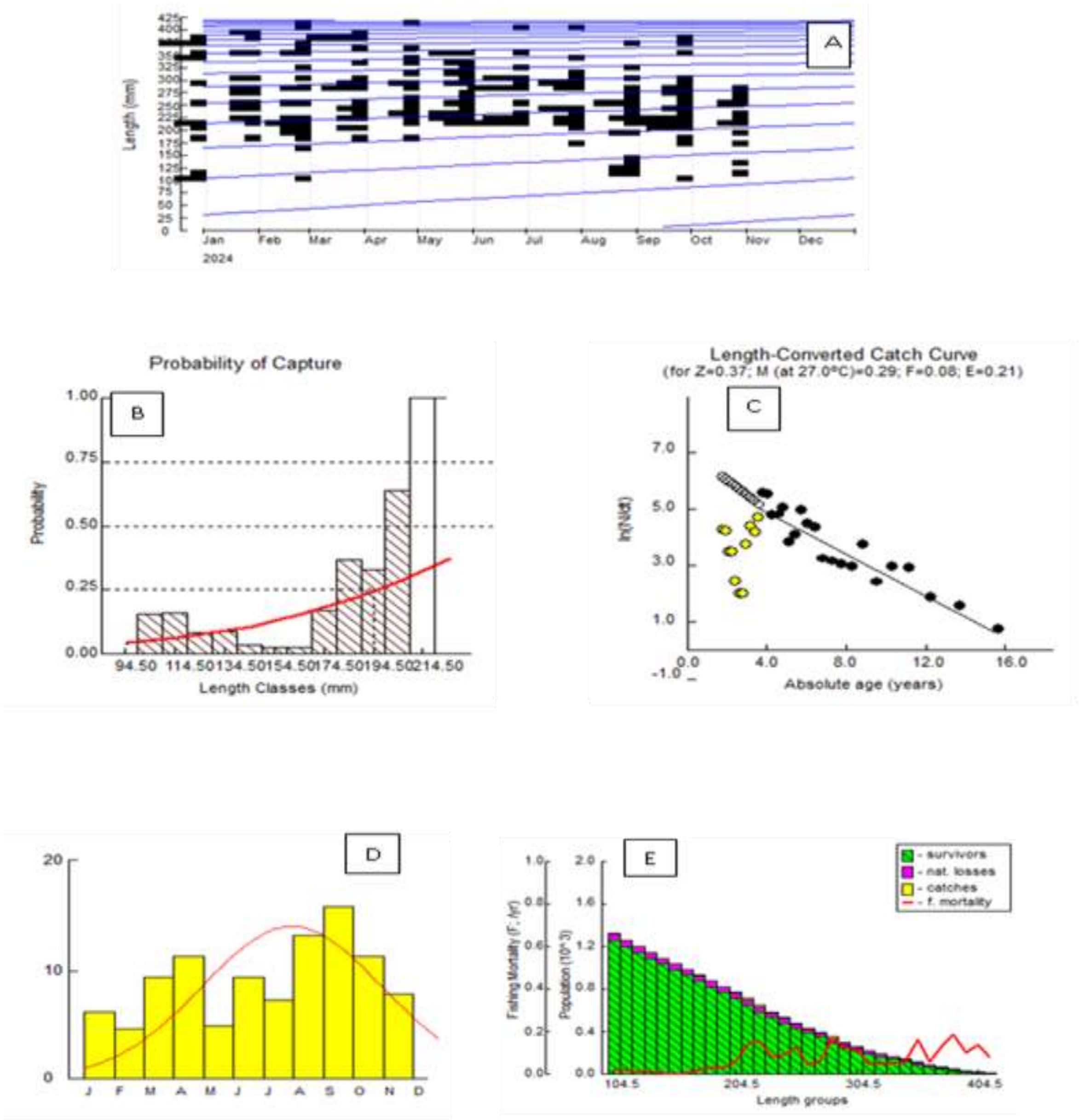


Figure 74: Growth parameters of Mahseer: A. Growth curve, B. Probability of capture C. Length converted catch curve, D. Recruitment pattern, E. VPA analysis

4.3.2. Snow trout (*Schizothorax richardsonii*)

Snow trout possess a cylindrical body covered with minute scales, a snout that is obtuse, a mouth that is inferior, transverse, and slightly arched, followed by a fleshy and flat, well-developed lower lip covered with a set of raised papillae. The barbells are two pairs about half the length of the eye. Dorsal fin inserted almost midway between snout tip and base of caudal fin, anal fin not reaching the base of caudal fin; spine strong and serrated. Lateral line scales ranges from 98-100 (Fig. 75). The snow trout are mostly herbivores; they primarily feed upon aquatic plants, algae and detritus. Snow trout have specialized mouthpart of scraping algae from stones and rock.

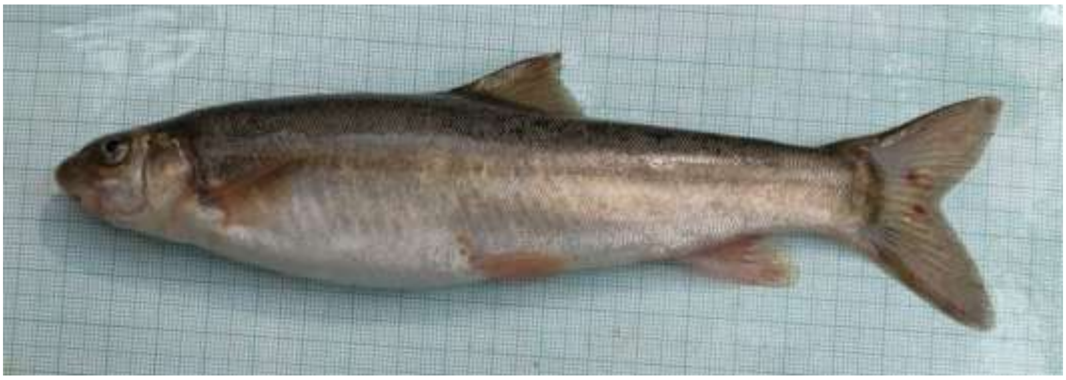


Figure 75: A fresh specimen of *Schizothorax richardsonii* (Snow trout)

Von Bertalanffy's (1938) equation for growth in length for this species (VBGF) is L_∞ = 540.23 mm and K = 0.10 yr^{-1}. The instantaneous rate of the total mortality coefficient (Z) was estimated to be 0.29 yr^{-1}. The natural mortality coefficient (M) was computed to be 0.17 yr^{-1}. The fishing mortality (F) estimated was 0.12 yr^{-1}. The estimated exploitation ratio (E) was 0.40. The computed L_{25}, $L_{50,}$ and L_{75} values for the species were 292.5 mm, 504.7 mm, and 716.9 mm, respectively (Fig. 76). The exploitation ratio (E) was observed to be below the optimum level of 0.50, suggesting that the population is being exploited judiciously. Moreover, the fishing mortality was observed to be maximum in the length range of 204 to 304 mm. Two peaks were observed for the annual recruitment patterns of *S. richardsonii,* which were found between February and April and September and October, respectively.

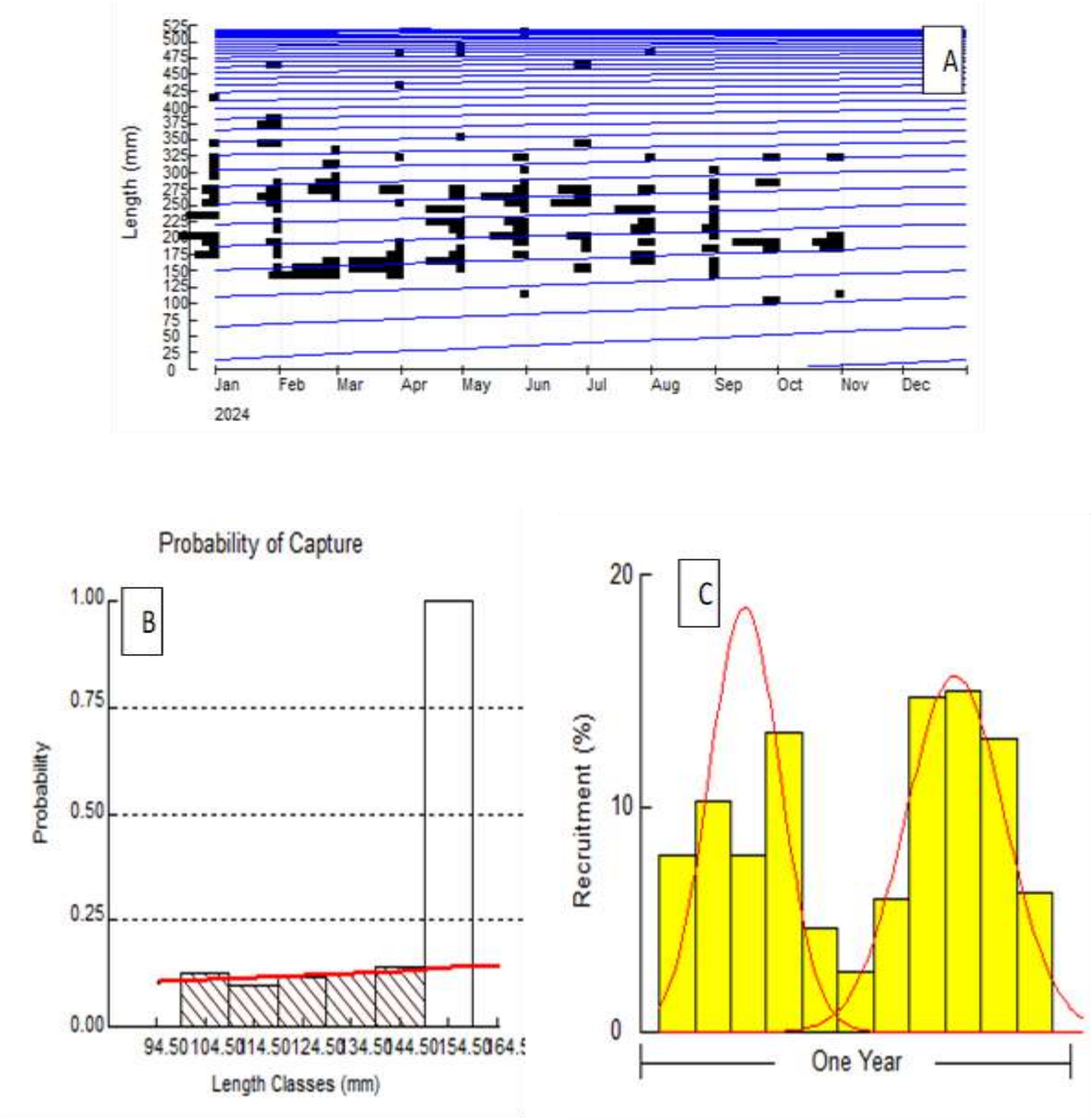


Figure 76: Growth parameters of snow trout, A. Growth curve, B. Probability of capture, C. Recruitment pattern

4.3.3. Landing of Mahseer in Tehri Reservoir (Uttarakhand)

Regular monitoring of fish landing in Tehri Reservoir is carried out under the project to assess the landing of Mahseer and the exotic Common carp. The annual mean per day catch of the species is presented in Table 12. The mean catch per day of Mahseer was 68±12.0 kg while that of common carp was 32±12.3 kg. The assessment of length frequency of mahseer revealed the minimum length of 20.2 cm and maximum of 105.7 cm. Conversely, common carp was found to be much smaller in size, with a minimum length of 18.1 cm and a maximum of 62.4 cm. Monthly catch estimates have shown that the increased catch during June to October for Mahseer and common carp (Fig. 77). During January to March and July to August, the landing estimates are difficult owing to extreme climatic conditions.

Table 12: Mean catch per day of Mahseer and Common carp in Tehri reservoir, Uttarakhand

Species	Mean catch per day ±SD (kg)	Length range (cm)	Weight range (kg)	Weight (t)	Mean % in Total catch
Mahseer	68±12.0	20.2-105.7	0.25-8.00	0.903	68
Common carp	32±12.3	18.1-62.4	0.28-3.82	0.427	32

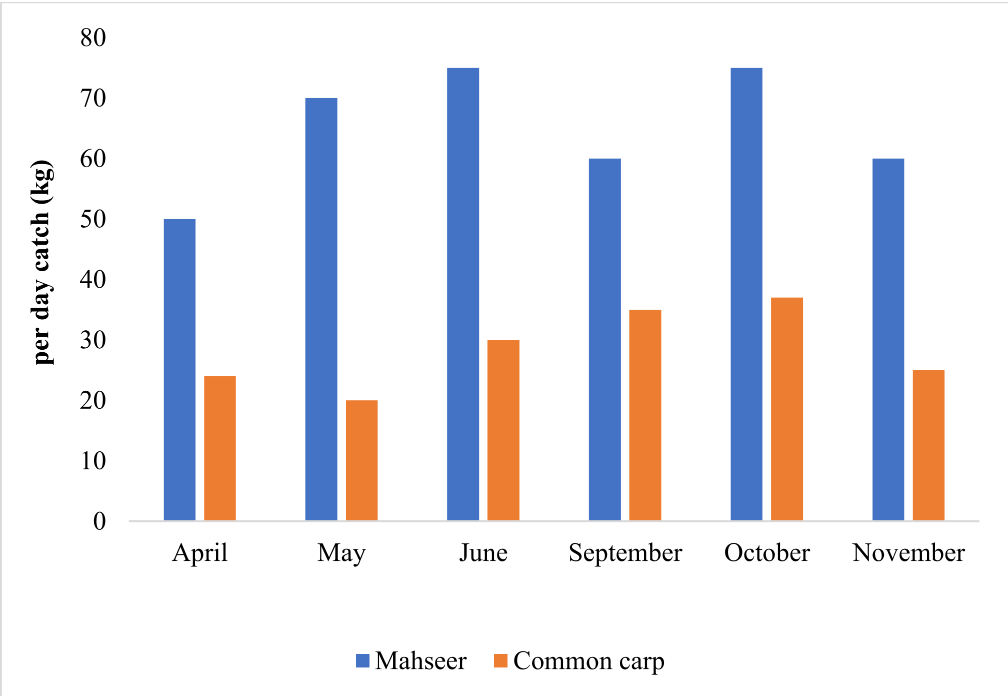


Figure 77: Monthly per day catch estimates of Mahseer and common carp from Tehri Reservoir, Uttarakhand during 2024

5. COMPONENT: IV

Stock assessment of important fishes in selected tributaries and wetlands of Ganga River Basin further conservation and management

5.1. OBJECTIVE I: ASSESSING THE FISH DIVERSITY IN SELECTED TRIBUTARIES AND WETLANDS OF THE GANGA RIVER BASIN

The river Ganga, one of the most significant rivers in India, is fed by numerous tributaries that contribute to its vast drainage system. Significant tributaries include the Yamuna, Ghaghara, Gandak, Kosi, and Son. These rivers originate from the Himalayan mountains, the Vindhya ranges, and other regions, carrying water from different catchment areas. The tributaries are crucial for sustaining agricultural activities, providing drinking water, supporting ecosystems, and enabling transportation in the regions they flow through. They also play a vital role in flood control and the replenishment of groundwater resources. The combined waters of these tributaries make the Ganga a lifeline for millions of people, fostering biodiversity and economic activities across India.

In Uttarakhand, the River Ganga is fed by several important tributaries, primarily from the Himalayan ranges. Key tributaries include the Alakananda, Bhagirathi, Mandakini, and Pindar rivers. The Alakananda, formed by the confluence of the Dhauliganga and Nandakini rivers, and the Bhagirathi, which originates from the Gangotri Glacier, are particularly significant as they merge to form the Ganga at Devprayag. The Mandakini, which flows through the Kedarnath region, and the Pindar, which contributes to the Pindari Glacier, are also vital. These tributaries play a critical role in feeding the Ganga with fresh water, supporting agriculture, hydropower generation, and providing water for drinking and irrigation. Additionally, they are integral to Uttarakhand's religious and cultural heritage, as many of these rivers hold sacred significance for pilgrims visiting the Char Dham shrines. The tributaries help maintain the ecological balance in the region, preserving biodiversity and sustaining the livelihoods of local communities.

In Uttar Pradesh, the River Ganga is joined by several vital tributaries, including the Yamuna, Gomti, Ghaghara, and Rapti rivers. The Yamuna, one of the Ganga's largest tributaries, merges with the Ganga at Prayagraj (Prayagraj) and is crucial for irrigation, agriculture, and drinking water supply in the region. The Gomti, which flows through the city of Lucknow, and the Ghaghara, which originates from the Tibetan Plateau, provide significant water resources to Uttar Pradesh, supporting both agricultural and industrial activities. The Rapti River, originating in Nepal, also contributes to the Ganga system. These tributaries play a vital role in the economy and the daily lives of millions of people by supporting agriculture, maintaining groundwater levels, providing water for consumption, and fostering local biodiversity. They also hold cultural and religious significance, with many towns along these rivers being essential pilgrimage destinations. The tributaries help manage floodwaters and sustain the region's vibrant agricultural practices.

In Bihar, the River Ganga is joined by several significant tributaries, including the Gandak and Kosi rivers. The Gandak, originating from the Nepalese Himalayas, is a major contributor to the Ganga’s flow, providing water for irrigation in Bihar's fertile plains. The Kosi, known for its unpredictable and often devastating floods, also brings substantial water to the Ganga, supporting agriculture but posing challenges for flood management. The Son, which flows from the Vindhya hills, is another critical tributary that enhances the Ganga's water supply. These tributaries are vital for sustaining agriculture, the backbone of Bihar's economy, by providing irrigation in a region largely dependent on river water. They also support local biodiversity, ensure groundwater recharge, and serve as crucial drinking water sources. Moreover, these rivers are of cultural and religious significance, with many towns along their banks being key pilgrimage sites.

The River Hooghly in West Bengal is fed by several important tributaries, primarily from the region's Ganga and other smaller rivers. Key tributaries include the Rupnarayan, Damodar, and the Mundeswari. The Rupnarayan, flowing from the western part of the state, merges with the Hooghly near the town of Gadiara, while the Damodar, which flows from the Chota Nagpur Plateau, joins the Hooghly near the city of Haldia. These tributaries are vital for irrigation, agriculture, and local transportation, supporting the agrarian economy of West Bengal. The Damodar, in particular, is known for its role in flood control and power generation, as it is home to several dams and reservoirs. The tributaries also contribute to the region’s rich biodiversity. They are essential for maintaining water quality in the Hooghly, which serves as a critical waterway for the port city of Kolkata. Additionally, these rivers are significant for local fishing industries and hold cultural and historical importance (Fig. 78).

ICAR-CIFRI, under its third phase of NMCG, monitored 16 rivers of the Gangetic Basin. Alakananda, Nayar, Saryu, Ramganga, Bhilangna, Yamuna, Gandak, Kosi, Damodar, Rupnarayan, Jalangi, Churni, Adi Ganga, Ichamati, Matla and Haldi. The detailed map of the sampling spots is presented in Fig. 79.

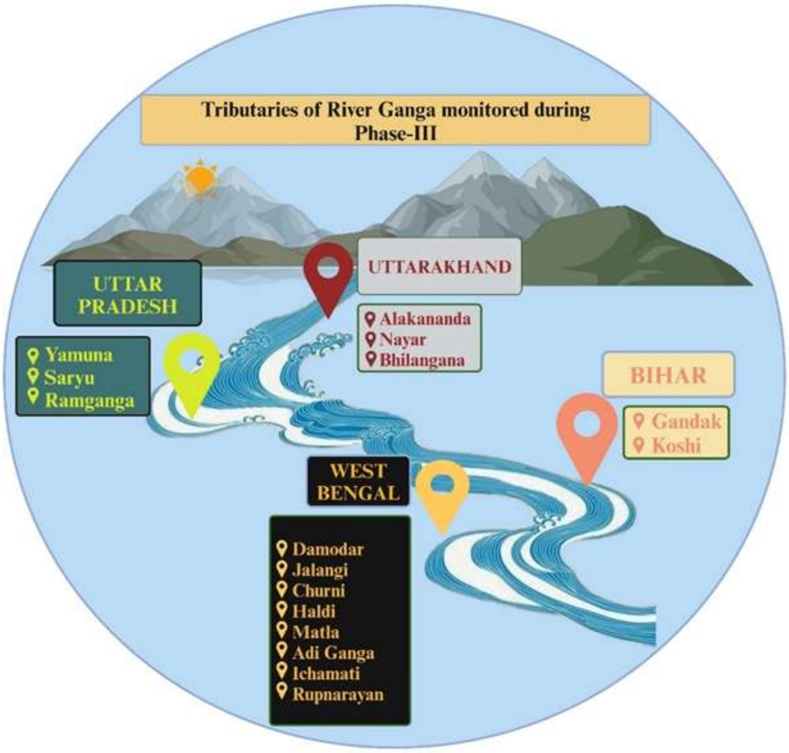


Figure 78: List of the state-wise Gangetic tributaries surveyed during 2023-24 under Phase-III

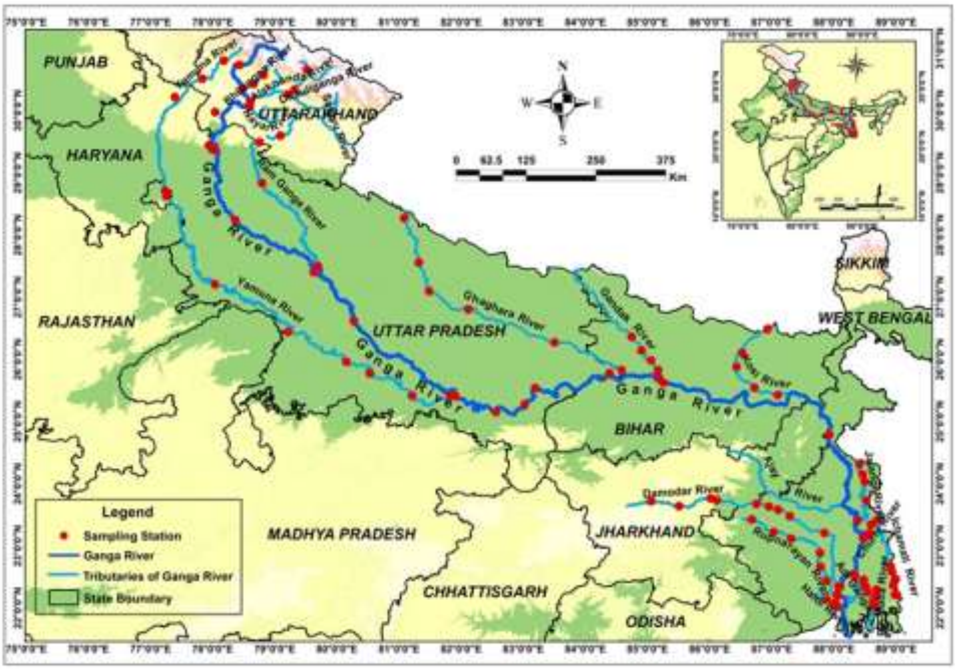


Figure 79: GIS map showing the sampling sites of different tributaries covered under the NMCG phase (III)

5.1.1. ADI GANGA

Adi Ganga, historically called Gobindapur Creek, is a former sacred distributary of the Bhagirathi-Hooghly River, once a key inland navigation route. It originates from Hooghly at Hestings (South Kolkata) and joins the Piyali River at Tribeni (South 24 Parganas), spanning about 86 km. The river is now highly degraded due to urban encroachment, sewage discharge, and solid waste dumping, functioning more as a polluted canal than a river.

5.1.1.1. Study Area

Six sites were selected across the lower and upper stretches of Adi Ganga: Hestings, Keoratala (Sahnagar), Radhanagar (Sonarpur), Begampur (Baruipur), Uttarbhag Bridge, and Tribeni Dosa (Fig. 80). Two sites experience daily tidal effects. Sampling was conducted during pre-monsoon (April–May), monsoon (July–August), and post-monsoon (October–November). The sampling stretch spans the South 24 Parganas and Kolkata districts. Geographic coordinates ranged from 22.256972°N, 88.541594°E to 22.546793°N, 88.3245°E (Fig. 81).

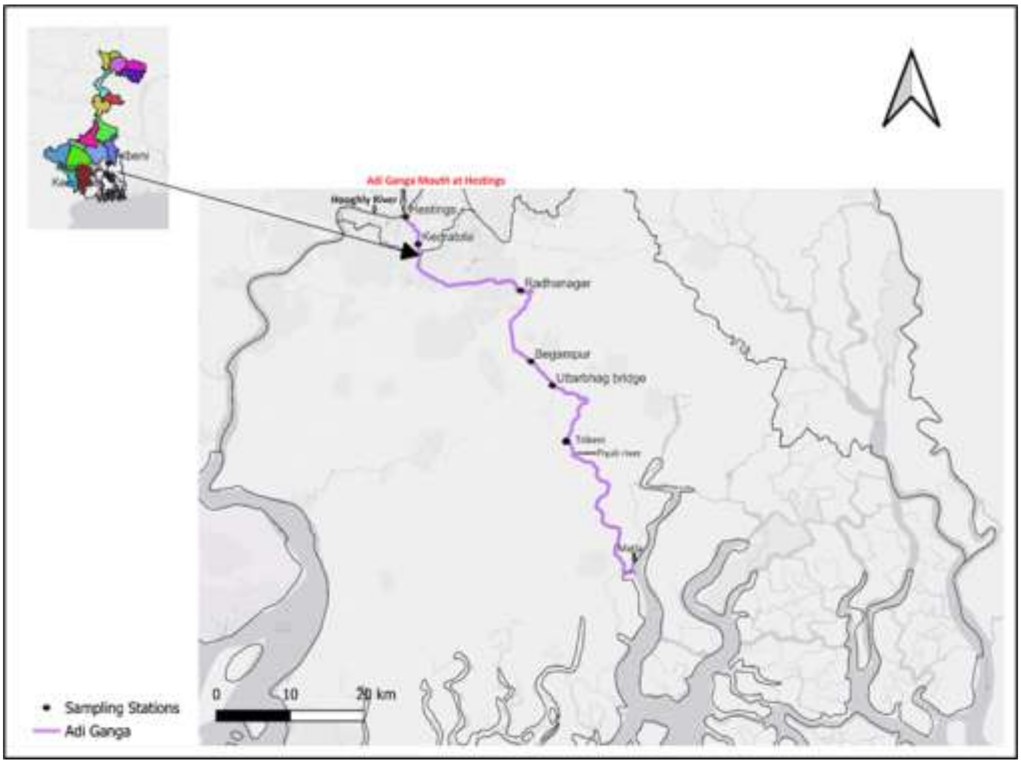


Figure 80: GIS map showing sampling points in the river Adi Ganga

Figure 81: Habitat status of different sampling sites of river Adi Ganga, A. Hestings, B. Keoratala, C. Radhanagar (Sonarpur), D. Begampur (Baruipur), E. Uttarbhag bridge, F. Tribeni Dosa

5.1.1.2. Water quality

A seasonal assessment of six Adi Ganga River sites: Hestings, Keoratala, Radhanagar, Baruipur, Uttarbhag Bridge, and Tribeni Dosa, revealed site-specific variations driven by urban runoff, estuarine influence, and monsoonal changes. Pre-monsoon, DO ranged from 0.4 ppm (Keoratala) to 3 ppm (Uttarbhag Bridge); Tribeni Dosa showed the highest COD (168 mg/L) and total solids (2.624 ppm), while Baruipur had the lowest COD (20 mg/L) and TDS (0.012 ppm). Turbidity peaked at Hestings (40.8 NTU), total phosphorus at Radhanagar (1.4079 ppm), and chlorophyll-a at Uttarbhag Bridge (16.9984 mg/m^3) were observed to be highest during monsoon. DO was highest at Tribeni Dosa (5 ppm), lowest at Keoratala (0.4 ppm); BOD peaked at Tribeni Dosa (3.8 ppm). COD was highest at Keoratala (86 mg/L) and Uttarbhag Bridge (64 mg/L), and lowest at Baruipur (12 mg/L). Transparency improved at Baruipur (52 cm), declined at Uttarbhag Bridge (18.3 cm). Radhanagar had the highest phosphate (0.8811 ppm) and total phosphorus (1.0986 ppm), while chlorophyll-a was highest at Keoratala (34.46 mg/m^3). Post-monsoon, DO ranged from 0.2 ppm (Keoratala) to 5.8 ppm (Tribeni Dosa); Keoratala had the highest phosphate (1.5582 ppm) and total phosphorus (2.2644 ppm). Tribeni Dosa recorded the maximum conductivity (16.8 mS/cm), and Uttarbhag Bridge had the highest salinity (11.73 ppt). Chlorophyll-a peaked at Hestings (39.18 mg/m^3), lowest at Keoratala (1.14 mg/m^3);

transparency ranged from 180 cm (Radhanagar) to 39 cm (Baruipur). Keoratala and Hestings consistently exhibited extreme values across parameters, identifying them as ecologically stressed zones with frequent hypoxia, eutrophication, and pollution.

5.1.1.3. Sediment status

A seasonal sediment quality assessment at six Adi Ganga River sites: Hestings, Keoratala, Radhanagar, Baruipur, Uttarbhag Bridge, and Tribeni Dosa—showed marked variations influenced by land use and runoff. Pre-monsoon, pH ranged from 8.81 (Hestings) to 7.34 (Baruipur), with conductivity highest at Baruipur (1107 µS/cm) and lowest at Radhanagar (295 µS/cm). Silt and clay were lowest at Baruipur (0.5%) and highest at Uttarbhag Bridge (32%). Keoratala had peak total phosphate (54.72 ppm) and available phosphate (3.94 ppm); Tribeni Dosa had the lowest available phosphate (1.06 ppm). Organic carbon was highest at Uttarbhag Bridge (2.25%) and lowest at Tribeni Dosa (0.56%). Monsoon values showed increased conductivity, peaking at Baruipur (2150 µS/cm); pH declined, especially at Baruipur (5.64). Baruipur also had the highest silt and clay (19%), organic carbon (2.63%), and total nitrogen (340 ppm), while Radhanagar had 96.5% sand and the lowest conductivity (1542 µS/cm). $CaCO_3$ peaked at Hestings (9%), and nitrogen was lowest there (10 ppm). Post-monsoon, Baruipur again showed high conductivity (1856 µS/cm), silt and clay (40%), and available nitrogen (50.24 ppm). Tribeni Dosa recorded the highest total (41.56 ppm) and available phosphate (4.11 ppm). Organic carbon remained high at Baruipur and Keoratala (1.96%), lowest at Hestings (0.63%). Overall, Baruipur and Keoratala emerged as nutrient-rich, high-conductivity zones, while Tribeni Dosa showed elevated phosphorus post-monsoon, indicating hotspots of runoff-driven sediment enrichment and eutrophication risk.

5.1.1.4. Plankton and periphyton community

A seasonal analysis of plankton and periphyton in the Adi Ganga River revealed distinct ecological shifts driven by nutrients, hydrology, and pollution. During the pre-monsoon period, 27 plankton species (9 classes) were recorded, dominated by Cyanophyceae (>40%), with key genera such as Oscillatoria, Phormidium, and Anabaena. Zooplankton included *Brachionus* and *Mesocyclops*. Periphyton comprised 22 species, also Cyanophyceae-dominant (60–98%), peaking at Keoratala (3.31 million units/cm^2) and lowest at Baruipur (31,500 units/cm^2). During monsoon, Bacillariophyceae (~40%) became dominant, especially *Nitzschia* and *Fragilaria*, while Cyanophyceae (30–50%) persisted in urban sites like Hestings; Chlorophyceae (20–25%)

were more common in cleaner sites like Uttarbhag. Zooplankton peaked at Tribeni (Rotifera 60%). Periphyton remained Cyanophyceae-rich (up to 98.8% at Keoratala), with mixed groups at Radhanagar and Utterbagh. Post-monsoon, Bacillariophyceae dominated phytoplankton (45–50%), followed by Cyanophyceae (25–30%) and Chlorophyta (10–15%), with genera like *Nitzschia*, *Navicula*, and *Volvox*. Zooplankton contributed 5–10%, including *Keratella* and *Diaptomus*. Periphyton remained Cyanophyceae-dominant (80–91% at Hestings, Keoratala), but Bacillariophyceae and Chlorophyceae rose (~40–50%) at Radhanagar, Utterbagh, and Tribeni (Fig. 82). Overall, Cyanophyceae dominated year-round, with diatoms and green algae peaking seasonally, reflecting eutrophic conditions and localized ecological stress.

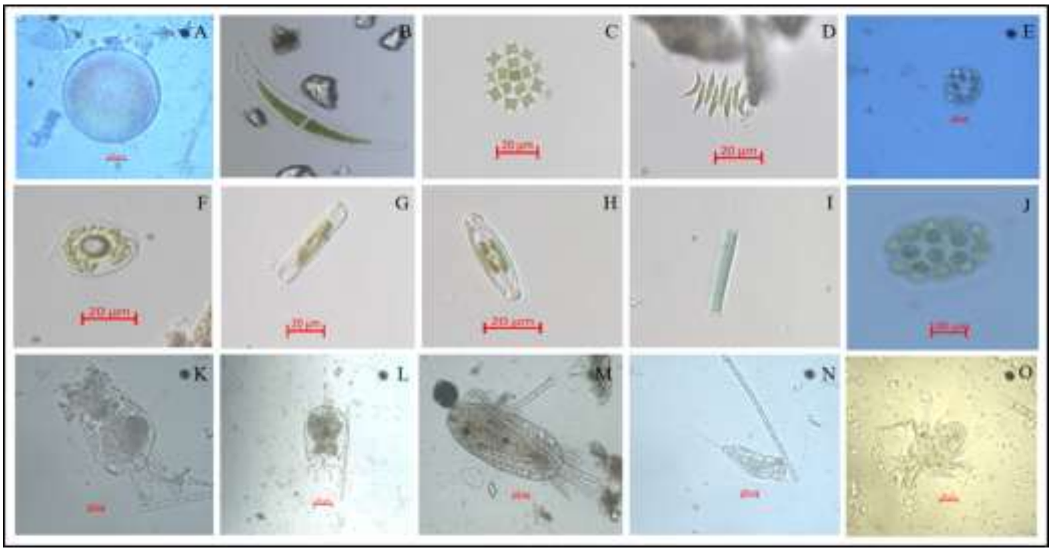


Figure 82: Microscopic photograph plankton of river Adi Ganga, A. Coscinodiscus sp., B. Closterium sp., C. *Pediastrum* sp., D. *Scenedesmus* sp., E. *Closterium* sp., F. *Phacus* sp., G. *Pinnularia* sp., H. *Navicula* sp., I. *Lyngbya* sp., J. *Pandorina* sp., K. *Brachionus* sp.

5.1.1.5. Benthic diversity and abundance

A seasonal assessment of benthic macroinvertebrates in the Adi Ganga River showed notable spatial and temporal variation. Pre-monsoon recorded 62 benthic organisms, and 10 gastropod species, with Baruipur showing the highest diversity—*Gyraulus convexiusculus* (390 inds/m²), *Lymnaea luteola* (346), and *Indoplanorbis exustus* (303). In Hastings, *Filopaludina bengalensis* (260) and *Idiopoma dissimilis* (216) comprised 92% of the abundance. Keoratala had peak *Tarebia granifera* (173), and both *Melanoides tuberculata* and *Gabbia orcula* at 87 inds/m². Monsoon saw *Tubifex tubifex* dominate Hastings (346, 100%), with *F. bengalensis* and *Tubifex* (87 each) in Uttarbhag. Tribeni Dosa had highest *M. tuberculata* (390), while Radhanagar was dominated by *G. convexiusculus* (303). *T. granifera* peaked at Keoratala (390, 56% RA) and

M. tuberculata at Tribeni (75% RA). Post-monsoon, *F. bengalensis* and *I. dissimilis* dominated Uttarbhag and Tribeni, *while G. convexiusculus* remained dominant at Radhanagar. *L. luteola* and *L. acuminata* appeared at Begampur. *T. granifera* was exclusive to Uttarbhag. Non-molluscan taxa, such as Chironomus and Oligochaeta, at Tribeni and Hastings, indicated organic pollution. Overall, Uttarbhag and Tribeni Dosa showed higher richness and abundance, while Hastings remained ecologically stressed with low diversity (Fig. 83).

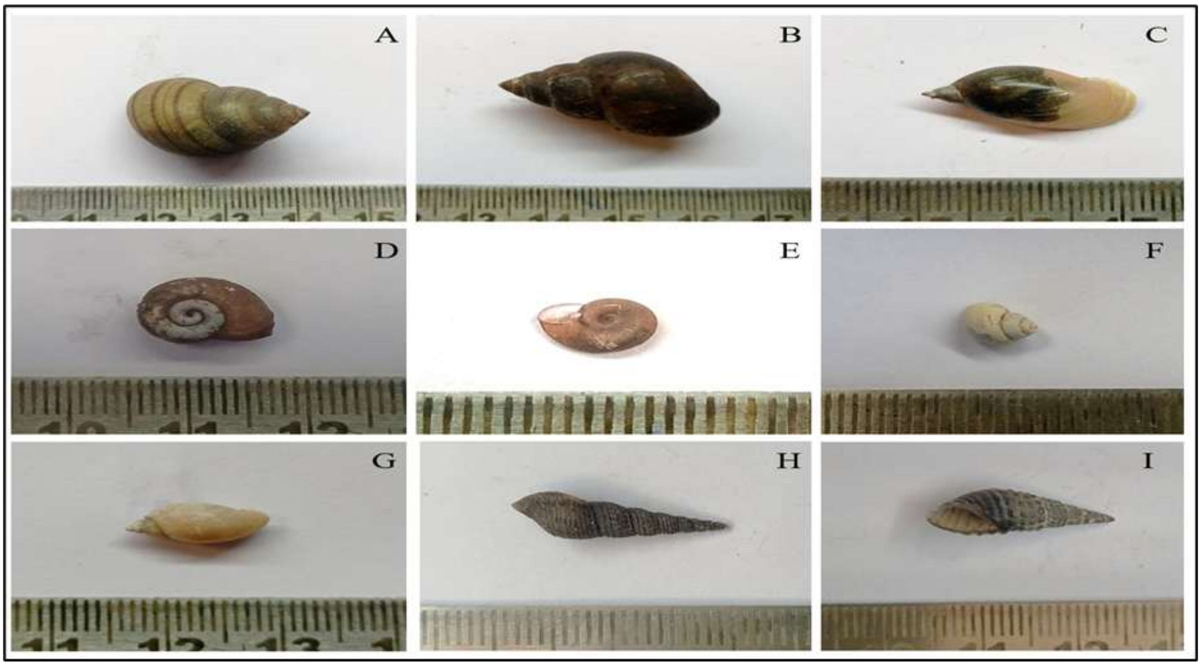


Figure 83: Benthos diversity at different sites of Adi Ganga River A. *Filopaludina bengalensis*, B. *Idiopoma dissimilis*, C. *Lymnaea acuminata*, D. *Indoplanorbis exustus*, E. *Gyraulus convexiusculus* F. *Gabbia orcula*, G. *Lymnaea luteola*, H. *Melanoides tuberculata*, I. *Tarebia granifera*

5.1.1.6. Macrophytes

Seasonal macrophyte assessments revealed spatial variation and moderate diversity. Pre-monsoon surveys recorded five species, with *Pontederia crassipes* being the dominant species throughout. Uttarbhag and Baruipur had the highest richness (four species). Monsoon diversity increased to ten species, concentrated at Baruipur, Uttarbhag, and Radhanagar, where *Ceratophyllum demersum* and *Alternanthera philoxeroides* were common. Radhanagar had the highest monsoon richness (eight species). In the post-monsoon, *A. philoxeroides* dominated, especially at Radhanagar, which consistently showed the highest diversity and abundance. Submerged species like *Hydrilla verticillata* and *Vallisneria spiralis* were absent, likely due to turbidity and degraded habitats.

5.1.1.7. Fish diversity

Seasonal fish diversity assessment across six sites of the Adi Ganga River- revealed substantial spatial and temporal variability in species richness and abundance, comprising 40 species belonging to 19 families and 10 orders (Fig. 84). In the pre-monsoon 18 species from 8 orders and 10 families were recorded, with Belonidae contributing the highest proportion and *Salmostoma acinaces*, *Puntius sophore*, and *P. conchonius* as the most dominant species. Uttarbhag Bridge exhibited the highest fish diversity, followed by Tribeni Dosa, while Baruipur recorded the lowest diversity, represented solely by *P. sophore* (100% relative abundance). *S. acinaces* dominated at Uttarbhag (43.2%), and *Mystus vittatus* at Tribeni Dosa (36.8%). During the monsoon, species richness increased to include 22 fish families, with Cyprinidae being the dominant family at Begampur and Tribeni Dosa, and key species such as *Puntius conchonius*, *P. sophore*, and *Labeo bata*. *Channa punctata* showed broad distribution, while the exotic *Oreochromis niloticus* was abundant at Uttarbhag Bridge (26 individuals).

Figure 84: Fish diversity at different site of Adi Ganga River; A. *Mystus vittatus*, B. *Puntius sophore*, C. *Oreochromis niloticus*, D. *Trichogaster fasciata,* E. *Parambassis lala*, F. *Parambasis baculis*, G. *Glossogobius giuris*, H. *Salmostoma acinaces*, I. *Macrognathus pancalus,* J. *Xenentodon cancila,* K. *Lepidocephaliicthys guntea*

Hastings and Keoratala displayed reduced diversity with hardy, pollution-tolerant species such as *Mystus gulio*, *Lepidocephalichthys guntea*, and *Pterygoplichthys disjunctivus*. In the post-monsoon period, 14 families were represented, with Tribeni Dosa exhibiting the highest species richness, including *P. sophore* and *Amblypharyngodon mola*, while Uttarbhag recorded the peak abundance of *Trichogaster fasciata*. Begampur hosted a balanced community of *Cirrhinus reba*, *Channa punctata*, and *Mystus vittatus*. Hastings and Keoratala again exhibited low diversity, with only 2–3 species, including *T. fasciata* and *Aplocheilus panchax*. The presence of both native and invasive species, as well as shifts in dominance across seasons, highlights the influence of water quality, habitat fragmentation, and anthropogenic pressures on the ichthyofaunal structure along the river stretch.

5.1.1.8. Fishing craft and gears

The primary fishing gears in the Adi Ganga River cast nets and bag nets reflect a shift toward shallow, stagnant water fishing, dominated by Small Indigenous Fishes (SIFs) like *Puntius* sp., *Channa* sp., *Xenentodon cancila*, and *Salmostoma acinaces*. Due to severe pollution and habitat degradation, larger carnivorous species (*Ompok* sp., *Wallago attu*) and Indian Major Carps have been completely eradicated, with no established target fisheries remaining.

5.1.1.9. Nutrient profiling

Nutrient profiling of four fish species *Xenentodon cancila*, *Salmostoma acinaces*, *Puntius conchonius*, and *Trichogaster fasciata* from the Adi Ganga River revealed distinct biochemical traits. *X. cancila* and *S. acinaces* were identified as protein-rich, lean fishes, while *P. conchonius* and *T. fasciata* were oil-rich species. All four were rich in essential amino acids, with glutamic acid being predominant, followed by lysine, leucine, or glycine, and aspartic acid as the major non-essential amino acid. In terms of fatty acids, myristic (C14:0) and palmitic acid (C16:0) were dominant saturated fatty acids across species. Among MUFAs, *X. cancila* showed higher palmitoleic acid (C16:1), while the other three were rich in oleic acid (C18:1). As for PUFAs, docosahexaenoic acid (C22:6) was dominant in *X. cancila* and *T. fasciata*, while arachidonic acid (C20:4) was highest in *S. acinaces* and *P. conchonius*. These findings highlight the nutritional value of Adi Ganga fish, especially their potential as sources of essential amino and fatty acids.

5.1.1.10. Microplastics

Microplastic pollution in the Adi Ganga River showed distinct spatial and seasonal variation. In water, fragments dominated, peaking at Hastings (150 items/L, post-monsoon) and Baruipur (102, monsoon); fibres were next highest, with Hastings also leading (83, pre-monsoon). Films and beads were rare, found mainly at Hastings and Keoratala; Radhanagar had the lowest MP counts with no films or beads. In sediments, Hastings had the highest MP load—fragments (544 items/kg) and fibres (212, pre-monsoon), followed by Keoratala. Tribeni Dosa showed low sediment MPs except for a monsoon fibre peak (173). Foams appeared only at Keoratala; beads were highest at Baruipur (13). Benthic samples had minimal MPs, with Radhanagar highest in pre-monsoon (45 items/L) and nearly zero during monsoon/post-monsoon. Overall, Hastings and Keoratala were the most impacted, while Tribeni and Radhanagar were the least impacted.

5.1.1.11. Heavy metal contamination

Heavy metal analysis of the Adi Ganga River revealed elevated levels of Fe, Cr, Zn, and Mn, particularly at Keoratala, where the water recorded peak concentrations of Fe (30,185.35 mg/L) and Cr (35.86 mg/L). Baruipur had the highest As (91.01 mg/L). Sediments showed high Fe (6531.33 mg/kg) and Al (3620.89 mg/kg) at Keoratala, and As (9.101 µg/L) at Baruipur. Monsoon water had peak Cd (0.000307 mg/L) and Pb (0.018538 mg/L) at Keoratala, and Cr (0.020787 mg/L) at Hastings. Post-monsoon, Cd was highest at Radhanagar (0.043824 mg/L), Cr at Keoratala (0.085 mg/L), and Pb at Hastings (0.069467 mg/L), exceeding ecological safety limits. Sediment metals peaked in monsoon with Cr (94.87 mg/kg) and Pb (32.93 mg/kg) at Keoratala; Cd was highest at Radhanagar (0.523 mg/kg). Fish samples showed variable metal accumulation, with *P. sophore* having highest Cd (0.000775 µg/g), Cr (0.003799 µg/g), and As (0.033943 µg/g), all within FAO (1983) permissible limits.

5.1.1.12. Coliform contamination

The MPN index of coliform bacteria in the Adi Ganga River showed seasonal variation, peaking during the monsoon with Hastings and Keoratala recording the highest contamination (2000 MPN/100 mL), followed by Sonarpur (920 MPN) and Baruipur and Uttarbhag (540 MPN). Tribeni Dosa showed the lowest (220 MPN). Post-monsoon levels declined at most sites—Baruipur (350 MPN), Uttarbhag (220 MPN), and Tribeni Dosa (170 MPN)—while Hastings and Keoratala remained consistently high (2000 MPN), indicating ongoing faecal contamination.

5.1.1.13. Bisphenol A contamination

The analysis of Environmental Bisphenol A (eBPA) in the Adi Ganga River reveals widespread contamination across all six sites, with concentrations ranging from 432.54 to 702.33 ng/L, peaking at Tribeni, Keoratala, and Uttarbhag during the post-monsoon season. Elevated levels at Hastings and Radhanagar further reflect the impact of urban runoff, sewage discharge, and plastic waste accumulation. Monsoon sampling also revealed high BPA presence, with a notable concentration of 586.32 ng/L at Keoratala, likely intensified by rain-driven surface pollution. This consistent detection of BPA—a known endocrine disruptor—underscores the growing threat of plastic-related pollutants in the river ecosystem. It highlights the urgent need for enhanced waste management and pollution control measures to protect aquatic health and public safety.

5.1.1.14. Carbon sequestration potential

Seasonal analysis of the Adi Ganga River showed clear spatial variation in Dissolved Organic Carbon (DOC) and Dissolved Inorganic Carbon (DIC). In the pre-monsoon, Keoratala had the highest DOC (64.65 mg/L) due to sewage input, while Tribeni had the lowest DOC (28.05 mg/L) and DIC (3.56 mg/L); Uttarbhag recorded the highest DIC (8.53 mg/L). Riverbed bulk density averaged 1.28 g/cm³, lower than upland soil (1.52 g/cm³). During the monsoon, DOC remained high at Hastings (62.1 mg/L) and Keoratala (61.12 mg/L), while Baruipur showed peak DIC (12.5 mg/L). In the post-monsoon period, Keoratala again had the highest DOC (64.12 mg/L) and Uttarbhag had the highest DIC (10.21 mg/L). Tribeni consistently showed the lowest values for both, indicating minimal carbon loading. Overall, urban zones (Keoratala, Hastings, and Uttarbhag) exhibited elevated DOC and DIC levels, indicating organic and inorganic pollution, whereas Tribeni remained the least impacted.

5.1.1.15. Conclusion

The comprehensive assessment of the Adi Ganga River underscores a severely degraded ecological state, driven by persistent urban encroachment, sewage discharge, and pollution influx. Seasonal variations in water quality parameters exhibit severe fluctuations, characterised by consistently low dissolved oxygen and high turbidity during the pre- and monsoon seasons, indicating unstable ecological conditions. Sediment analyses reveal nutrient-rich and polluted zones at Baruipur and Keoratala, with elevated levels of total phosphorus, organic carbon, and heavy metals like chromium, arsenic, and lead surpassing permissible limits. Microplastic pollution, particularly fibres and fragments, highlights the burden of urban plastic waste. Biotic communities, particularly plankton and periphyton, remained dominated by Cyanophyceae, reflecting nutrient enrichment and degraded water quality. Fish diversity has drastically shifted, with a decline in native fish species, dominance of pollution-tolerant and exotic fishes (e.g. Tilapia), and the absence of larger carnivorous taxa due to habitat loss and contamination.

Benthic macroinvertebrates and macrophyte communities showed localized diversity peaks. Alarmingly high coliform and bisphenol A levels confirm ongoing faecal and chemical pollution, posing risks to public health and food safety. Despite certain areas, such as Tribeni, showing relative resilience, the overall scenario calls for urgent, integrated restoration strategies. These must include pollution source reduction, sewage treatment, sediment remediation, and biodiversity conservation to reclaim the ecological integrity of the Adi Ganga River. The river requires a sustained policy intervention, inter-agency coordination, and long-term ecological stewardship to restore its biodiversity and legacy.

5.1.2. ALAKANANDA RIVER

The Alakananda River is a significant upstream tributary of the Ganga River. The river originates from the Sathopath and Bhagirathi Kharak glaciers in the Chamoli district, Uttarakhand state of India. Then the river flows through various famous towns such as Badrinath, Jyosimath, Vishnuprayag, Nandaprayag, Karanaprayag, Rudraprayag, and Srinagar, and thereafter, it merges with the Bhagirathi River at Devprayag with a total length of 195 km. The River Dhauli Ganga joins the river from the left near Joshimath, which makes one of the first prayag of Panchprayag. After merging with the Dhauli Ganga, the two rivers flow together as the Alakananda. At Nandprayag (the second Prayag of Panchprayag), Alakananda meets with the Nandakini River from the left bank, which originates from Nandaghuti. Nandakini River loses its identity at Nandprayag and becomes part of the Alakananda River

.5.1.2.1. Study area

Five sampling sites were selected along the entire river Alakananda, viz., Devprayag, Rudraprayag, Karnprayag, Nandprayag and Vishnuprayag (Fig. 85).

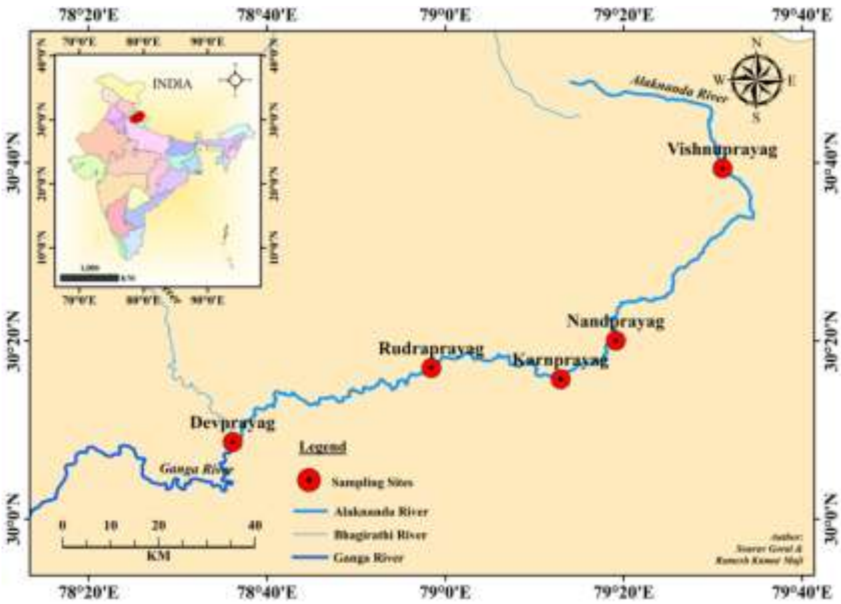


Figure 85: GIS map showing the study sites in River Alakananda

5.1.2.2. Water quality

The water quality of the Alakananda River was assessed during the pre-monsoon (PRM), monsoon (MON), and post-monsoon (POM) seasons, revealing significant spatial and temporal differences in physical, chemical, and biological parameters. The shallower depth (0.15 m) was recorded at Nandpryag during the PRM, and the deeper (2.4 m) depth was recorded at Devprayag during the POM season. The PRM temperature peak at 25.4 °C (Karnprayag) decreased during POM (6.5 °C) at Vishnuprayag due to weather conditions. Transparency was found to be highest (215.2 cm) at Vishnuprayag and lowest (5.6 cm) at Nandprayag, with turbidity ranging from 4.09 NTU (Vishnuprayag) to 814 NTU (Karnaprayag), indicating monsoonal run-off impact. Elevated conductivity (215 µS/cm) was seen during POM and reduced (53.5 µS/cm) during MON due to dilution. The pH of the river ranged from slightly alkaline (7.53) to alkaline (8.72) in nature. Dissolved oxygen was found highest (10.8 mg/L) in POM at Rudraprayag and lowest in MON (7.8 mg/L) at Karnprayag, suggesting seasonal influences. Total alkalinity peaked (94 mg/L) during PRM at Nandaprayag and dropped (16 mg/L) at Vishnuprayag during MON. Total hardness was recorded at 40 mg/L at Vishnuprayag during MON and 106 mg/L at Nandaprayag during POM. Lower and higher values of chlorinity and salinity were obtained during POM and MON, respectively. Nutrient levels vary, with phosphorus highest during PRM at Devprayag (1.957 mg/L), nitrogen peaking (1.83 mg/L) at Nandprayag during PRM and silicate concentration highest (11.21 mg/L) at Devprayag during

MON. Pollution-indicating parameters, including BOD (2.8 mg/L) and COD (64 mg/L), were elevated during PRM at Nandaprayag and Vishnuprayag, respectively. TS and TSS were reported high during PRM at Nandaprayag. Overall, the water quality of the river Alakananda was found to be under the national and international standard limits, except for turbidity.

5.1.2.3. Sediment quality of the river Alakananda

The sediment quality of river Alakananda revealed greater seasonal and spatial differences among different parameters. The sediment pH ranged from slightly alkaline to alkaline in nature (7.48–8.66), increasing during MON and PRM due to runoff and dilution effects. Specific conductivity was found to be highest (0.337 mS/cm) during POM and lowest (0.048 mS/cm) during PRM. Calcium carbonate content increases during PRM and decreases during MON, with a range of 3-20%. Sand content (81.60–94%) dominated the sediment texture throughout all seasons, with a slight rise in silt and clay content during POM. Total phosphorus and available nitrogen concentrations were found to be the highest at 78.62 and 9.24 mg/100 g, respectively, during PRM and POM. Organic matter also varied seasonally (0.03–0.17%), reflecting changes in organic input, runoff and decomposition. Overall, these patterns indicate the strong relationship between water and sediment interaction in the river.

5.1.2.4. Plankton and the Periphyton Community

The study of phytoplankton and periphyton communities in the Alakananda River revealed significant seasonal variations (n = 27). During the post-monsoon season, diatoms were the most common type of phytoplankton, especially at Rudraprayag, where there were 570,000 cells/L, leading to an average of 336,000 cells/L overall. This proliferation is attributed to low temperatures and nutrient-rich, stable waters that favour diatom growth. Cyanophyceae exhibited peak abundance during the monsoon season, with the highest value at Nandprayag (44,800 cells/L). However, their density declined notably during the pre-monsoon and post-monsoon periods, likely due to reduced dilution and increased turbulence that limit their growth. In the pre-monsoon period, a substantial drop in overall phytoplankton density was observed (119,840 cells/L). In contrast, the periphyton density of Bacillariophyceae increased sharply in the post-monsoon period, likely due to favourable and stable substrate conditions. The post-monsoon season saw the highest total periphyton density (7,868,000 cells/cm^2) due to increased sunlight, higher nutrient availability, and slower water flow, which facilitated better growth of periphyton. Bacillariophyceae dominated the phytoperiphyton community. Seasonal variations were also evident in the zooplankton community structure. Rotifera emerged as the dominant group during the post-monsoon season, with eight species recorded and a maximum density of 12 ind/litre. In contrast, monsoon conditions led to a decline in zooplankton diversity and abundance (two species), primarily due to increased water turbulence and dilution.

5.1.2.5. Benthic diversity and abundance

During the study, researchers found 13 types of benthic macroinvertebrates at different locations along the Alakananda River, which were classified into 4 groups (like Ephemeroptera, Plecoptera, Trichoptera, Diptera) and 11 families. The Ephemeroptera order was dominant, followed by Trichoptera and Diptera at different sampling sites (Fig. 86). The highest average total abundances (individual/m²) of the benthic species were recorded at Nandprayag (264), followed by Karnprayag (257), Devprayag (227), Rudraprayag (217) and Vishnuprayag (201), respectively, from the Alakananda River. During the study period the dominant benthic fauna, *Heptagenia* sp., *Baetis* sp. and *Hydropsyche* sp. were recorded at different sites. During the study period, the abundance range of macrobenthic invertebrates, viz. *Baetis* sp. 118 individuals/m² were recorded highest at Devprayag and lowest at 30 individuals/m² in Vishnuprayag. *Heptagenia* sp. 78 individuals/m² was the dominant at Nandprayag (78 individuals/m²), followed by *Hydropsyche* sp. and *Leptophlebia* sp. 54 individuals/m² and 29 individuals/m², respectively. *Chironomus* sp. was the dominant benthic species 17 individuals/m² at Devprayag, respectively. *Blepharicera* sp. 17 individuals/m² belonging to Class Insecta, Order Diptera, and Family Blephariceridae were recorded from Karanprayag during the pre-monsoon season. *Leptocella* sp. 7 individuals/m² belonging to Class Insecta, Order Trichoptera, and Family Leptoceridae were observed at Rudraprayag, Karanprayag, Nandprayag, and Vishnuprayag, except Devprayag, during post-monsoon.

5.1.2.6. Fish diversity

The Alakananda River recorded a total of 11 fish species during the 2024 sampling period, representing 8 genera, 3 families, and 2 orders (Fig. 87). The observed ichthyofaunal diversity reflects the ecological richness of this Himalayan River system. The dominant fish species recorded included *Garra gotyla*, *Garra lamta*, *Tor putitora*, *Schizothorax richardsonii*, *Schizothorax plagiostomus*, *Naziritor chelynoides*, *Barilius vagra*, *Opsarius bendelisis*, and *Glyptothorax cavia*. During the 2024 sampling, the highest fish species richness (n = 10) was recorded from Devprayag and Rudraprayag during the pre-monsoon season. On the other hand, Vishnuprayag recorded the lowest species richness, with only a single species (n = 1) during the post-monsoon period. With over 91% of the total fish diversity, the order Cypriniformes dominated the taxonomic composition, with the Siluriformes following with 9%.

Ironodes sp.

Baetis sp.

Caenis sp.

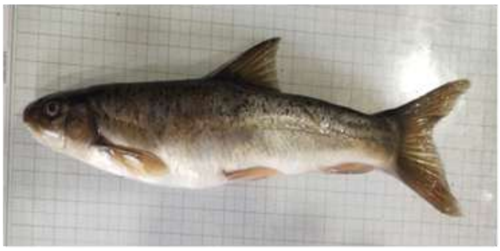
Chironomus sp.

Hydropsyche sp.

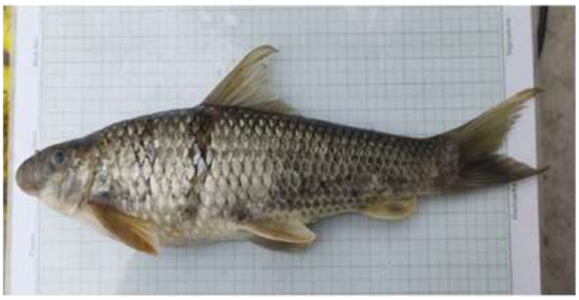
Blephariceraa sp.

Figure 86: Macrobenthos of river Alakananda

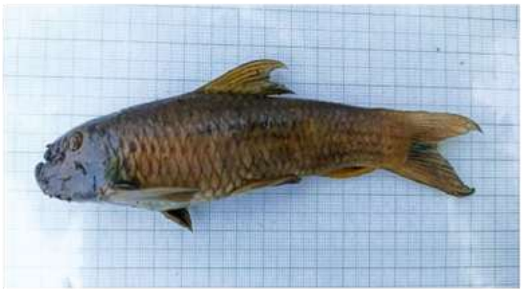
Schizothorax plagiostomus



Schizothorax richardsonii



Tariqilabeo latius



Garra gotyla

Figure 87: Common fishes of river Alakananda

5.1.2.7. Fishing crafts and gear

In the upper reaches of rivers like the Alakananda, where cold-water fish such as snow trout (*Schizothorax* spp.) and mahseer (*Tor* spp.) reside, the fishing methods employed are typically simple, traditional, and small-scale, focusing on local needs and protecting the fish population. The major types of gears recorded include gill nets, cast nets, hooks and lines and baskets. Among all of these, cast nets are widely used.

5.1.2.8. Conclusion

The Alakananda River, a major Himalayan tributary of the Ganga, exhibits distinct seasonal and spatial variations in water, sediment, and biological parameters (Fig. 88). Water quality generally remains within standard limits, though turbidity spikes during monsoon due to runoff. Sediment analysis shows dominance of sand with seasonal shifts in nutrient and organic content, indicating strong land-water interactions. Plankton and periphyton communities, especially Bacillariophyceae, thrive in post-monsoon, while Cyanophyceae peak during monsoon. Zooplankton diversity is highest during the post-monsoon period, with Rotifera being the dominant group. Benthic macroinvertebrates, notably Ephemeroptera and Trichoptera, show high abundance at Nandprayag and Devprayag. Eleven fish species were recorded, with Cypriniformes dominating, reflecting the river's ecological richness. Traditional fishing methods, such as cast nets and hooks, help sustain the river's cold-water fishery. Overall, Alakananda supports a vibrant ecosystem; however, continued monitoring and sustainable practices are essential for its conservation.

Figure 88: Field activities and habitat status at different sampling sites of river Alakananda

5.1.3. Bhilangna River

The Bhilangna River is a significant tributary of the Bhagirathi River in the Himalayan region of Uttarakhand, India. Emerging from the Khatling Glacier in the Tehri Garhwal district, the Bhilangna is encircled by snow-covered Himalayan peaks. Stretching 80 km in length, the Bhilangna joins with its primary tributary, the Bal Ganga, at Ghansali before merging into the Bhagirathi River at Old Tehri, the site of the Tehri dam. Within the Garhwal Himalaya, the Bhilangna River Basin is prone to various geological phenomena, including rainfall-induced mass movements, debris flows, and snow avalanches. This area has garnered attention because of its dynamic and sometimes hazardous natural processes.

5.1.3.1. Study area

Two sampling sites were selected along the Bhilangna river, viz. Ghuttu and Ghansali (Fig. 89).

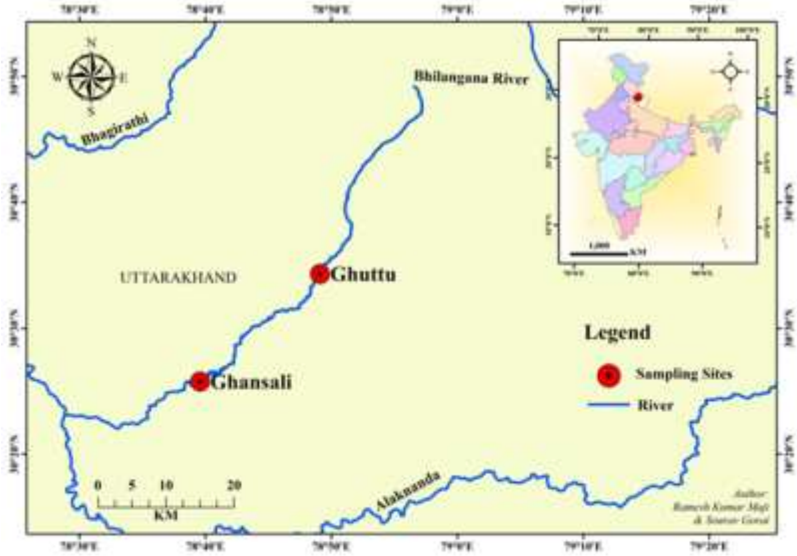


Figure 89: Study area map of the Bhilangna River

5.1.3.2. Water quality

The detailed water quality assessment of the Bhilangna River reveals significant seasonal and spatial variations in physical, chemical, and biological parameters across multiple sites. Shallow locations like Ghuttu (0.3 m depth) exhibit greater temperature fluctuations, while deeper sites such as Pipaldalit (2.9 m) maintain more stable conditions. Climate conditions recorded the highest temperature of 28.1 °C (Pipaldali, MON) and the lowest of 6.8 °C (Ghuttu, POM). Transparency was highest at Pipaldali (96.6 cm) and lowest at Ghansali (10.3 cm), with turbidity ranging from 10.91 NTU (Pipaldali) to 260 NTU (Ghansali), indicating runoff impact during MON. Conductivity during POM was recorded at its maximum (159.1 µS/cm) and minimum (62 µS/cm) values during MON, due to dilution, while the pH remained generally alkaline, with a maximum value of 8.74 in Pipaldali. Dissolved oxygen was highest in POM (10.8 mg/L, Ghuttu) and lowest (7.2 mg/L, Pipaldali). The maximum value (64 mg/L) of alkalinity was observed at Pipaldali in MON and the minimum (24 mg/L) during POM; the peak value of total hardness (78 mg/L) was obtained at Ghuttu during POM. Chlorinity and salinity ranges during MON were obtained as 4 – 12 mg/L and 0.007 – 0.022 g/L, respectively. Nutrient levels vary, with phosphorus maximum during PRM at Ghansali (0.169 mg/L), nitrogen highest at Ghansali, and silicate concentrations peaking at Ghuttu sites (9.381 mg/L). The highest BOD was found 2.4 mg/L in PRM and COD 75.67 mg/L at Ghuttu, with total solids (TS and TSS) also high in PRM, particularly at Ghansali. Overall, the water quality of the Bhilangna River was found to be under national and international norms, except turbidity parameter.

5.1.3.3. Sediment status of river Bhilangna

The sediment analysis of the Bhilangna River revealed clear seasonal trends across multiple parameters. The sediment pH ranged from slightly alkaline to alkaline (7.6–8.1), increasing during and after the MON due to runoff and dilution effects. Specific conductivity was highest (0.225 mS/cm) in the POM due to ionic accumulation and lowest (0.07 mS/cm) during PRM. Calcium carbonate content followed a similar trend (2–11%), peaking in PRM and decreasing in MON. Sediment texture was dominated by sand content across all seasons, with a slight rise in silt and clay content during the MON due to soil erosion. Total phosphorus and nitrogen concentrations were highest in POM at 84.43 and 29.68 mg/100 g, respectively, and lowest during MON and PRM at 5.83 and 1.68 mg/100 g, respectively. The organic carbon content also varied seasonally, with a range of 0.03–1.13%. Overall, these patterns indicate the strong influence of hydrological changes on the sediment characteristics of the river.

5.1.3.4. Plankton and the Periphyton Community

The phytoplankton and periphyton in the Bhilangna River (n = 15) revealed seasonal shifts. During the post-monsoon season, Bacillariophyceae dominated, with an average density of 165,000 cells/L and a peak of 252,000 cells/L recorded at Ghansali. In contrast, monsoon flows led to heightened turbidity and dilution, causing Bacillariophyceae densities to drop to their seasonal minimum of 49,000 cells/L. Cyanophyceae were present during the pre-monsoon and monsoon periods likely promoted by increased nutrient input. The monsoon season in the Bhilangna River showed a reduced phytoplankton density of 98,300 cells/L. This decline is attributed to increased water flow. In contrast, the pre-monsoon season results in a sharp increase in periphyton, especially Bacillariophyceae, with the highest total periphyton density recorded at 15,880,000 cells/cm^2. This spike reflects enhanced nutrient availability and lower flow velocity. The zooplankton community in the Bhilangna River exhibited significant seasonal variation in both species' composition and density. The monsoon season was associated with a decline in zooplankton diversity and abundance (n = 1). Arthropoda emerged as the most dominant group during the post-monsoon season, with two species recorded.

5.1.3.5. Benthic diversity of river Bhilangna

In 2024, the Bhilangna River yielded a total of 40 benthic macroinvertebrate species, representing 7 orders and 25 families (Fig. 90). Spatially, the highest average benthic abundance was observed at Ghuttu (652 individuals/m²), followed by Ghansali (133 individuals/m²) and Pipaldali (68 individuals/m²). The classes Gastropoda and Insecta were observed only from the Ghansalicenter, conversely, the macro-benthic fauna that was documented from Ghutu and Pipaldali belonged to the class Insecta. The gastropod (*Physella acuta*) was observed only at Ghansali. The benthic community of the river Bhilangna, was dominated mainly by the family Heptageniidae and Limnephilidae, accounting for 12 % of the total abundance. The presence of Physidae, Coenagrionidae, Caenidae, Psephenidae, Ptilodactylidae, Simuliidae, Rhyacophilidae, Hydropsychidae, Brachycentridae and Blephariceridae, etc., with 3.33%, is the least abundant at all sampling sites during the study. The higher abundance of Limnephilidae and Heptageniidae underscores their biological resilience, likely attributed to their flexibility in responding to environmental changes.

The macrobenthic community in the Bhilangna River exhibited seasonal variation across all sampling sites. At Ghuttu, the highest macrobenthic density was recorded in the post-monsoon season (590 individuals/m²), followed by monsoon (520 individuals/m²) and pre-monsoon (500 individuals/m²). *Diamesa* sp. and *Orthocladius* sp., which are insects from the Diptera order and Chironomidae family, were found only at the Ghuttu sampling sites during the post-monsoon season, with 10 and 20 individuals per square meter, respectively. The minimum benthic diversity was recorded during the pre-monsoon: 500 individuals/m² at Ghuttu, followed by 80 individuals/m² at Ghansali and 20 individuals/m² at Pipaldali, respectively.

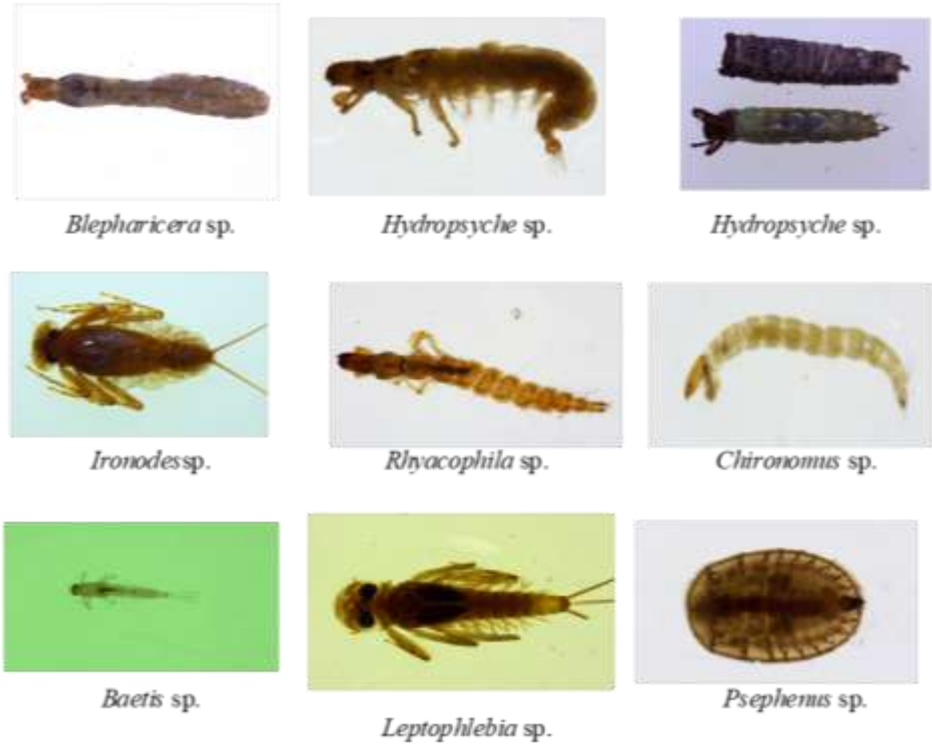


Figure 90: Macrobenthic diversity of river Bhilangna

5.1.3.6. Fish diversity

During the pre-monsoon, monsoon, and post-monsoon surveys conducted in 2024, a total of 11 fish species were recorded from the Bhilangna River, representing 9 genera, 2 families, and 1 order (Fig. 91). *Tor putitora, Schizothorax richardsonii, S. plagiostomus*, and *Naziritor chelynoides* were the dominant fish species at both sampling sites. Exotic fish species *Cyprinus carpio var. communis* were recorded at both sampling sites. *T. putitora, S. richardsonii, S. plagiostomus, Opsarius bendelisis, S. progastus, N. chelynoides, Barilius vagra* and *Puntius sophore* were the dominant fish species at Ghansali. *S. richardsonii, S. plagiostomus, O. bendelisis, T. putitora, B. vagra* and *P. sophore* were the dominant fish species at Ghuttu and Pipaldali, respectively. The highest fish diversity recorded was 11 species in pre-monsoon sampling and four species in post-monsoon at Ghuttu during 2024. Cyprinidae is recorded as the most dominant fish family, accounting for 82% of the total fish population. This was followed by Danionidae, contributing 18% to the overall fish composition.

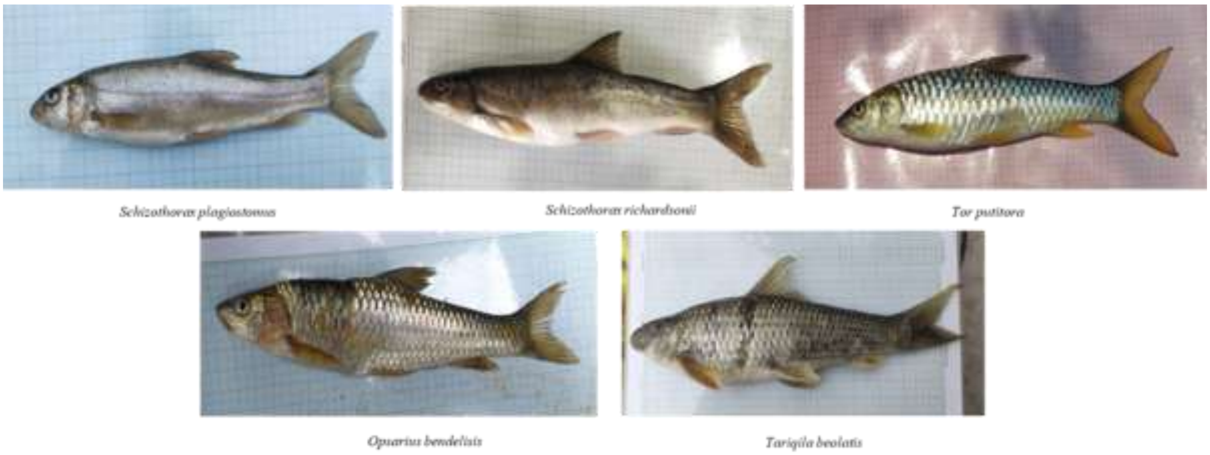


Figure 91: Fishes of river Bhilangana

5.1.3.7. Fishing crafts and gear

Due to the shallow, fast-flowing, and rocky terrain, the use of watercraft is very limited or absent in most parts of the Bhilangna River. The gears used are adapted to target cold-water fish: gill nets, cast nets, and hook and line.

Figure 92: Field activities and habitat status at different sampling sites of river Bhilangna

5.1.3.8. Conclusion

The ecological assessment of the Bhilangna River highlights a dynamic yet fragile Himalayan River system, influenced strongly by seasonal hydrological shifts and variable anthropogenic pressures. Water quality remains within acceptable national and international standards, although monsoon-induced turbidity spikes reflect sediment runoff and erosion. Spatial disparities are evident, with Ghansali showing elevated nutrient loads and turbidity, suggesting localized catchment disturbances. Sediment analyses reveal seasonal enrichment of organic carbon and nutrients post-monsoon, indicating enhanced catchment flushing and allochthonous input. Planktonic and periphytic communities respond sensitively to seasonal changes, with Bacillariophyceae dominating in low-flow conditions and declining under monsoon turbulence. Benthic macroinvertebrate diversity, particularly Heptageniida and Limnephilidae, demonstrates ecological responsiveness and habitat specificity, with Ghuttu showing the highest macrofaunal density (Fig. 92). The ichthyofaunal survey identified 11 species, predominantly Cyprinids, with the highest diversity during the pre-monsoon, reflecting optimal thermal and flow conditions. The presence of exotic species and fluctuating fish abundance underscores ecological stress and habitat fragmentation. Overall, the study emphasizes the need for sustained environmental monitoring and basin-level conservation efforts to preserve the Bhilangna River's biodiversity and hydrological integrity in the face of seasonal variability and emerging anthropogenic influences.

5.1.4. CHURNI RIVER

Tributaries like the River Churni serve as critical ecological habitats, transporting organic matter, nutrients, and aquatic organisms. They support biodiversity, fish migration, and macroinvertebrate dispersal, thereby creating biological "hotspots" and enhancing primary productivity in river systems. However, data on fish community responses to environmental change in such systems remain limited.

5.1.4.1. Study area

The seasonal field exploration was carried out from January 2024 to December 2024 to collect fish fauna, water, sediment samples and data related to various aspects of biotic and abiotic factors from different stations in the river Churni. As shown in Fig. 93, five sampling sites were selected, viz., Rabonbore Ferry Ghat (site-1), Kalinarayanpur Foot Bridge (site-2), Aranghata

Ferry Ghat (site-3), Jafarnagar Ferry Ghat (site-4), and Churni Resort Ferry Ghat, Shivnivas (site-5).

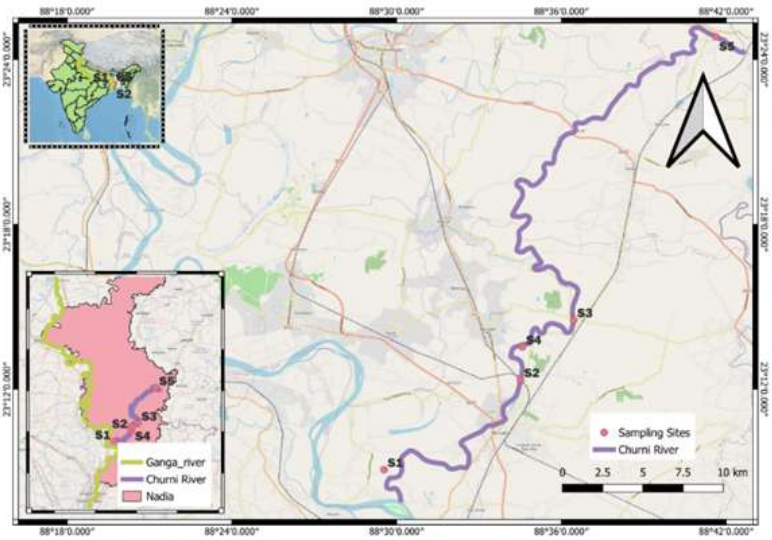


Figure 93: GIS map showing sampling points of river Churni

5.1.4.2. Water quality

The River Churni exhibits marked seasonal and spatial variations in water quality and habitat conditions across five monitored sites. Depths are highest during the monsoon (up to 6.1 m at Kalinarayanpur) and decline significantly in the post- and pre-monsoon periods. Water temperatures peak in the pre-monsoon (up to 34.4 °C), drop in the post-monsoon (~22 °C), and remain moderate during the monsoon. Transparency is highest during the monsoon, particularly at Rabonbore, while turbidity is elevated due to runoff and suspended sediments, especially at Kalinarayanpur. Dissolved oxygen (DO) is highest in the post-monsoon (up to 8.6 mg/L at Rabonbore) and lowest (1.4 mg/L) during monsoon and pre-monsoon, reflecting oxygen stress likely from organic load and reduced flow. Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) peak in the post-monsoon, indicating moderate organic and chemical pollution. Alkalinity and hardness are highest during the pre- and post-monsoon, especially at Churni Resort, and drop during the monsoon due to dilution from rain. Total solids (TS), total dissolved solids (TDS), and total suspended solids (TSS) follow a similar trend, with lower values during the monsoon and higher concentrations during drier periods. Nutrient levels (total phosphorus and nitrogen) are elevated in both the pre- and post-monsoon seasons, with the highest phosphorus levels recorded during the monsoon due to surface runoff. Silicate concentrations are also highest in pre- and post-monsoon, declining sharply during the monsoon. Chlorophyll concentrations spike in the monsoon (up to 11.37 mg/m³ at Churni

Resort), indicating algal blooms possibly driven by nutrient influx. Specific conductivity is highest post-monsoon due to ionic concentration from evaporation and lowest during monsoon, showing clear seasonal influence on ionic content and overall water quality dynamics.

5.1.4.3. Sediment status

The sediment quality of the Churni River exhibits significant seasonal and spatial variation, influencing aquatic ecology and fisheries. Sediment pH remained slightly alkaline, peaking during the pre-monsoon (up to 9.03) due to reduced freshwater input, while monsoon rainfall caused a decline. Specific conductivity varied, with the highest values post-monsoon (941 µS/cm) at Aranghata due to ion concentration, and the lowest (169 µS/cm) during monsoon from dilution. Calcium carbonate content was highest pre-monsoon (33.5%) and lowest during the monsoon due to leaching. Sediment texture shifted from sand-dominated in dry seasons to increased silt and clay during monsoon due to runoff. Total phosphorus and nitrogen levels peaked pre- and post-monsoon, driven by agricultural runoff and reduced river flow, while monsoon dilution lowered their concentrations. Organic carbon content followed a similar trend, highest during pre-monsoon (2.86%) and lowest during monsoon (0.17–1.14%), rebounding afterwards. These sediment characteristics directly impact benthic habitats, fish spawning, and nutrient cycling. Elevated nutrients and organic matter promote productivity but also risk eutrophication, thereby affecting fish health and the overall ecological integrity of the riverine system.

5.1.4.4. Plankton and Periphyton community

The plankton of 17 classes and 16 periphyton classes of the River Churni displayed apparent seasonal and spatial variations, closely linked to environmental changes and human activities. In the pre-monsoon season, Bacillariophyceae and Coscinodiscophyceae dominated phytoplankton, with Rabonbore Ferry Ghat recording extremely high densities (129,600 cells/L), while Cyanophyceae peaked at Kalinarayanpur. Zooplankton, especially Rotifera, were abundant at Aranghata and Jafarnagar. Monsoon conditions reduced overall plankton counts due to dilution but favoured Cyanophyceae and Rotifera growth, particularly at Kalinarayanpur, driven by nutrient-rich runoff. Post-monsoon, Bacillariophyceae resurged, Cyanophyceae declined, and Rotifera remained moderately abundant, indicating ecological stabilization. High Palmer Index values, due to the presence of *Oscillatoria* sp., *Phormidium* sp., and *Euglena* sp., signaled significant organic pollution. Dominant taxa included

Aulacoseira sp., *Fragilaria* sp., *Phormidium* sp., and *Mytilina* sp. Periphyton also reflected seasonal dynamics—Bacillariophyceae dominated during the pre-monsoon period, while Chlorophyceae and Rotifera surged during the monsoon, and a general decline followed post-monsoon, marking a period of recovery. These trends underline the sensitivity of planktonic communities to nutrient inputs and hydrological shifts, reinforcing their value as indicators of river health.

5.1.4.5. Benthic diversity and abundance

Six benthic species distribution in the River Churni (Fig. 94) varied across Kalinarayanpur, Aranghata, Jafarnagar, and Shibnibas, reflecting local environmental conditions. The benthic community was dominated by Viviparidae (55.55%), indicating their strong adaptability, followed by Lymnaeidae (19.42%) and Planorbidae (16.55%), which favoured the river's pulmonate gastropod-friendly habitat. Other families, such as Thiaridae, Bithyniidae, and Ampullariidae, were less abundant. Species such as *Filopaludina bengalensis* were most abundant in Shibnibas and Aranghata, while *Lymnaea luteola* dominated overall, especially in Shibnibas and Aranghata. Seasonal changes influenced species abundance: during the monsoon, *Filopaludina bengalensis* exhibited widespread dominance, with peak counts, and new species, such as Gabbia orcula and Gabbia stenothyroides, appeared, suggesting seasonal habitat shifts. Post-monsoon, *Filopaludina bengalensis* remained prevalent, with slight shifts in species diversity, including appearances of *Mekongia crassa* and *Gyraulus convexiesculus*. Benthic fauna counts also showed seasonal fluctuations, with Shibnibas and Aranghata recording high numbers pre-monsoon, Jafarnagar peaking during monsoon, and Rabonbore and Shibnibas showing strong post-monsoon recovery. These patterns highlight the dynamic nature of benthic communities in response to seasonal and environmental changes.

Figure 94: Benthic diversity of River Churni

5.1.4.6. Fish diversity

Fish diversity in the Churni River (Fig. 95), recorded across three main sites—Rabanbore, Kalinarayanpur, and Aranghata comprised 24 species from 20 genera, 14 families, and 9 orders. Rabanbore showed the highest species richness (20 species), followed by Aranghata (16) and Kalinarayanpur (14), with lower diversity at Kalinarayanpur likely due to poorer water quality influenced by industrial effluents. Seasonal patterns indicated greater fish availability in the pre-monsoon period (53%) and post-monsoon (47%), while monsoon catches were negligible.

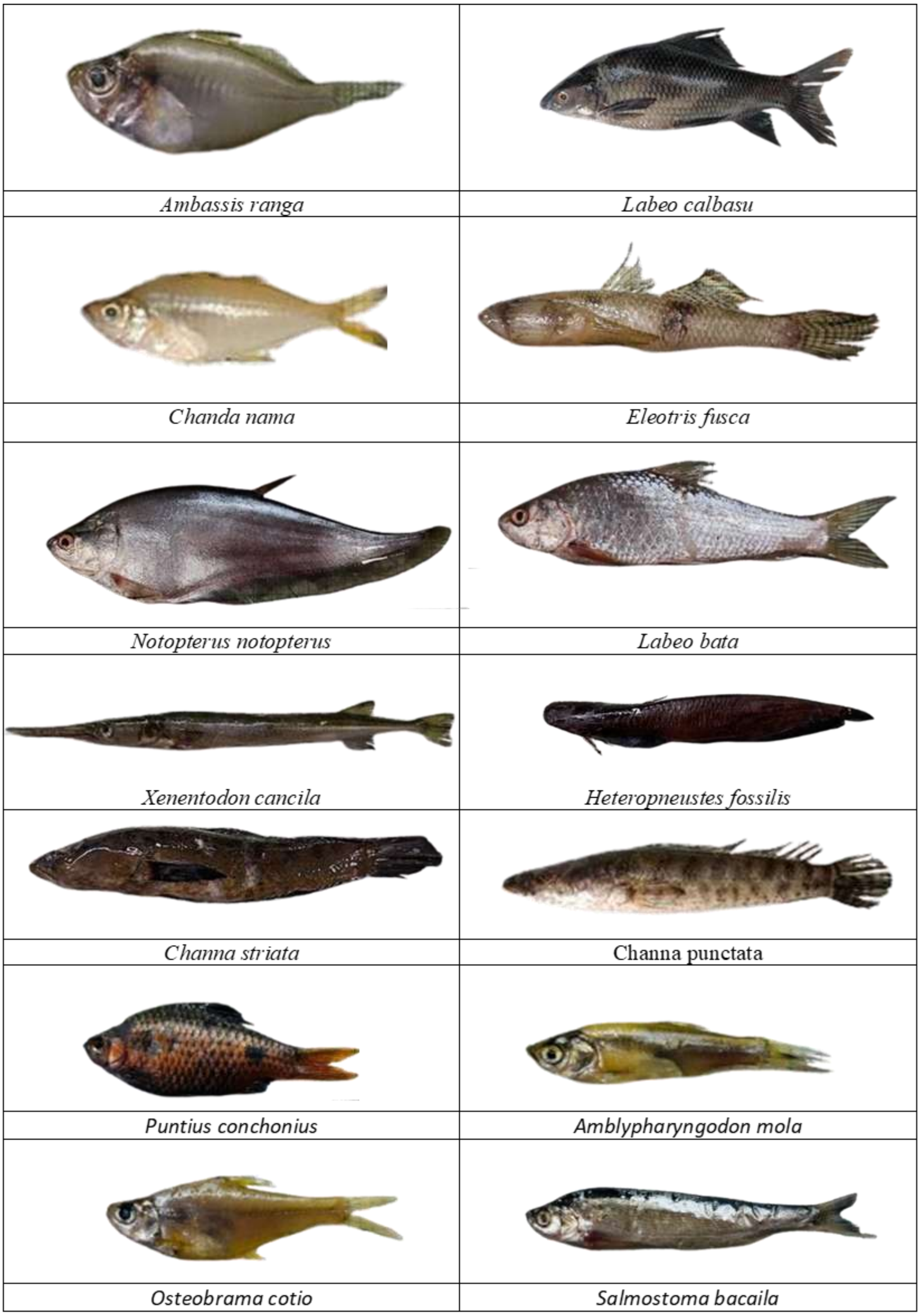


Figure 95: Fish diversity of river Churni

Figure 96: Fish and fishing activities in river Churni

The higher diversity (Fig. 96) pre-monsoon is attributed to favorable conditions during March–May, when southwest monsoon winds and southerly airflows promote congregation of fish shoals in suitable water quality areas.

5.1.4.7. Fishing craft and gears

During our study, two main types of fishing crafts were observed on the Churni River: wooden boats and steel tin sheet boats (Fig. 97). The steel tin boats, smaller and suited for shallow, low-water conditions, are mainly used during the dry seasons, while the larger wooden boats operate year-round. Various fishing gears are employed, including pole and line, cast nets, Charpata Jaal, Suti Jaal, Bessel Jaal, Chinese dip nets, gill nets, and mosquito nets with mesh sizes from 10 to 25 mm. Traditional methods like spear fishing, light fishing, and box traps are also practised. Although there are no targeted fisheries, catches mostly consist of Small Indigenous Fishes (SIFs) and weed fish species. Alarmingly, some fishermen use toxic substances such as "Super Killer 25" pesticides and Calfox tablets to poison fish, throwing them upstream early in the morning. This drives fish towards the ghat for easy

Figure 97: Crafts and gears operation observed at different site of Churni River

collection but severely harms aquatic life, especially juvenile fish and eggs, disrupting reproductive cycles and threatening the river's ecological balance.

5.1.4.8. Nutrient profiling

A single fish species, *Heteropneustes fossilis*, was collected from the River Churni for nutrient profiling, which included analysis of its gross chemical composition, amino acid content, and fatty acid profile. The study revealed that *H. fossilis* is rich in protein. Regarding amino acids, it contains high levels of essential amino acids, with glutamic acid being the most abundant, followed by lysine and leucine, along with the non-essential amino acid aspartic acid. In the fatty acid composition, lauric acid (C12:0) was the predominant saturated fatty acid, followed by undecanoic acid (C11:0). Among unsaturated fatty acids, oleic acid (C18:1) was the main monounsaturated fatty acid (MUFA), while arachidonic acid (C20:4) was the dominant polyunsaturated fatty acid (PUFA).

5.1.4.9. Microplastics

During the pre-monsoon period in the Churni River, microplastic fragments peaked at Kalinarayanpur (35 items/L) and were lowest at Rabonbore Ferry Ghat (17 items/L), while fibres were most abundant at Rabonbore (32 items/L) and films peaked at Churni Resort Ferry Ghat (9 items/L); beads appeared only at Jafarnagar (2 items/L). In the monsoon, fragments remained dominant, highest at Kalinarayanpur (50 items/L) and lowest at Churni Resort Ferry Ghat (14 items/L), with fibres again highest at Kalinarayanpur (37 items/L), films detected only at Aranghata (6 items/L), and beads exclusively at Kalinarayanpur (1 particle/L). When measured per kilogram, pre-monsoon fragments were highest at Kalinarayanpur (150 items/kg), followed by Aranghata (130 items/kg). Fibres were most abundant at Aranghata (95 items/kg), and films were absent across all sites. Foam particles and beads were only found at Kalinarayanpur (4 and 5 items/kg, respectively). During monsoon, Aranghata recorded the highest concentrations of fragments (124 items/kg), fibers (103 items/kg), and foam (9 items/kg). In comparison, beads appeared solely at Churni Resort Ferry Ghat (3 items/kg), highlighting significant seasonal and spatial variation in microplastic pollution across the river.

5.1.4.10. Heavy metal contamination

Heavy metal contamination in the Churni River was assessed across water, sediment, and aquatic biota, revealing elevated levels of arsenic (As) and chromium (Cr) that exceed BIS (2012), USEPA (2024), and Canadian sediment quality guidelines. In water, peak concentrations of Cd (0.00096 mg/L), Cr (0.03830 mg/L), Cu (0.02161 mg/L), and Pb (0.01794 mg/L) were recorded at Shivnibas post-monsoon, while As (0.34472 mg/L) peaked pre-monsoon, indicating potential health risks. Sediment samples showed the highest contamination during the monsoon at Jafranagar Ferry Ghat, with Cd (4.42 µg/g), Cr (83.84 µg/g), and As (29.88 µg/g) exceeding safe limits, likely due to runoff and industrial discharge. Fish samples also showed bioaccumulation, particularly of Cu (0.69403 µg/g in *Macrobrachium rosenbergii*, Cd (0.01658 µg/g in *Labeo calbasu*), and As (0.03556 µg/g) in *Epinephalus lanceolatus*, posing ecological and human health concerns from consumption.

5.1.4.11. Coliform contamination

The MPN index of coliform bacteria in the Churni River exhibited significant seasonal variation, peaking during the monsoon with the highest contamination at Kalinarayanpur and Jafarnagar (110 MPN). In comparison, other sites ranged from 94 to 110 MPN. Pre-monsoon levels were also notably high, with 63 MPN recorded at Rabonbore and Churni Resort Ferry Ghats, indicating persistent baseline contamination. Although post-monsoon levels declined, they remained elevated at specific locations, such as Kalinarayanpur (63 MPN), reflecting continued bacterial presence and potential health risks.

5.1.4.12. Bisphenol A contamination

Environmental Bisphenol A (eBPA) concentrations in the Churni River exhibited a clear seasonal variation, with the highest levels recorded during the pre-monsoon season at Jafarnagar (270.2 ng/L) and the lowest during the monsoon at Shibnibas (229.73 ng/L), likely due to dilution from increased water flow. Post-monsoon levels rose slightly but remained below pre-monsoon values, indicating partial reaccumulation of pollutants. Kalinarayanpur and Jafarnagar consistently exhibited higher eBPA levels across all seasons, suggesting ongoing pollution sources or limited natural degradation. These patterns highlight the impact of seasonal dynamics on eBPA distribution and underscore the need for targeted pollution control in hotspot areas.

5.1.4.13. Carbon sequestration potential

Seasonal fluctuations in dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) in the Churni River have a significant impact on aquatic ecology. Pre-monsoon DOC peaks at 48.61 mg/L in Kalinarayanpur, reducing light penetration and limiting photosynthesis, which can lower primary productivity and impact higher trophic levels, such as zooplankton and fish. However, elevated DOC may also reduce the toxicity of certain heavy metals through complexation, offering some protection to aquatic life. Post-monsoon DOC levels rise again, reflecting a resurgence in carbon input, while DIC remains stable, ensuring consistent inorganic carbon availability. These dynamics underscore the importance of regular carbon monitoring to support ecosystem and fisheries management.

5.1.4.14. Macrophytes

During the pre-monsoon period in the Churni River, five macrophyte species were observed across five sites, with *Pontederia crassipes* being the most dominant. Aranghata showed the highest diversity, hosting four species, while *Potamogeton* sp. was uniquely present in Shibnibas. In the monsoon season, quadrat sampling recorded seven species, with *Alternanthera philoxeroides* emerging as the dominant and widely distributed species, especially in Shibnibas and Rabonbore, suggesting its invasive potential. *Pontederia crassipes*, *Pistia stratiotes*, and *Hydrilla verticillata* were also present across all sites, though in varying densities. Species like *Ceratophyllum demersum*, *Potamogeton* sp., *Hygrophila auriculata*, and *Vallisneria spiralis* were absent, likely due to seasonal or site-specific factors. Post-monsoon surveys confirmed the continued dominance of *A. philoxeroides*, with *P. crassipes* and *H. verticillata* maintaining widespread presence. *Pistia stratiotes* was most abundant in Jafarnagar, while *Potamogeton* sp. reappeared in Shibnibas and Jafarnagar, indicating specific habitat preferences. These seasonal and spatial patterns reflect the dynamic structure of the macrophyte community, influenced by hydrological conditions.

5.1.4.15. Conclusion

The comprehensive assessment of the Churni River reveals significant ecological degradation marked by declining fish diversity, deteriorating water quality, and increased pollution levels. Once home to 41 fish species, the river now supports only 24 species in its lower stretch, with the highest diversity observed at Rabanbore, likely due to favorable habitat conditions and reduced pollution. Seasonal patterns show that fish richness peaks during the pre-monsoon, facilitated by suitable hydrological and thermal conditions, whereas monsoon sampling yields minimal catch due to unfavorable flow dynamics. Water quality parameters across sites and seasons exhibit pronounced fluctuations, with post-monsoon conditions characterised by higher dissolved oxygen and lower turbidity, indicating a temporary recovery. However, the consistently poor conditions at Kalinarayanpur, such as low transparency, high turbidity, and elevated biological and chemical oxygen demand, underscore the chronic impact of industrial effluents, particularly from the Darshana Sugar Mill. Heavy metal analyses further highlight contamination hotspots, especially at Churni Resort and Shibnibas, where arsenic and chromium levels exceed permissible limits in both water and sediments, indicating long-term ecological risks. The accumulation of microplastics and heavy metals in fish tissue raises serious concerns about food safety and trophic transfer, with species like Labeo calbasu and Heteropneustes fossilis exhibiting the highest toxic metal burdens. Additionally, elevated nutrient loads, especially total phosphorus, coupled with sediment-bound pollutants, indicate ongoing eutrophication and sediment toxicity. Overall, the study highlights a pressing need for integrated river basin management strategies that focus on pollution control, effluent treatment, and habitat restoration to safeguard the ecological integrity of the Churni River and preserve its declining ichthyofaunal diversity.

5.1.5. DAMODAR RIVER

The Damodar River is a significant tributary of the River Ganga, flowing through Jharkhand and West Bengal. Known historically as the "Sorrow of Bengal" due to its severe flooding, the Damodar has since been partially tamed by dam construction. Originating in the Chotanagpur Plateau, it flows 592 km before joining the Hooghly River, passing through a region heavily impacted by mining and industrial activities.

5.1.5.1. Study area

Ten sampling sites were selected, viz., Pipawar, Ramgarh, Tenughat, Phusro, Chandrapura thermal power station, Panchet dam, Burnpur, Mejia (Raniganj), Durgapur, Sadarghat, Burdwan and Garchumuk (Fig. 98). The sampling sites of the river covered several districts of two states, i.e. Jharkhand and West Bengal. The positional co-ordinates ranged between 85.057724 N, 23.720507 E to 88.074307º E, 22.348941º N.

Figure 98: GIS map showing sampling points in river Damodar

5.1.5.2. Water Quality

The detailed water quality assessment of the Damodar River reveals significant seasonal and spatial variations in physical, chemical, and biological parameters across multiple sites. Shallow locations like Piparwar (0.5 m depth) exhibit greater temperature fluctuations, while deeper sites such as Tenughat (6.5 m) maintain more stable conditions. Pre-monsoon temperatures peak at 33.9 °C (Piparwar), decreasing during monsoon (26-28 °C) due to rainfall. Transparency is highest at Chandrapura (166 cm) and lowest at Tenughat (6.3 cm), with turbidity ranging from 4.2 NTU (Piparwar) to 53.2 NTU (Garchumuk), indicating the impact of runoff. Conductivity is elevated in pre-monsoon due to evaporation and reduced during monsoon from dilution, while pH remains generally alkaline, peaking at 9.3 in Burnpur Asansol. Dissolved oxygen is highest in post-monsoon (up to 13.4 mg/L, Garchumuk) and lowest in pre-monsoon (3.4 mg/L at Burnpur, Asansol and Sardar Ghat), suggesting seasonal oxygen stress. Alkalinity and hardness peak at Garchumuk during the pre-monsoon season and drop at Ramgarh during the monsoon, with chlorinity and salinity similarly decreasing due to rainfall. Nutrient levels vary, with phosphorus highest during post-monsoon at Burnpur Asansol (1.69 mg/L), nitrogen peaking at Mejia Raniganj, and silicate concentrations highest at sites like Chandrapura (34.42 mg/L). Chlorophyll levels, indicating phytoplankton growth, are highest at Ramgarh (24.944 mg/m³) in pre-monsoon and at Sadar Ghat during monsoon (32.483 mg/m³). Pollution indicators show elevated BOD (up to 3.8 mg/L post-monsoon) and COD (up to 124 mg/L at Sadar Ghat), with total solids (TS, TDS, TSS) also high in pre- and monsoon seasons, particularly at Piparwar and Ramgarh. Overall, water quality tends to degrade in pre- and post-monsoon periods due to concentrated pollutants, while the monsoon season brings a dilution effect that temporarily improves conditions.

5.1.5.3. Sediment status of the river Damodar

The sediment analysis of the Damodar River revealed clear seasonal trends across multiple parameters. Sediment pH ranged from mildly acidic to alkaline (6.51-8.98), increasing during and after the monsoon due to runoff and dilution effects. Specific conductivity was highest (1440 µS/cm at Tenughat) during the pre-monsoon period due to ionic accumulation and lowest (Chandrapura, 43.3 µS/cm) during the monsoon due to dilution, with a partial increase post-monsoon. Calcium carbonate content followed a similar trend (0.5-14.5%), peaking pre-monsoon (14.5%, Sadar Ghat), decreasing in monsoon (0.4%, Garchumuk), and recovering afterwards. Sediment texture was dominated by sand across all seasons, with a slight increase in silt and clay during the monsoon due to erosion. Total phosphate and nitrogen concentrations were highest in the pre-monsoon at Tenughat (29.36 mg/100 g) and Phusro (250 mg/100 g), respectively. They declined during the monsoon at Tenughat (7.37 mg/100 g) and partially rebounded post-monsoon, indicating seasonal nutrient fluxes. Organic carbon content also varied seasonally (0.34-2.83%), reflecting changes in organic input, runoff, and decomposition. Overall, these patterns indicate the strong influence of hydrological changes on sediment characteristics in the river.

5.1.5.4. Plankton and periphyton community

The plankton and periphyton analysis of the Damodar River revealed significant seasonal variations. Overall, the community comprised over 12 orders, 18 families, and more than 75 genera, indicating a diverse planktonic assemblage that reflects both nutrient-rich and moderately polluted environments across the sampled sites. In the pre-monsoon season, phytoplankton like Bacillariophyceae, Chlorophyceae, and Cyanophyceae were most abundant, especially at Chandrapura (1874 cells/L, 95,533 cells/L, 592,667 cells/L, respectively), driven by warm temperatures and nutrient-rich, stable waters. Cyanophyceae peaked dramatically in this period but declined during monsoon and post-monsoon due to rainfall-driven dilution and turbulence. Harmful algal blooms, especially at Phusro and Chandrapura sampling sites during the pre-monsoon season, were linked to species like Anabaena, Nostoc, and Microcystis, fueled by nutrient enrichment and stagnant conditions. Zooplankton such as Rotifera were also most abundant pre-monsoon in Chandrapura (233 ind/L). During the monsoon, phytoplankton density dropped Bacillariophyceae remained prominent at Sadarghat (3,052 cells/L) and Durgapur Barrage (1,344 cells/L). Coscinodiscophyceae was found dominated at Raniganj (1008 cells/L). Chlorophyceae with notable observations at Burnpur (294 cells/L). Cyanophyceae showed its peak in Raniganj (17,542 cells/L)., but in periphyton, especially Bacillariophyceae (578,910 cells/cm²) and Cyanophyceae (618,180 cells/cm²), increased sharply due to nutrient-laden runoff. The monsoon season recorded the highest total periphyton density (1,266,165 cells/cm²), while post-monsoon levels dropped across most groups. Overall, pre-monsoon supported higher plankton abundance, whereas monsoon conditions favored periphyton growth due to eutrophication from runoff.

5.1.5.5. Benthic diversity and abundance

The study of benthic fauna in the Damodar River revealed significant seasonal and spatial variation in species composition and abundance (Fig. 99). Thiaridae dominated the benthic community (39.47%), followed by Viviparidae (24.21%) and Unionidae (17.89%), reflecting their environmental adaptability. Cyrenidae (8.42%) and Planorobidae (6.84%) add to the diversity, while Neritidae (2.63%) and Lymnaeidae (0.53%) appear in much smaller numbers. Pre-monsoon showed peak abundance of species like *Filopaludina bengalensis* and *Brotia costula*, while some species were absent (*Melanoides tuberculata*, *Lymnaea luteola*, and *Neripteron violaceum*). During the monsoon, species composition shifted-*Tarebia*

Figure 99: Benthic diversity of river Damodar

granifera and *Neripteron violaceum* peaked, while others like *Brotia costula* disappeared. Post-monsoon saw the resurgence of species like *Parreysia shurtleffiana* and *Melanoides tuberculata*, with some new species emerging (*Mieniplotia scabra* and *Parreysia caerulea*) and others vanishing (*Tarebia granifera*, *Neripteron violaceum*, and *Corbicula assamensis*). Benthic abundance also varied by site and season, with Burnpur and Durgapur leading in pre-monsoon, increased abundance at Ramgarh and Panchet Dam during monsoon, and a general decline post-monsoon across most locations.

5.1.5.6. Fish diversity

The fish diversity assessment of the Damodar River recorded 49 species across 36 genera, 17 families, and 11 orders (Fig. 100). The richest sites in terms of species were Ramgarh and Durgapur (30 species each), followed by Phusro and Panchet Dam (24 species), with the lowest diversity observed in Raniganj, likely due to industrial pollution.

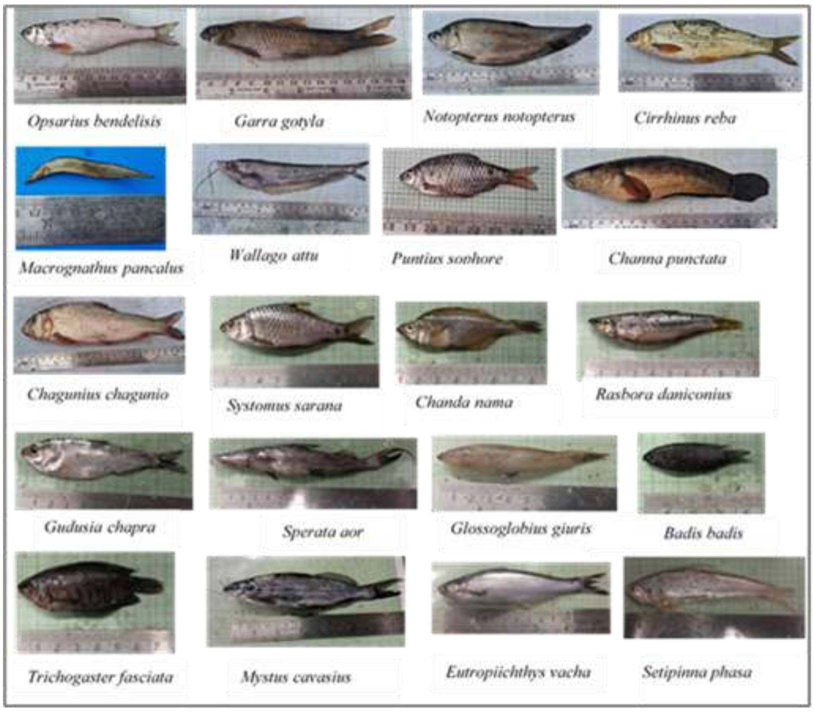


Figure 100: Fish diversity of river Damodar

Seasonally, the highest fish diversity was recorded in the post-monsoon period (41%), followed by pre-monsoon (31%) and monsoon (28%), reflecting better ecological stability and nutrient availability after rainfall. Cypriniformes dominated the fish community (42%), while beloniformes and tetraodontiformes had the lowest representation (2%). *Gudusia chapra* was the dominant species (RA 14.25%) recorded from Garchumuk, followed by Pethia conchonius (RA 11.0%) from Durgapur and *P. conchonius* (8.34%) from Garchumuk. Other dominant species were *Glossogobius giuris* (RA 3.24) and *Puntius sophore* (RA 6.48%), documented from Durgapur and Garchumuk, respectively.

5.1.5.7. Fishing craft and gears

The Damodar River supports a diverse range of fish and shellfish species with various fishing gears. Standard fishing methods include gill nets, seine nets, hand-drifted push nets, and hook-and-line methods. Among these, gill nets are predominantly used, particularly in deeper pool areas of the river, where they are most effective. This reflects the adaptability of local fishing practices to the river's ecological conditions and the availability of fish.

5.1.5.8. Nutrient profiling

The nutrient profiling of 13 fish species from the Damodar River (viz., *Ailia coila*, *Xenentodon cancila*, *Rasbora daniconius*, *Parambassis ranga*, *Sperata seenghala*, *Gudusia chapra*, *Barilius bendelisis*, *Labeo dyocheilus*, *Cirrhinus reba*, *Notopterus notopterus*, *Labeo bata*, *Chagunius chagunio* and *Pethia conchonius*) revealed distinct nutritional qualities across species. Gross chemical composition identified *Ailia coila*, *Rasbora daniconius*, *Gudusia chapra*, *Barilius bendelisis*, *Chagunius chagunio*, and *Puntius conchonius* as oil-rich species. At the same time, *Xenentodon cancila*, *Parambassis ranga*, *Sperata seenghala*, *Labeo dyocheilus*, *Cirrhinus reba*, *Notopterus notopterus*, and *Labeo bata* were protein-rich**.** Amino acid analysis revealed that most species were rich in essential amino acids, such as lysine and glutamic acid, and non-essential aspartic acid. Fatty acid composition revealed myristic and palmitic acids as dominant saturated fatty acids across species. Oleic acid was the most common MUFA, while docosahexaenoic acid (DHA, C22:6) consistently dominated the PUFA profile. Overall, the fish species exhibit valuable nutritional properties, offering rich sources of essential amino acids and beneficial fatty acids, with notable variation based on species-specific metabolism and habitat conditions.

5.1.5.9. Microplastics

Microplastic contamination in the Damodar River is an emerging environmental issue, with higher concentrations found near industrial and urban areas, such as Durgapur, Sadarghat, and Gorchumuk. Microplastics accumulate more in slow-moving water near discharge points, with 31% fragments, 25% beads, and 12% fibers observed. In water samples, fragments and fibers were dominant, especially at Ramgarh, while beads were absent. In sediments, fragments were the most common type, peaking at Ramgarh and Piparwar, followed by fibers and foams. Beads were rare, appearing only at a few locations like Chandrapura. Overall, fragments are the primary pollutant type, and contamination peaks during the monsoon and in areas with industrial impacts.

5.1.5.10. Heavy metal contamination

Heavy metal analysis of the Damodar River showed elevated levels of Cr (> 0.003 mg/L) and Pb (> 0.01 mg/L) in water, exceeding permissible limits during monsoon and pre-monsoon. Sediment samples had high As (0.138 ± 0.023 to 13.815 ± 1.798 µg/g.) and Cd (0.01 to 0.6634 ± 0.097 µg/g), with arsenic notably above safe levels. Fish samples accumulated metals like Cd, Cr, and As, with *Ailia coila* and *N. notopterus* showing highest concentrations. However, all fish samples remained within FAO limits for human consumption, though continued monitoring is essential.

5.1.5.11. Coliform contamination

The MPN index of coliform bacteria in the Damodar River showed seasonal variation, peaking during the monsoon with Sardar Ghat recording the highest (240 MPN), followed by other sites at 210 MPN. Pre-monsoon levels were also high at Durgapur and Sardar Ghat (170 MPN), indicating persistent contamination. Post-monsoon saw mixed results, a notable drop at Durgapur and Sardar Ghat (14 MPN), but continued high levels at Piparwar and Ranighat (170 MPN), highlighting localised pollution sources.

5.1.5.12. Bisphenol A contamination

The analysis of eBPA (environmental Bisphenol A) in the Damodar River reveals increasing contamination from upper catchment areas (Ramgarh, Panchet Dam) to lower industrial zones (Burnpur, Nejia, Durgapur). Concentrations ranged from 241.67 to 474.58 ng/L, with the highest levels near industrial and urban centres due to plastic waste and industrial effluents. This pattern underscores the impact of anthropogenic activities, with BPA levels posing ecological and health risks. Urgent interventions, such as wastewater treatment upgrades and stricter pollution control measures, are needed to mitigate the impact of this endocrine disruptor.

5.1.5.13. Carbon sequestration potential

Dissolved Organic Carbon (DOC) in the Damodar River showed seasonal variation, with highest levels at Garchumuk (25.64 mg/L) and Panchet Dam (23.47 mg/L) during pre- and post-monsoon (Fig.101). Monsoon rains diluted DOC, especially at Phusro and Durgapur. Sediment carbon was highest at Raniganj (34.42 mg C/ha) and Durgapur (29.61 mg C/ha), while Ramgarh (3.35 mg C/ha) and Chandrapura (4.34 mg C/ha) had the lowest. Burnpur's tributary sediment held 6.6 times more carbon than its reference site, highlighting localized differences in carbon sequestration.

Figure 101: Habitat status of different sampling site at Damodar River

Figure 102: Field activities at different sampling sites of river Damodar

5.1.5.14. Conclusion

The Damodar River is under considerable ecological pressure due to industrial pollution, seasonal runoff, and urban waste. Significant seasonal and site-specific variation in water quality was noted, with higher pollution and temperature during pre- and post-monsoon, and improved conditions during the monsoon due to dilution. Key issues include low dissolved oxygen, high turbidity, and elevated nutrient and pollutant levels, especially near industrial zones (Piparwar and Ramgarh). Sediment texture was sand-dominated across all seasons, with a slight rise in silt and clay during the monsoon due to erosion. Seasonally, the highest fish diversity was recorded in Ramgarh and Durgapur sites with the post-monsoon period (41%), followed by pre-monsoon (31%) and monsoon (28%), reflecting better ecological stability and nutrient availability after rainfall. Microplastic contamination in the Damodar River is an emerging environmental issue, with higher concentrations near industrial and urban areas like Durgapur, Sadarghat, and Gorchumuk. Heavy metal analysis of the Damodar River showed elevated levels of Cr and Pb in water samples, exceeding permissible limits during monsoon and pre-monsoon. MPN index of coliform bacteria in the Damodar River revealed continued high levels at Piparwar and Raniganj, highlighting localized pollution sources. BPA levels showed increasing contamination in Ramgarh and Panchet Dam to lower industrial zones (Burnpur, Mejia, and Durgapur). An interesting fact was observed in Burnpur's tributary sediment as it showed 6.6 times more carbon sequestration potential than its reference site, highlighting localized differences in carbon sequestration. In conclusion, while the River Damodar supports diverse biological communities and fisheries, the decline in water quality and the rise of contaminants such as microplastics, coliforms, heavy metals, and BPA necessitate urgent management and conservation efforts.

5.1.6. GANDAK RIVER

The Gandak River, a vital tributary of the Ganga, rises in the trans-Himalayan area of Tibet and flows through Nepal before entering the state of Bihar in India. It spans an estimated length of 630 km before converging with the Ganga in Hajipur. The river is recognized for its dynamic hydrology, rapid flow, and sediment-laden flows. It delivers vital ecological services to millions of people in two nations, especially via fisheries, agriculture, and household water provision. The biological richness is seen in the varied aquatic life it sustains, including several vulnerable and rare fish species. Nevertheless, human-induced stressors, such as habitat modification, sewage and plastic pollution, overfishing, and dam construction, have progressively disrupted its biological equilibrium.

5.1.6.1. Study area

Thorough seasonal field surveys were conducted during the pre-monsoon (April–May), monsoon (July–August), and post-monsoon (October–November) intervals. Five representative stations were selected based on hydrological variety and fishing activity. The stations included Anandpur Ghat (Sonepur), Mahadev Ghat, Rewa Ghat (Haranbadha), Dak Bangla Ghat, and Dumaria Ghat (Fig. 103). The research area extended over 221 kilometers of the river. Sampling occurred at several cross-sectional locations, including riverbanks and midstream, between 7:30 AM and 9:30 AM. Triplicate water and biological samples were obtained using conventional APHA (2005) techniques, assuring temporal and geographical representation.

Figure 103: GIS map of river Gandak

5.1.6.2. Water Quality

The river's water quality displayed significant seasonal variation, influenced mainly by monsoonal rainfall and upstream discharges. During the pre-monsoon period, relatively low water levels were observed, with depths ranging between 0.64 meters and 2.38 meters. In contrast, monsoonal inflow drastically raised water levels, with depths reaching 12.5 meters in some sections. Temperature followed a seasonal gradient, increasing from 21.8°C in the pre-monsoon to over 30°C in the monsoon. Transparency values, which indicate water clarity, declined sharply during the monsoon due to silt-laden runoff, reducing light penetration and primary productivity.

The pH remained neutral to slightly alkaline, with higher values during the monsoon (maximum of 8.67 at Dak Bangla Ghat). Dissolved oxygen (DO), a crucial parameter for aquatic life, showed a decline (6 mg/L) at Mahadev Ghat trend during the monsoon, likely due to higher organic matter load and reduced mixing. Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were significantly higher (5.8 mg/L and 80 mg/L, respectively) at Anandpur ghat in the pre-monsoon period, indicating the presence of organic pollutants that became diluted during the rainy season. Total Suspended Solids (TSS) 0.06 g/L at Dak banglow ghat to 0.196 g/L at Anandpur ghat, Total Dissolved Solids (TDS) at Dak banglow ghat (1.552 g/L), followed by Rewa ghat (0.976 g/L), and turbidity peaked during monsoon, indicating elevated sediment input and potential pollutant loading. Conductivity and salinity values also decreased during the monsoon due to dilution from freshwater influx. Collectively, these variations underscore the impact of seasonal hydrology on river water chemistry and its implications for aquatic organisms.

5.1.6.3. Plankton and Periphyton Diversity

Plankton, the base of the aquatic food chain, exhibited marked seasonal dynamics. The pre-monsoon season recorded the highest plankton productivity and diversity, with Chlorophyceae dominating (46,840 cells/L), followed by Coscinodiscophyceae (17,920 cells/L) and Bacillariophyceae (6,960 cells/L). Zygnematophyceae (5,760 cells/L), Cyanophyceae (3,960 cells/l), and Mediophyceae (520 cells/L), attributed to stable temperature, moderate flow, and nutrient availability. Dominant phytoplankton groups included Chlorophyceae, Bacillariophyceae, and Coscinodiscophyceae. Maximum cell densities were observed at Dak Bangla Ghat, with *Actinastrum* sp. reaching up to 37,800 cells/L. During the monsoon, plankton populations declined due to high turbidity and nutrient dilution. However, some resilient taxa, such as Bacillariophyceae and *Spirogyra* sp., persisted. The post-monsoon period showed signs of recovery, especially in downstream locations. These patterns suggest a strong correlation between the flow regime and plankton community structure. Periphyton communities, composed of algae and microorganisms attached to submerged surfaces, varied significantly across stations and seasons. Zygnematophyceae were the most abundant, especially at Anandpur Ghat (50,400 cells/cm²), reflecting favorable conditions such as nutrient enrichment and slow water flow. Chlorophyceae showed substantial presence at Mahadev and Dumaria Ghats, while Bacillariophyceae remained consistently distributed, adapting to a wide range of ecological conditions. Cyanophyceae, including *Microcystis* and *Synechocystis*, were localized but notable, especially at Rewa and Dak Bangla Ghats, suggesting episodic eutrophication. The observed patterns reflect the influence of substrate type, nutrient loading, and hydrodynamics on periphyton productivity.

5.1.6.4. Benthic Diversity

The benthic macroinvertebrate community was primarily composed of molluscs, with Viviparidae being the dominant family, accounting for over 42% of the total benthic fauna. During the pre-monsoon, *Filopaludina bengalensis* was dominant (87 ind./m²), while *Idiopoma dissimilis* was less abundant (22 ind./m²). Monsoon brought a surge in benthic abundance, with *Indoplanorbis exustus* peaking at 119 ind./m² and *Idiopoma dissimilis* rising sharply to 97 ind./m². Post-monsoon, *Idiopoma dissimilis* remained high at 78 ind./m², while *F. bengalensis* declined further to 17 ind./m², indicating apparent seasonal shifts in species composition (Fig. 104).

Figure 104: Benthic community represented in sampling sites of the Gandak River

Planorobidae, Bithyniidae, Ampullariidae, and Lymnaeidae followed in abundance. The benthic community structure indicates a moderately healthy sedimentary environment capable of supporting detritus processing and secondary productivity. Seasonal variations, especially during the monsoon, affected benthic density due to sediment scouring and resuspension.

5.1.6.5. Fish Diversity and Abundance

An ichthyofaunal assessment revealed a total of 62 finfish species from various ecological communities. Dominant species included *Ailia colia, Amblyphryongodon mola, Wallago attu, Sperata seenghala, Labeo rohita, Cirrhinus mrigala,* and *Channa striata*. Notably, endangered species such as *Ompok pabda* and *Bagarius bagarius* were recorded, reflecting the ecological richness and conservation value of the river (Fig. 105).

Figure 105: Fish community represented in sampling sites of the Gandak River

The post-monsoon season exhibited the highest species richness and abundance, aligning with breeding migration and improved habitat connectivity. Fish were sampled using a combination of experimental gill nets, cast nets, and trap nets. Catch per unit effort (CPUE) data suggested higher productivity during the dry season when water levels receded, concentrating fish populations. Species composition varied with habitat type, reflecting the mosaic of niches within the river system.

5.1.6.6. Craft and Gear

Fishing crafts observed along the Gandak River were primarily traditional plank-built wooden boats and dugouts, operated manually or with small motors. Gears used included gill nets, seine nets, drag nets, cast nets, and various traps. The choice of gear depended on flow conditions, target species, and local knowledge. Seasonal shifts in fishing effort were evident, with peak activity occurring in the post-monsoon period due to favourable catch conditions. The dependence on artisanal fishing reflects both the cultural and economic reliance of local communities on riverine resources (Fig. 106).

Figure 106: Gears are represented (drag net, traps, cast net, gill nets, etc.) in the sampling sites of the Gandak River

5.1.6.7. Nutrient Profiling of Fish

Nutritional analysis of captured fish, including small indigenous species (SIFs), revealed high levels of protein, essential amino acids, and omega-3 fatty acids. Fish such as *Crossocheilus latius*. Exhibited especially valuable nutritional profiles, making them critical components of food security for local communities. The study reaffirmed the importance of conserving native fish biodiversity not only for ecological balance but also for human nutrition, especially among economically vulnerable groups (Fig. 107).

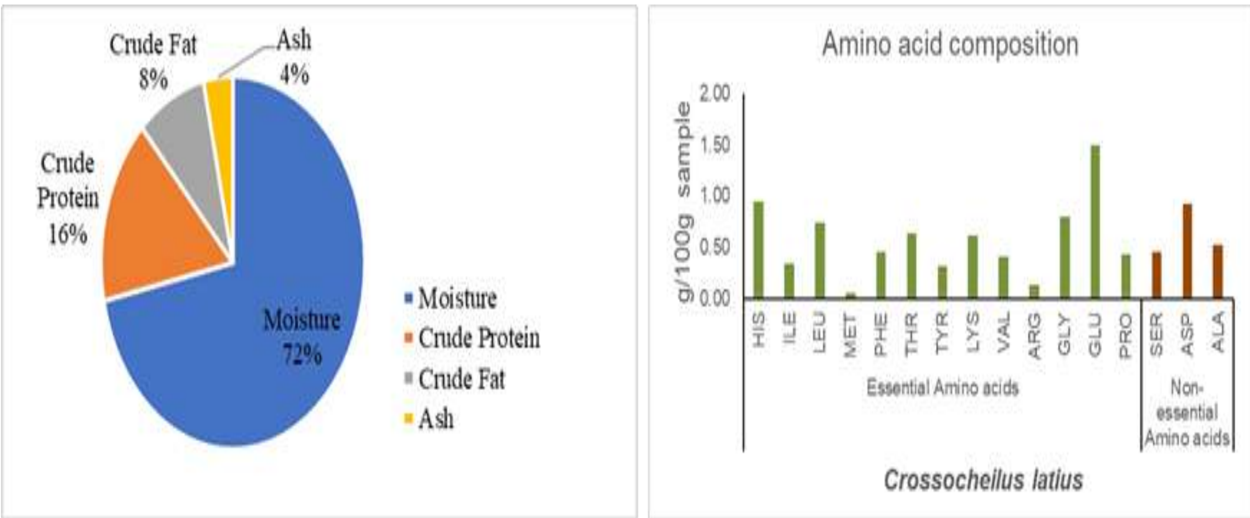


Figure 107: Variation in gross chemical composition and amino acid in C. latius collected from the River Gandak

5.1.6.8. Microplastic Contamination

Microplastic analysis revealed the widespread presence of synthetic polymer particles in both water and sediments. Higher concentrations were observed during the pre-monsoon season due to accumulation from daily waste and lower flow. The dominant microplastic types included polyethylene and polypropylene, confirmed through fluorescence microscopy and FT-IR spectroscopy. These were traced to familiar sources such as packaging materials, fishing gear, and urban plastic discharge. Microplastics pose a long-term threat to aquatic life and require urgent intervention in waste management (Fig. 108).

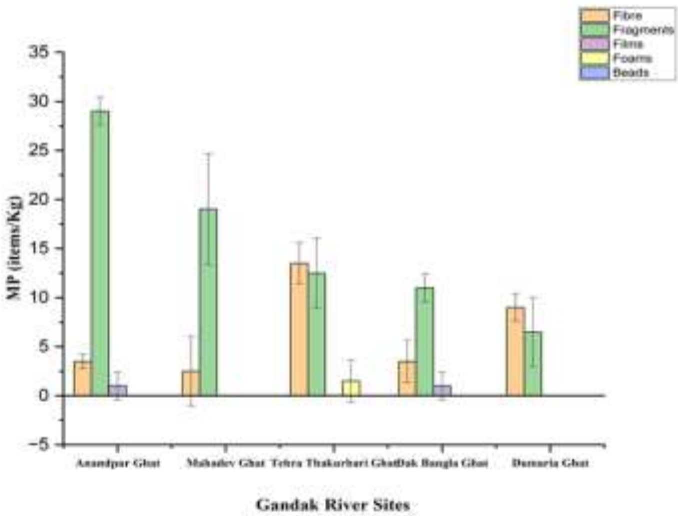


Figure 108: Types of microplastics in the water samples of the river Gandak

5.1.6.9. Heavy Metals and Emerging Pollutants

Heavy metal analysis across water, sediment, and fish samples identified elevated levels of chromium, lead, and arsenic. Water samples exceeded permissible BIS/USEPA limits for chromium and lead, particularly during the monsoon season. Sediments near Anandpur Ghat showed arsenic levels above safety thresholds, attributed to untreated urban wastewater (Fig. 109). Fish tissue analysis confirmed bioaccumulation of heavy metals, although concentrations remained within FAO safe limits. *Eutropiichthys vacha* and *Ailia coilia* were found to accumulate the highest concentrations (Fig. 110). Environmental Bisphenol A (eBPA), an emerging pollutant of concern, was detected in surface water, with higher concentrations during the pre-monsoon period (26.64 ng/L), decreasing during the monsoon due to dilution (Fig. 111). These highlights growing industrial and pharmaceutical contamination in riverine systems.

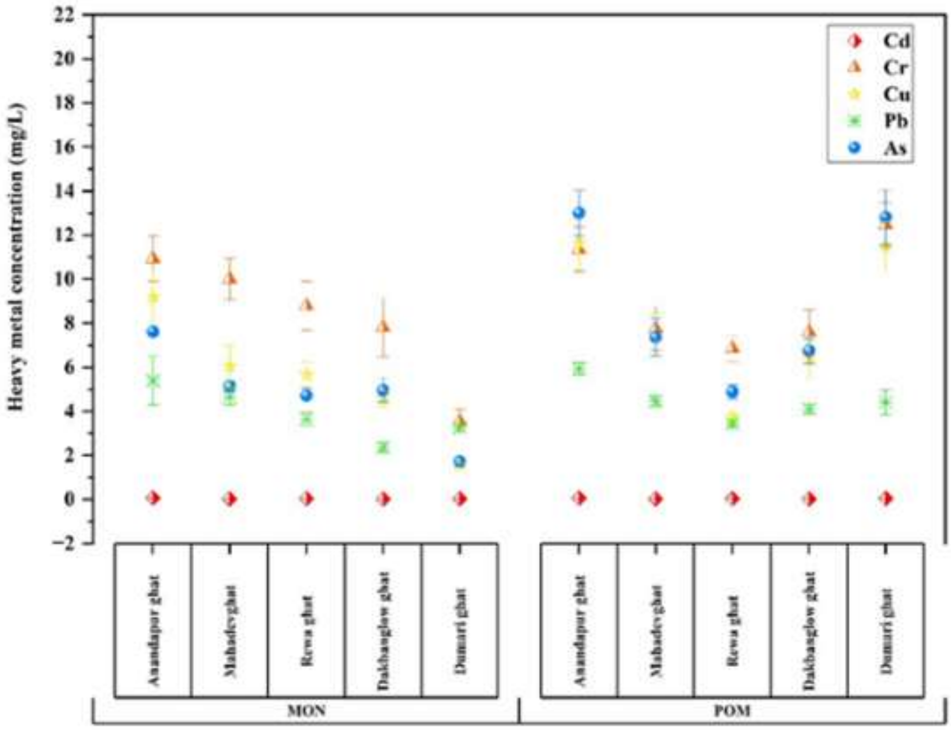


Figure 109: Seasonal variation of heavy metals in the waters of the river Gandak

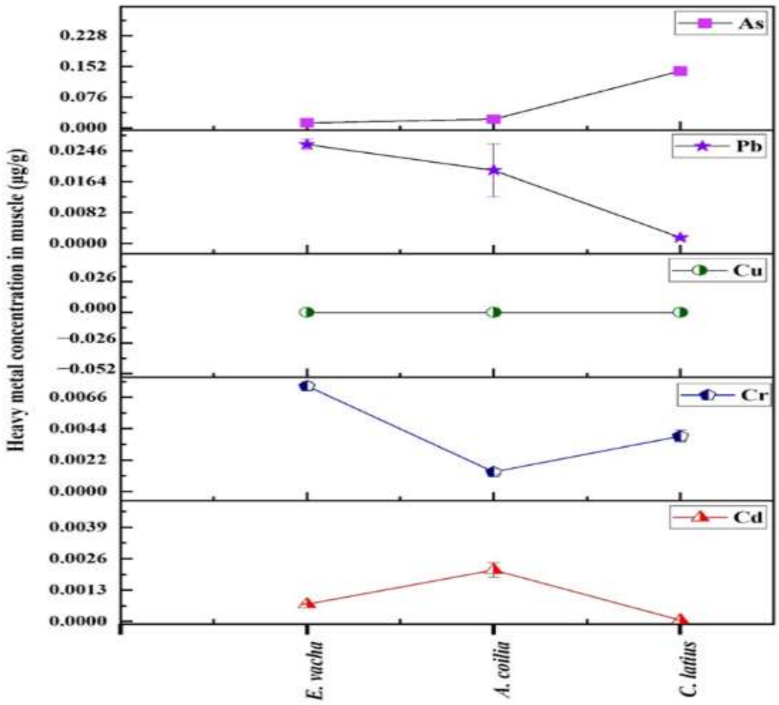


Figure 111: Seasonal variation of heavy metals in fishes of the river Gandak

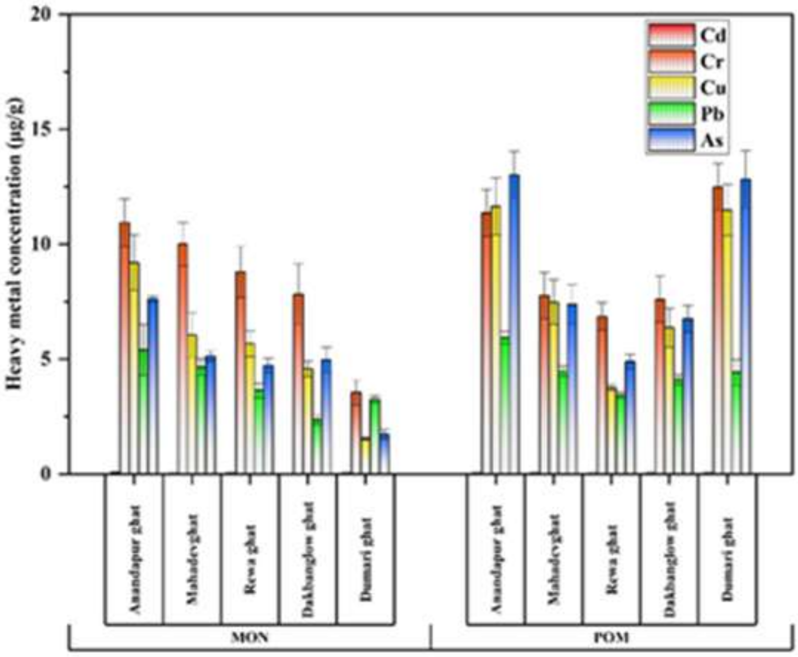


Figure 110: Seasonal variation of heavy metals in the sediments of the river Gandak

5.1.6.10. Conclusion

The comprehensive assessment of the Gandak River reveals a gradual yet significant ecological decline, characterized by reduced fish diversity, fluctuating water quality, and increasing anthropogenic pressures. Although 62 finfish species were recorded, seasonal variations and localized stressors indicate shifting species dominance, with post-monsoon seasons showing higher richness due to improved hydrological connectivity. Water quality parameters exhibited distinct seasonal fluctuations, with monsoonal dilution temporarily improving certain conditions, such as conductivity and turbidity. The bioaccumulation of heavy metals in fish tissues raises critical concerns regarding food safety and ecological health. Elevated eBPA levels further indicate the growing presence of emerging contaminants, linked to pharmaceutical and plastic waste. While efforts under the NMCG have initiated steps toward restoration, there is an urgent need for expanded and integrated river basin management strategies. Priorities must include strengthening effluent treatment, reducing microplastic and heavy metal sources, implementing river ranching, and empowering local communities through sustainable fisheries practices.

5.1.7. HALDI RIVER

In East Midnapur District, West Bengal, surveys were conducted at five sites along a 30.74 km stretch of the Haldi River to assess fish diversity, sediment quality, and hydrological conditions under tidal influence. Site selection considered fish diversity, pollution sources, accessibility, and migration patterns. The study aimed to: i) analyze fish population responses to environmental changes and assess biotic integrity, ii) promote awareness and conservation of Hilsa fish, and iii) evaluate crab fattening practices and explore profitability potential.

5.1.7.1. Study area

Five sampling sites were selected: Haldia Ferry Ghat, Balughata Ferry Ghat, Teropekhya Ferry Ghat, Teropara Locgate (TLG) and Narghat Rail Bridge (Fig. 112). The positional co-ordinates ranged between 22º0´29.706´´ N 88º0´61.214´´ E to 22º1´33.998´´ N 87º8´90.324´´ E.

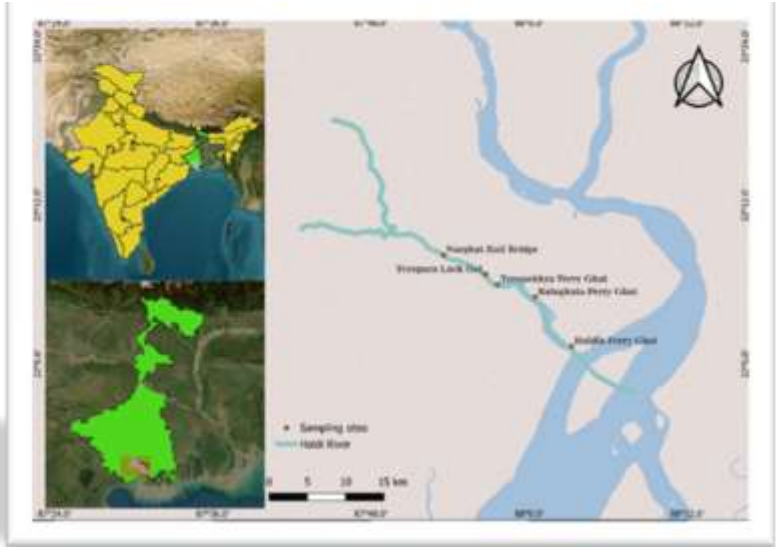


Figure 112: GIS map showing sampling points in the river Haldi

5.1.7.2. Water Quality

Hydrological Parameters: Haldia Ferry Ghat exhibits the highest water depths (up to 17.5 m), while TLG shows the lowest (3.2–4.6 m). Narghat and other sites showed moderate fluctuations. Water temperature: Peaks in pre-monsoon (up to 33 °C), lowest in post-monsoon (17–21 °C), with moderate monsoon values. Transparency was lowest in post-monsoon (1.9–3.1 cm), highest in pre-monsoon (up to 18.3 cm), and intermediate in monsoon. Specific Conductivity: Highest in pre-monsoon (up to 26320 µS/cm), moderate in post-monsoon, lowest during monsoon due to dilution. pH: Ranges from slightly acidic to alkaline (7.4–8.55), with the highest values in pre-monsoon. Dissolved Oxygen (DO): Highest in pre-monsoon (up to 7.2 mg/l), lowest in post-monsoon (as low as 4.8 mg/l), reflecting oxygen availability. Turbidity: Extremely high post-monsoon (up to 813 NTU), low pre-monsoon, moderately high during monsoon due to runoff. Hardness & Alkalinity: Hardness peaks in pre-monsoon (up to 1800 mg/l), alkalinity is highest post-monsoon, and both decline in monsoon. Salinity & Chlorinity: Highest in post and pre-monsoon, sharply decline during monsoon due to rain-induced dilution. BOD & COD: Both peak in pre-monsoon (COD up to 588 mg/l), suggesting higher organic load, lowest in monsoon. Solids (TS, TDS, TSS): Highest in pre-monsoon (TS up to 27.48 g/l), lowest in monsoon, reflecting dilution. Nutrients: Phosphorus and nitrogen are highest post-monsoon, lowest in monsoon. Silicate peaks in the post-monsoon and monsoon. Chlorophyll: Highest monsoon (up to 97 mg/m³ at Teropekhya), lowest pre-monsoon, variable post-monsoon. Heavy Metals in Water: Cr occasionally exceeds permissible limits; others remain within safe levels, with seasonal fluctuations. Heavy Metals in Sediment: Highest contamination during pre-monsoon, especially at Narghat, with Cr, Pb, and Cu peaking.

5.1.7.3. Sediment Status

Sediment parameters showed marked seasonal and spatial variability. pH remained slightly alkaline pre- and post-monsoon, with monsoon values dropping due to freshwater influx. Conductivity peaked pre-monsoon at Haldia ferry ghat (3910 µS/cm) and dipped during monsoon, reflecting dilution. $CaCO_3$ content was highest at Teropekhya pre-monsoon (34%) and declined during monsoon, rebounding post-monsoon. Silt-clay increased during monsoon due to sediment input, especially at Haldia (21%), while sand dominated throughout. Total phosphate and nitrogen levels peaked pre-monsoon at Haldia and Teropekhya, decreased during the monsoon, and partly recovered post-monsoon, indicating a monsoonal influence on nutrient dynamics. Organic carbon rose significantly during monsoon (up to 0.74% at Teropekhya), indicating runoff-driven organic loading, and then declined post-monsoon but remained elevated.

5.1.7.4. Plankton and Periphyton status

The study recorded 11 groups of plankton, with Coscinodiscophyceae and Bacillariophyceae showing the highest abundance, likely due to turbid water favoring their growth. Zooplankton was dominated by Arthropoda, while Amoebazoa was least abundant. Phytoplankton density peaked in the pre-monsoon season due to higher salinity, light, and nutrient availability, while Cyanophyceae dominated during monsoon due to nutrient-rich runoff. Plankton density varied across locations, with TLG showing the maximum abundance and Teropekhya the minimum. Periphyton diversity included 7 groups, with Zygnematophyceae as the most dominant, particularly during monsoon due to high nutrient levels. Balughata showed (Fig. 113) significant periphyton density, especially of Zygnematophyceae and Cyanophyceae.

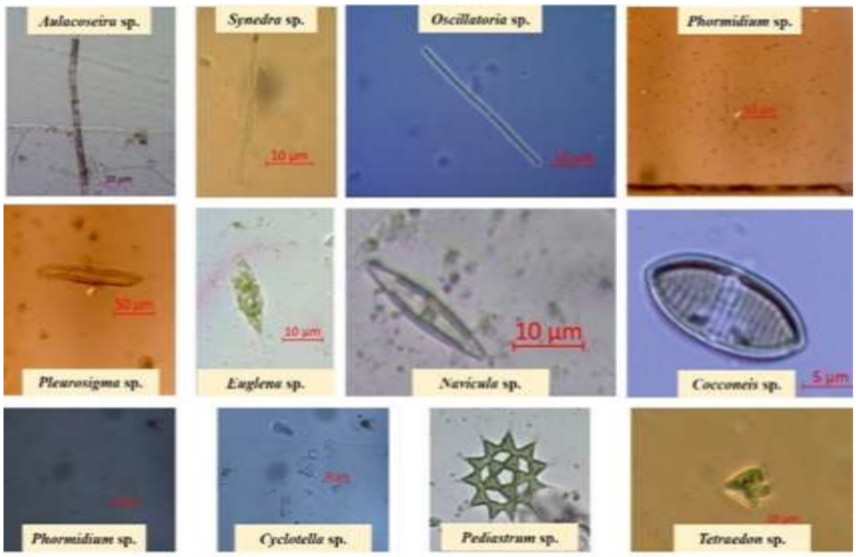


Figure 113: Plankton Diversity of river Haldi

5.1.7.5. Coliform Bacteria Status

The MPN index of coliform bacteria in the Haldia region varied seasonally, peaking during the monsoon, especially at Teropekhya Lock Gate (210 MPN). Although levels decreased post-monsoon, sites like Balughata and Teropekhya still showed high levels of contamination, indicating an ongoing microbial presence.

5.1.7.6. Finfish and Shellfish Status

The survey of the Haldi River recorded 39 finfish and 6 shellfish species, spanning 38 genera, 23 families, and 12 orders from five sites, with active fishing observed only at Haldia. *Tenualosa ilisha* (Hilsa) was notably present during winter and post-monsoon seasons. The river's daily tidal influx supports a rich diversity of euryhaline fish. Fish diversity was highest in the pre-monsoon season (21 species), followed by post-monsoon (19) and monsoon (9). Dominant species varied by season, with Hilsa most abundant pre-monsoon and *Mystus gulio* during monsoon (Fig. 114). The river and its canals serve as important nursery grounds for various shellfish, though their diversity remains understudied.

Figure 114: Finfish and Shellfish Diversity of river Haldi

The Haldi River supports both traditional (dinghis, country boats) and mechanized (motorized country boats) fishing crafts, used according to water depth and distance. Various fishing gears like gillnets, cast nets, drag nets, traps, and hook-and-line are employed to catch species such as Hilsa, mullets, catfishes, prawns, and crabs. Fishing activity and gear usage vary seasonally, with peak catches in the post-monsoon period and a decline during summer.

5.1.7.8. Microplastic Status

The highest concentration of microplastics (MPs) in water was recorded at TLG (41 items/L), while the lowest was at Narghat (14 items/L). Films were detected only at Haldia Ferry Ghat (4 items/L), and no beads or films were found at most sites. In sediment samples, fragments were the most abundant MP type, followed by fibers. TLG had the highest fragment (85 items/kg) and fiber (106 items/kg) concentrations. Teropekhya recorded the lowest concentrations of fragments (24 items/kg) and fibers (35 items/kg), but the highest for films (9 items/kg). TLG also showed high levels of fragments (79 items/kg), fibers (56 items/kg), and foams (9 items/kg). Beads were detected only at Narghat (1 particle/kg).

5.1.7.9. Nutrient Profiling of the Fishes

The study analyzed eleven fish species namely *Mystus gulio, Otolithoides pama, Setipinna phasa, Amblypharyngodon mola, Salmostoma phulo, Butis butis, Notopterus notopterus, Scatophagus argus, Glossogobius giuris, Anodontostoma chacunda,* and *Polynemus paradiseus*. Most of these fish were identified as protein-rich, making them good sources of lean meat, while a few species like *Setipinna phasa, A. mola,* and *Anodontostoma chacunda* were noted as oil-rich. In terms of amino acids, all species were abundant in essential amino acids, particularly glutamic acid and lysine, with leucine, threonine, and glycine also present in notable amounts depending on the species. Non-essential amino acids such as aspartic acid and alanine were consistently found across the species.

The fatty acid profiles revealed that myristic acid (C14:0) and palmitic acid (C16:0) were the dominant saturated fatty acids in almost all fish species. Among monounsaturated fatty acids (MUFAs), oleic acid (C18:1) and palmitoleic acid (C16:1) were the predominant species-specific variations. For polyunsaturated fatty acids (PUFAs), docosahexaenoic acid (C22:6) was generally dominant, except in *Anodontostoma chacunda*, where linolenic acid (C18:3) was the major PUFA.

Specifically, *Mystus gulio* and *Otolithoides pama* were protein-rich with dominant myristic and palmitic acids, and their MUFAs were oleic acid and palmitoleic acid, respectively. Setipinna phasa and Amblypharyngodon mola stood out as oil-rich fish, with palmitoleic acid as the primary MUFA and docosahexaenoic acid as the dominant PUFA. *Salmostoma phulo, Butis butis,* and *Notopterus notopterus* were protein-rich, with myristic and palmitic acids dominating saturated fatty acids, and oleic or palmitoleic acids prevalent among MUFAs. *Scatophagus argus* and *Glossogobius giuris* were protein-rich with glutamic acid and unique amino acids like threonine and glycine, respectively. Their fatty acid profiles featured myristic and palmitic acids as saturated fatty acids, with oleic acid as the dominant MUFA and docosahexaenoic acid as the dominant PUFA. *Anodontostoma chacunda* was oil-rich with a fatty acid profile dominated by myristic acid, palmitic acid, palmitoleic acid, and linolenic acid as the main PUFA. *Polynemus paradiseus*, like most species, was protein-rich and had myristic and palmitic acids as saturated fatty acids, with oleic acid and docosahexaenoic acid as the dominant MUFA and PUFA, respectively. Overall, the nutrient profiling indicates that the fish species from the Haldi River provide valuable nutritional benefits through their rich protein content and diverse fatty acid profiles, with potential importance for human dietary needs.

Figure 115: Multiple Field Activities at the river Haldi

5.1.7.10. Conclusion

The thorough evaluation of the Haldi River indicates that eutrophication is a growing issue due to increased nutrient concentrations, plankton blooms, and oxygen depletion throughout the pre-monsoon and post-monsoon seasons. Estuarine resilience is demonstrated by 31 number of commercially important fish species, although microbial pollution, heavy metals, and microplastics progressively jeopardize this equilibrium (Fig. 115). Benthic health is adversely affected near urban-industrial areas due to sediment-associated pollutants. The river serves as an essential nursery for fish, especially for euryhaline species such as Hilsa, requiring seasonal and spatial fishing limitations. In the absence of enhanced sewage treatment, industrial regulation, and plastic waste management, the Haldi River faces ecological degradation and the potential collapse of its fisheries. It is strongly advised that the implementation of biomonitoring programs utilizing phytoplankton and periphyton as ecological indicators may improve river health. The regulation of industrial and domestic effluents, particularly during the pre- and post-monsoon periods, may prove effective. Enhancing riparian buffer zones to mitigate nutrient and plastic runoff can be efficacious. Promotion of sustainable fishing techniques, including seasonal prohibitions and gear limits, is essential. Implementing extensive awareness campaigns is vital to mitigate plastic and microbial pollution.

5.1.8. ICHAMATI RIVER

The Ichamati River, a transboundary river that flows through India and Bangladesh, is an ecologically rich waterway that supports a diverse array of aquatic and riparian life. Originating from the Mathabhanga River, it meanders through the districts of North 24 Parganas and Nadia in West Bengal before entering Bangladesh. The Ichamati plays a critical ecological role in sustaining regional biodiversity, especially in the lower Gangetic delta.

5.1.8.1. Study area

Six sampling sites were selected, covering about 216 km along the lower part of the Ichamati River. The positional coordinates ranged from N 22°.675191, E 88°.912091 to N 25°33'46.46", E 8356'14.64. To obtain a representative picture of river habitats and fish availability, the sampling sites were selected based on fish abundance, confluence points, pollution discharge points, and varying substrates, and to estimate the possible impact of environmental flow on both downstream and upstream areas (Fig. 116).

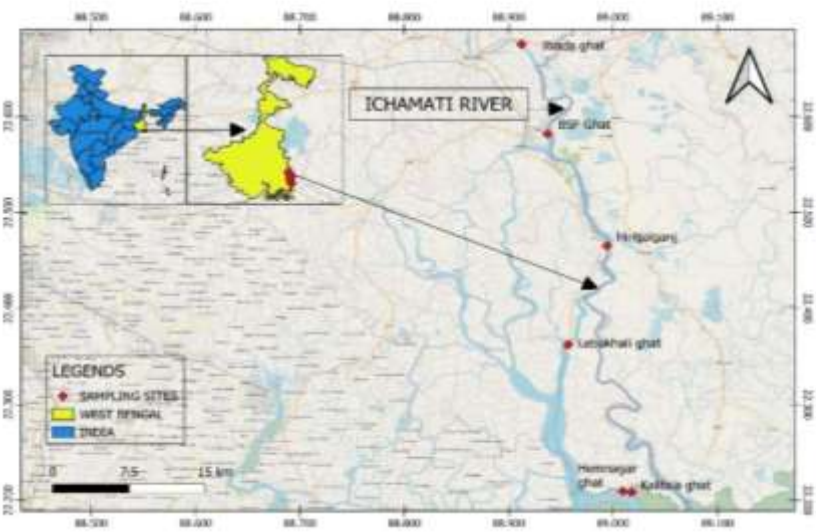


Figure 116: GIS map showing sampling points in river Ichamati

5.1.8.2. Habitat status

The Ichamati River features a sandy clay to muddy substrate and is influenced by strong tidal effects. Urbanization, settlements, and ferry services are present along its banks, but no agricultural activity is observed. Halophytic and mangrove vegetation are found in several sites. The river faces challenges such as domestic and industrial pollution, illegal land occupation, and heavy siltation (Fig. 117).

Figure 117: Photographs of the sampling sites of River Ichmati

5.1.8.3. Fin Fish and Shell Fish Diversity in Ichamati River

Ichamati River supports a diverse fish community across pre-monsoon, monsoon, and post-monsoon periods. A total of 51 fish species was found in which 28 finfish species were recorded during the pre-monsoon, spanning 12 orders and 20 families. Prominent families included Gobiidae (12.5%), Sciaenidae (10.7%), Mugilidae (8.9%), and Bagridae (7.1%). Additionally, nine shrimp and prawn species from the families Palaemonidae and Penaeidae were identified, including *Parapenaeopsis sculptilis* and *Macrobrachium rosenbergii*. Maximum diversity was recorded at Hemnagar, followed by Lebukhali and Itinda Ghat. In the monsoon, diversity increased to over 35 species, indicating high ecological richness. Dominant species included *Planiliza parsia* (86 individuals), *Palaemon styliferus* (32), and *Parapenaeopsis sculptilis* (32). Catfish (Ariidae, Bagridae), gobies (Gobiidae), and estuarine species (e.g., *Scatophagus argus*) were widespread, while some rare species like *Polynemus paradiseus* appeared in low numbers. During post-monsoon, 14 finfish species were identified from 9 orders and 11 families, including Synbranchidae, Polynemidae, and Paralichthyidae. Additionally, 12 shellfish species from the Palaemonidae and Penaeidae families were observed. Hemnagar again showed the highest diversity, followed by Lebukhali and Taki (Fig. 119).

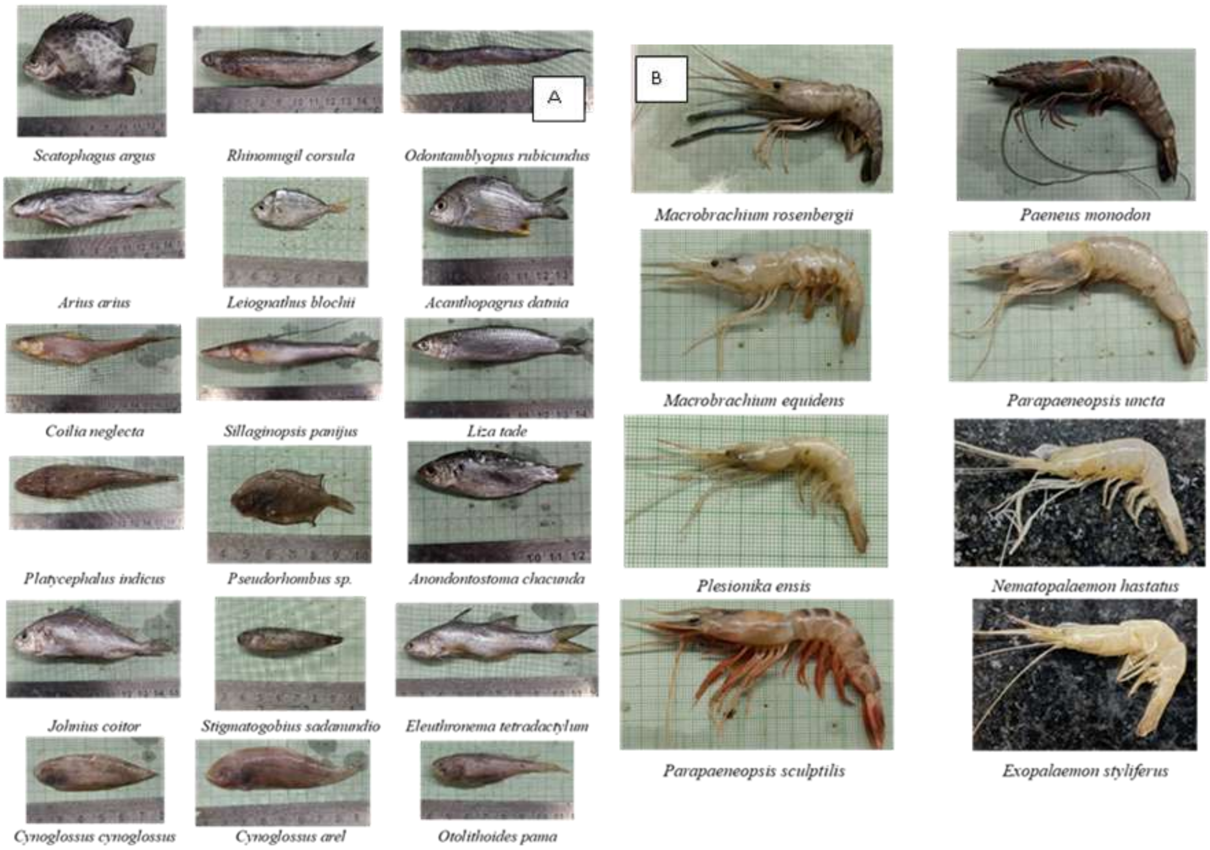


Figure 118: Photographs of Finfish Diversity of Ichamati River

5.1.8.4. Water quality

Seasonal water quality data from six Ichamati River stations show marked spatial and temporal variation. In Pre-monsoon and post-monsoon, the highest and lowest water temperatures (33 °C & 19.4°C) occur at Itinda, and salinity peaks at Hingalgunj (30.24 ppt) during pre-monsoon. Lebukhali shows the highest DO (8.4 ppm), with elevated BOD and COD at Lebukhali (9.6 mg/L) and Kalitala (3840 mg/L), indicating a heavy pollution load in this region. Hemnagar records maximum hardness (TH: 6700 ppm, Mg: 1527 ppm). Monsoon brings increased depth and velocity, especially at Hemnagar and Lebukhali, ranging from 7.5-15.3 m and 1.62-1.93m/s respectively, with salinity rising from 0.64 ppt to 8.66 ppt downstream. Kalitala shows high COD (2550 ppm), and Lebukhali records peak productivity (GPP/NPP: 840/720 $mgC/m^3/h$). Post-monsoon, DO reaches 10 ppm, and Kalitala again shows high COD (3840 ppm) and hardness (TH: 7400 ppm). Itinda has highest silicate (15.83 ppm), while Lebukhali leads in Community Respiration (300 $mgC/m^3/h$). Hemnagar and Lebukhali consistently show high salinity, hardness, and pollution indicators, while Itinda and Kalitala reflect fresher, yet nutrient-variable conditions, highlighting the need for site-specific water management.

5.1.8.5. Heavy metal Contamination

Heavy metal analysis in the Ichamati River reveals seasonal and spatial variation in water, sediment, and fish samples. In water, concentrations were within safe limits, except for chromium (Cr > 0.005 mg/L), which exceeded BIS and USEPA standards. Post-monsoon showed wide variations in copper levels, while the monsoon had elevated levels at Taki BSF due to runoff and effluent discharge. In sediments, Cr (up to 55.46 µg/g) and As (up to 16.29 µg/g) exceeded USEPA/Canadian guidelines, especially in monsoon, indicating accumulation. Post-monsoon copper and cadmium variation was highest between Hingalganj and Lebukhali. In fish muscle, Cd, Cr, Cu, Pb, and As were detected, with Cu (up to 94.76 µg/g in *N. caelatus*) and Pb (up to 2.67 µg/g in *T. lepturus*) exceeding FAO limits. Species like *S. argus* and *H. nehereus* showed high Cd, while *C. ramcarati* had the highest As. These findings suggest that bioaccumulation is influenced by species behaviour and habitat, highlighting the need for regular monitoring to mitigate ecological and public health risks.

5.1.8.6. BPA Analysis

The analysis of Environmental Bisphenol A (eBPA) concentrations across different sites shows that levels are relatively similar. Itinda Ghat has a BPA concentration of 350.75 µg/l, while BSF Ghat, Taki reports a slightly higher level at 370.25 µg/l. Lebukhali Ghat has a BPA concentration of 360.5 µg/l, and Hemnagar Ghat's level is 364.2 µg/l. Kalitala Gomti River shows a BPA concentration of 361.8 µg/l. Overall, the BPA concentrations across these sites are comparable, indicating similar levels of this chemical pollutant in the sampled locations

5.1.8.7. Sediment Quality Status

The sediment quality of River Ichamati exhibited distinct seasonal variations across key parameters. Sediment pH remained slightly to moderately alkaline year-round, with higher values during the pre- and post-monsoon seasons. Specific conductivity peaked in the pre-monsoon (up to 9430 µS/cm at Kalitala) due to evaporation, and declined during monsoon from rainfall dilution. Sediment texture was dominated by sand, although silt and clay increased post-monsoon. Calcium carbonate showed a post-monsoon rise, especially at Itinda (21.5%). Available and total phosphorus levels were highest during pre- and post-monsoon, ranging 0.44 mg/100g to 6.7 mg/100g and from 3.29 mg/100 g to 31.13 mg/100 g, respectively, indicating nutrient build-up. Available nitrogen declined sharply during monsoon, while total nitrogen peaked post-monsoon at Kalitala (200 mg/100g). Organic carbon was highest at Itinda during the pre-monsoon (1.44%) and dropped afterward. These patterns highlight the influence of seasonal hydrology on sediment chemistry. Overall, post-monsoon conditions favored nutrient accumulation due to reduced flow and sediment settling.

5.1.8.8. Plankton status

The Ichamati River exhibits a significant diversity of 12 plankton community, viz. Bacillariophyceae, Cyanophyceae, Mediophyceae, Coscinodiscophyceae, Noctilucophyceae, Xanthophyceae, Chlorophyceae, Zygnematophyceae, Euglenophyceae, Rotifera, Arthropoda, Ciliophora. In the pre-monsoon, Bacillariophyceae dominated phytoplankton, with *Fragilaria* (3,630 cells/L, 37.5%) and *Nitzschia* (380 cells/L, 25.6%) prevalent at Itinda. Zooplankton were led by Cyclopoids (930 ind/L, 13.4%) and *Polyarthra* (770 ind/L, 10.2%). The monsoon season saw a spike in Rotifera at Itinda, with 7,500 ind/L (31.4%), and an increase in phytoplankton, including *Coscinodiscus*, to 2,440 cells/L (18.5%). Post-monsoon, Bacillariophyceae peaked at Kalitala (4,160 cells/L, 28.3%), with *Bosmina* (640 ind/L) and *Daphnia* (520 ind/L) sustaining zooplankton diversity. These variations underscore the river's ecological responsiveness and the need for sustained monitoring (Fig. 120).

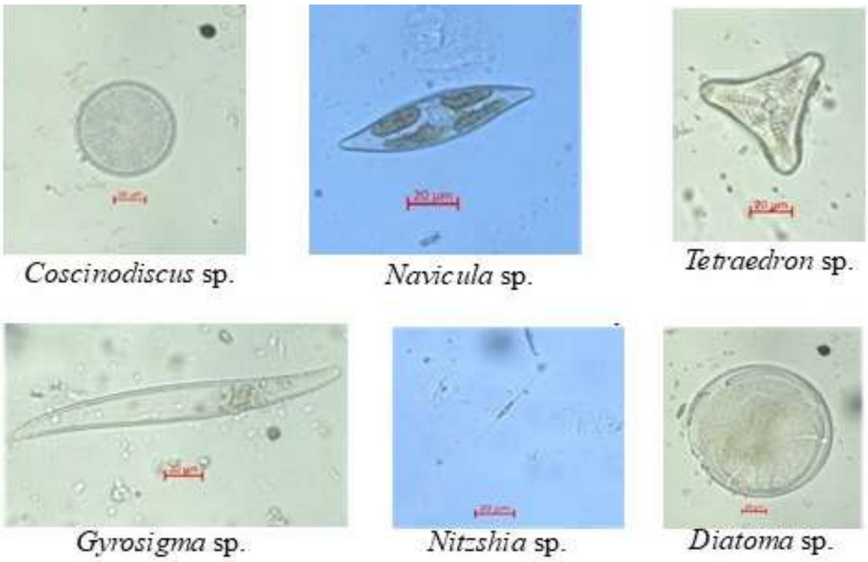


Figure 120: Plankton diversity of the Ichamati river

5.1.8.9. Coliform Bacteria

The coliform bacteria count in the Ichamati River, measured through the MPN index, exhibited marked seasonal and spatial variations. Monsoon season showed the highest contamination, with Itinda Ghat (150 MPN), followed by Hingalganj and Lebukhali (110 MPN each). In contrast, pre-monsoon levels were moderate, ranging from 25 to 48 MPN. Post-monsoon counts declined overall; however, sites like Lebukhali and Taki maintained elevated levels, suggesting persistent microbial pollution likely due to anthropogenic inputs or inadequate sanitation infrastructure.

5.1.8.10. Benthic Status of River Ichamati

The Ichamati River supports a rich benthic macrofaunal community, primarily dominated by molluscan families like Mytilidae (43%), Neritidae (24%), and Potamididae (20%), indicating a structured benthic ecosystem. Species such as *Byssogerdius striatulus* and *Nerita balteata* exhibited seasonal variations, with the highest densities occurring during the pre- and post-monsoon periods. *Byssogerdius striatulus* was most dominant at Itinda Ghat across seasons, while species like *Indothais sacellum* appeared only during the monsoon. Seasonal fluctuations in abundance reflect ecological adaptability and habitat specificity. Kalitala, Taki, and Itinda Ghat emerged as major benthic hotspots, while Hingalganj showed zero benthic presence in pre-monsoon (Fig. 121).

Figure 121: Benthic diversity of Ichamati River

5.1.8.11. Fishing craft and gear

Gill nets, drag nets, bag nets, purse seines, and scoop nets are among the few fishing methods used in Ichamati River. The river harbours a variety of fish and shellfish fauna and the number of fishing gears was observed to operate throughout the year. Information gathered from the local fishermen indicates that the peak fishing time extends from March to September, with maximum operation of bag nets. Modified drag nets (*Meen jal*) are mostly used for the seed collection of tiger Prawn. Gill nets and scoop nets are generally used for the fish and shrimp (Fig. 122).

Figure 122: Crafts and gears operated in Ichamati River

5.1.8.12. Microplastic Accumulation

The Ichamati River shows significant microplastic contamination, with the highest fragment concentration (45 items/L) at Hingalganj and the highest fiber concentration (32 items/L) at Hemnagar. Beads and foams were detected only at Lebukhali and Hingalganj, respectively. In sediments, Itinda Ghat recorded the highest fragment load (121 items/kg), while Hingalganj showed the highest fiber accumulation (72 items/kg). Films were mainly present at Lebukhali.

5.1.8.13. Nutrient Profiling of Fishes

Six fish species from the Ichamati River, namely *Cynoglossus arel, Mystus gulio, Acanthopagrus datnia, Arius arius, Otolithoides pama*, and *Mugil cephalus*, were analysed for their nutrient content. The study revealed that most species are protein-rich, except *Mystus gulio* and *Arius arius*, which are oil-rich. All species were found to be rich in essential amino acids, notably glutamic acid, lysine, and threonine, and the non-essential amino acid aspartic acid. In terms of fatty acids, oleic acid (MUFA) and docosahexaenoic acid (PUFA) were dominant across species, with myristic and palmitic acids leading among saturated fats.

5.1.8.14. Carbon Sequestration Potential

The Ichamati River exhibits varying carbon concentrations across its sites, with Itinda recording the highest levels of both DIC (57.89 mg/l) and DOC (85.24 mg/l), indicating strong carbon presence in water. In contrast, Kalitala and Hemnagar exhibited lower carbon concentrations, with dissolved organic carbon (DOC) absent in Kalitala. Sediment analysis across six tributary sites revealed Itinda as a major carbon sink (46.51 MgC/ha), followed by moderate sequestration in Lebukhali Ghat, Hemnagar, and Kalitala. BSF Taki and Hingalgunj had the lowest sequestration rates, while reference sites showed minimal carbon storage.

5.1.8.15. Conclusion

The Ichamati River demonstrates distinct seasonal patterns in fish diversity, with species richness peaking during the monsoon due to enhanced freshwater influx and nutrient availability. Pre-monsoon and post-monsoon periods showed moderate diversity, which might be influenced by tidal fluctuations and salinity variations. However, despite the ecological potential of the river to support 35 species, including key estuarine finfish and shellfish. The occasional presence of Hilsa (*Tenualosa ilisha*) in the lower stretches of the Ichamati and adjoining Indian Sundarbans estuaries reflects disrupted migratory patterns due to rising salinity, pollution, and habitat degradation. Elevated levels of pollutants such as BPA, heavy metals (Cr, Pb, As, Cu), and high COD/BOD values, especially at sites like Hemnagar, Kalitala, and Lebukhali, suggest a decline in ecosystem health. Additionally, bioaccumulation of toxic elements in fish muscle, widespread microplastic contamination, and persistent coliform presence indicate serious risks to both aquatic life and human consumers. This underscores the urgent need for integrated pollution control, habitat restoration, and sustainable fishery management to conserve Ichamati's biodiversity and secure the livelihoods dependent on it.

5.1.9. JALANGI RIVER

The Jalangi River, a tributary of the Padma, flows through the Murshidabad and Nadia districts of West Bengal, covering 250 km before joining the Bhagirathi River. The river supports a rich biodiversity, including ichthyofauna, plankton, and benthic organisms, while also playing a critical role in agriculture and fisheries. Historically significant for trade and cultural practices, the river now faces challenges from pollution, siltation, and urbanization. Efforts for conservation and sustainable management are imperative to restore its ecological balance and ensure the livelihoods of communities dependent on it.

5.1.9.1. Study area

The river stretch starting from the origin at Harirampur to the river mouth at Hulor ghat at Nabadwip, where it meets the Hooghly River later, is mapped using Google Earth Pro and QGIS and is depicted in Figure. 1. Samples were collected from Harirampur (24° 14' 48.012" N 88° 24' 47.016" E) (Site I), Islampur (24° 9' 2.754" N 88° 27' 45.738" E) (Site II), Malopara (24° 2' 3.6312" N 88° 29' 41.3952" E) (Site III) in Murshidabad district, while, Tehatta Ghat (23° 43' 48.5544" N 88° 31' 13.4004" E) (Site IV) and Jalangi Mouth, Nabadwip (23° 24' 39.276" N 88° 22' 50.61" E) (Site V) is in the Nadia district, West Bengal (Fig. 123).

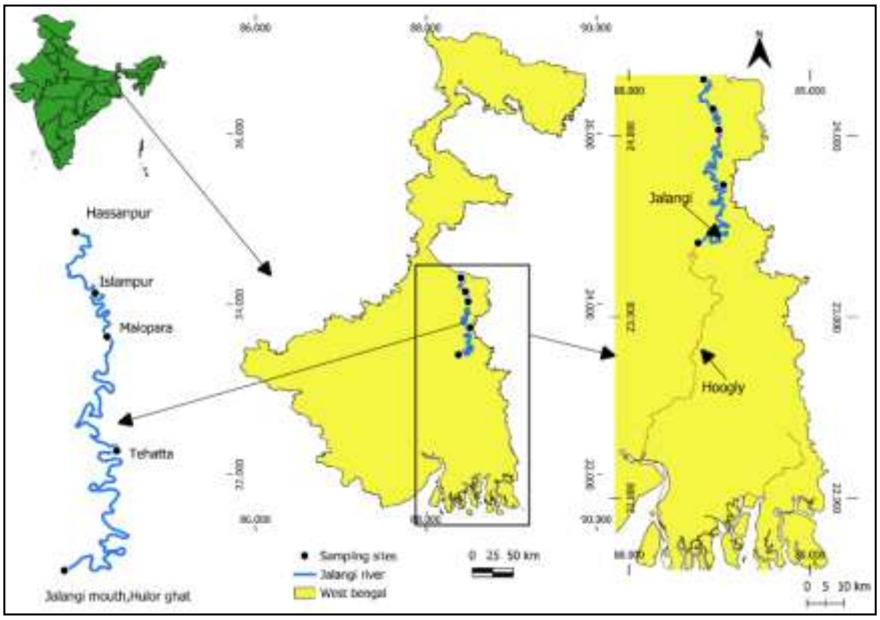


Figure 123: GIS Map of Jalangi River stretch from the origin, Harirampur, Murshidabad to the River mouth at Hulor ghat, Nabadwip, Nadia

5.1.9.2. Ichthyofaunal diversity

The survey recorded 35 fish species across 24 genera, 17 families, and 10 orders from four sites. Nabadwip (23 species) and Tehatta (22 species) were the most species-rich, likely due to their connection with the Ganga, followed by Islampur (10) and Malopara (9). Key families included Cyprinidae, Ambassidae, and Osphronemidae. The exotic species *Hypophthalmichthys molitrix* (Silver carp) accounted for 20% of the distribution. Monsoon had the highest diversity (38%), followed by pre-monsoon (34%) and post-monsoon (28%), reflecting favorable environmental conditions. Cypriniformes dominated, contributing 34% of the species, including notable fish such as *Labeo calbasu, Channa punctatus,* and *Wallago attu*, along with indigenous prawns (Fig. 124).

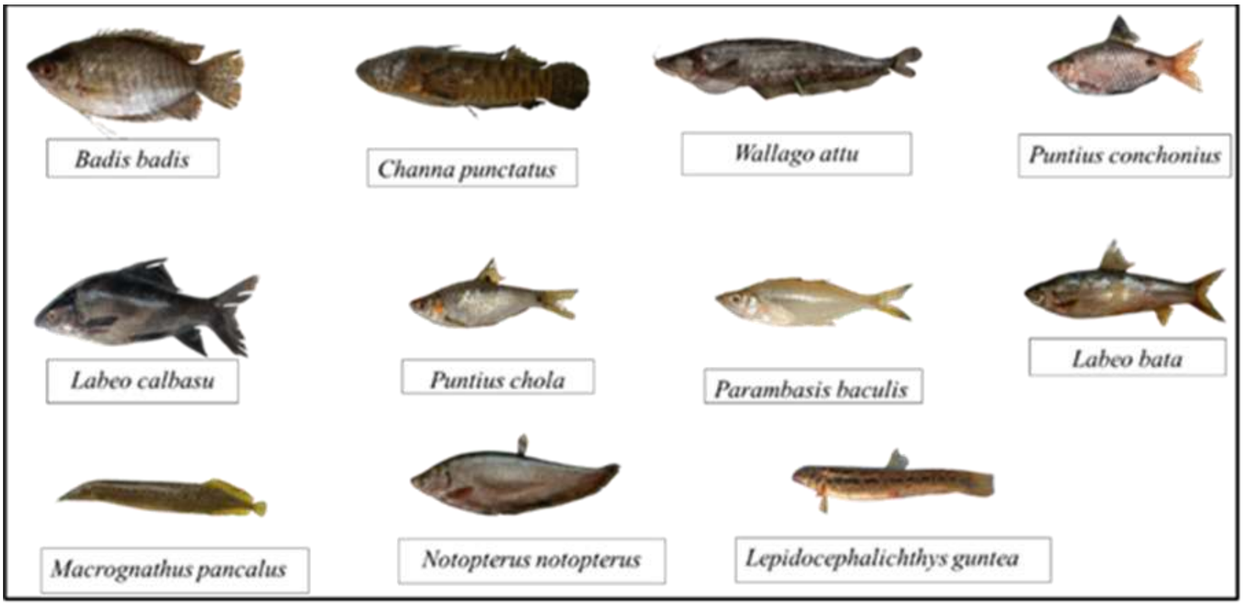


Figure 124: Fish diversity of Jalangi river

5.1.9.3. Fishing craft and gears

The fishing craft noticed during our study comprised traditional wooden and steel tin sheet boats (Fig. 125). Steel tin boats are mainly used for fishing during low water levels. This boat is only operated in shallow rivers. The wooden boat is large and operates throughout the year. The gears used for fish catch consisted of a pole and line, cast net, Charpata Jaal, Suti Jaal, Bessel Jaal, Chinese dip net, Gill net, and a mosquito net with mesh sizes ranging from 10 mm to 25 mm, along with spear fishing, light fishing, and box traps. There are no target fisheries in the river, but the catch mainly comprises Small Indigenous Fishes (SIFs) and weed fish species.

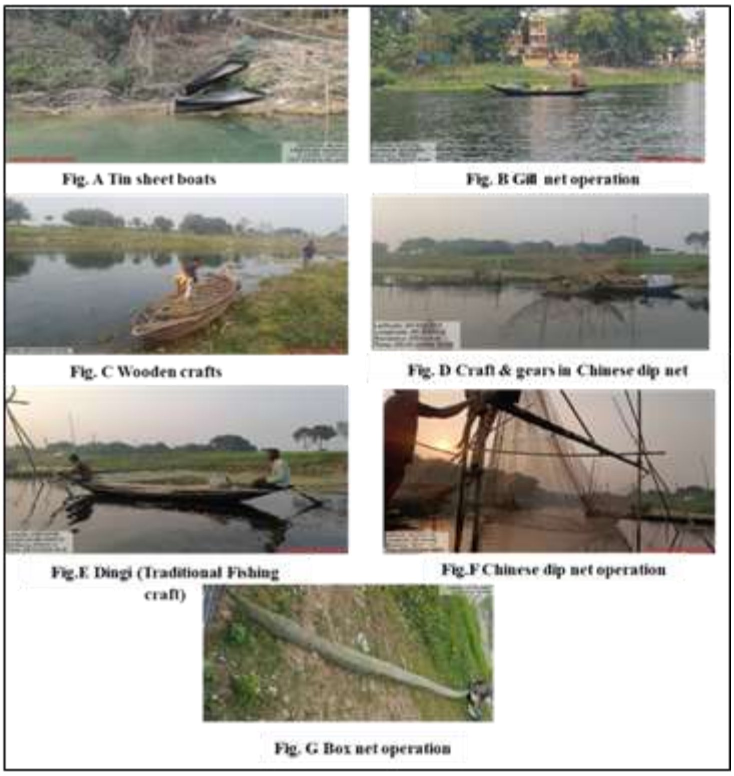


Figure 125: Crafts and gears operation observed at different sites of Jalangi river

5.1.9.4. Nutrient profiling

Nutrient profiling of four fish species from the Jalangi River, *Notopterus notopterus*, *Channa punctatus*, *Glossogobius guiris*, and *Mystus vittatus*, highlighted their distinct nutritional qualities. *N. notopterus* and *C. punctatus* were identified as protein-rich species, abundant in essential amino acids such as glutamic acid, lysine, and threonine, with palmitic acid and myristic acid as the dominant saturated fatty acids. Oleic acid emerged as the primary MUFA, and DHA (C22:6) was the leading PUFA, underscoring their value as nutritious meat sources. *G. guiris* also exhibited a similar amino acid and fatty acid profile, emphasizing its role as a source of lean meat. In contrast, *M. vittatus* was characterized as an oil-rich species, with significant levels of essential amino acids and linolenic acid (C18:2) as the dominant PUFA, along with palmitoleic acid as the primary MUFA. Collectively, these findings highlight the dietary significance of these species, providing a rich source of essential amino acids and beneficial fatty acids essential for human nutrition.

5.1.9.5. Water quality

During the monsoon season, water quality across five sites (Harirampur, Islampur, Malopara, Tehatta, and Nabadwip) showed significant variation, with air temperatures ranging from 33

°C to 39.2 °C and water temperatures between 31.2 °C and 32.1 °C. Nabadwip had the highest transparency (46.3 cm) and depth (7.7 m), while Islampur recorded the highest turbidity (580 NTU) and pH (7.95), indicating alkaline conditions. Dissolved oxygen levels ranged from 1.6 ppm (Tehatta) to 6 ppm (Islampur), and low conductivity (0.223–0.254 µS/cm) reflected freshwater conditions. Nutrient concentrations varied, with peak phosphate at Tehatta (0.5739 ppm), nitrogen at Malopara (0.2099 ppm), silicate at Islampur (10.6 ppm), and total solids at Nabadwip (2.74 ppm). In the post-monsoon season, sampling at Islampur, Malopara, Tehatta, and Nabadwip revealed cooler air temperatures (24.5–27.5 °C) and water temperatures (20.5–23.7°C), low water velocities (0.1–0.3 m/s), and depths ranging from 0.8 m to 5.2 m. Transparency improved (70–130 cm), turbidity dropped (0.89–4.52 NTU), and conductivity rose (342–548 µS/cm). The pH ranged from 6.9 to 7.51, with higher dissolved oxygen levels (11.2–13.2 ppm). Alkalinity and hardness levels increased, while total solids remained low (0.25–0.45 ppm). Nutrients showed higher silicate (18.5–36.17 ppm), phosphate (0.11–0.51 ppm), and BOD (2.2–8.8 ppm). Primary productivity data revealed that Gross Primary Productivity (GPP) peaked at 450 mgC/m³/h, Net Primary Productivity (NPP) ranged from 150–300 mgC/m³/h, and Community Respiration (CR) from 150–225 mgC/m³/h, with the second site being the most productive and efficient ecosystem.

5.1.9.6. Sediment status

Sediment characteristics across the study sites showed significant spatial and seasonal variations influenced by hydrology, salinity, and anthropogenic inputs. Sediment pH remained alkaline throughout, peaking at Islampur (9.29) during pre-monsoon and monsoon, while post-monsoon values slightly declined due to freshwater influx. Specific conductivity was highest at Jalangi mouth across all seasons, indicating saline influence, and lowest at Islampur, reflecting freshwater dominance. Calcium carbonate content varied widely, with Jalangi mouth recording the highest levels, especially post-monsoon (15%), suggesting intensified deposition. Sediment texture was sand-dominated, though silt and clay increased during monsoon, particularly at Tehatta Ghat (27%). Total phosphate and nitrogen levels fluctuated, with peak phosphorus at Malopara (36.16 mg/kg, pre-monsoon) and peak nitrogen at Tehatta Ghat (340 mg/kg, post-monsoon), influenced by runoff and sediment resuspension. Organic carbon increased sharply during monsoon (up to 2.54% at Tehatta Ghat), then declined post-monsoon. Available phosphorus was highest at Tehatta Ghat post-monsoon (4.32 mg/100g), highlighting it as a nutrient hotspot. In comparison, available nitrogen peaked at Tehatta Ghat pre-monsoon (42 mg/100g) and Jalangi mouth post-monsoon (36.4 mg/100g), indicating shifting nutrient dynamics linked to seasonal hydrological changes.

5.1.9.7. Plankton and periphyton community

Phytoplankton, zooplankton, and periphyton communities in the River Jalangi exhibited distinct spatial and seasonal variations driven by hydrological changes and nutrient dynamics. During the pre-monsoon, 36 plankton genera were identified (28 phytoplankton, 8 zooplankton), with highest abundance at Harirampur and dominance of *Spirogyra* sp. and Bacillariophyceae, especially at Nabadwip. Monsoon conditions led to a surge in Bacillariophyceae (peaking at Islampur), along with increased presence of Coscinodiscophyceae, Rotifera, and Chlorophyceae due to nutrient-rich runoff. Post-monsoon diversity was lower, with only 8 phytoplankton genera dominated by diatoms like *Melosira* sp. and *Fragilaria* sp., and cyanobacteria such as *Phormidium* sp. Zooplankton like *Brachionus* and *Keratella* thrived at Islampur during monsoon/post-monsoon, while and copepods were more abundant at Tehatta and Nabadwip. Periphyton analysis revealed 29 genera, with Bacillariophyceae, Ulvophyceae, and Cyanophyceae dominating, especially during the monsoon, when abundance peaked (up to 78,880 units/cm^2 at Nabadwip). Seasonal shifts in periphyton and plankton communities reflect the influence of flow conditions, nutrient input, and habitat characteristics, emphasizing the importance of continuous ecological monitoring.

5.1.9.8. Benthic diversity and abundance

The benthic community in the Jalangi River (Fig. 126) exhibited notable spatial and seasonal variation, comprising 11 species from six families, Viviparidae, Thiaridae, Lymnaeidae, Unionidae, Planorbidae, and Bithyniidae, reflecting a dynamic ecosystem influenced by hydrological changes. Viviparidae was the most dominant group (57.97%), with *Filopaludina bengalensis* being the most abundant species, peaking at 996 ind/m^2 in Nabadwip pre-monsoon and remaining dominant across seasons. Species like *Brotia costula*, *Melanoides tuberculata*, and *Idiopoma dissimilis* showed marked seasonal shifts, with Idiopoma peaking during monsoon (346 ind/m^2). Monsoon rains introduced new species such as *Parreysia shurtleffiana* and *Novaculina gangetica*, and favoured aquatic insects like *Baetis* sp. and Ranatra sp., though overall benthic abundance declined during this period. Post-monsoon, several species rebounded or newly appeared, such as *Gabbia orcula* (390 ind/m^2) and *Tarebia granifera* (260 ind/m²) while others declined or disappeared due to changing habitat conditions. Site-wise, Malopara had the highest overall abundance, peaking at 1342 ind/m² post-monsoon, while Tehatta showed complete loss of benthic organisms' post-monsoon. Islampur and Harirampur recorded no organism's pre-monsoon but saw increases post-monsoon, indicating seasonal recovery. These patterns underscore the influence of flow regime, habitat conditions, and nutrient inputs on benthic biodiversity and distribution.

Figure 126: Benthic diversity of Jalangi river

5.1.9.9. Macrophytes

Macrophyte diversity in the Jalangi River exhibited clear spatial and seasonal variation, strongly influenced by hydrological conditions and nutrient availability. During the pre-monsoon period, five species were recorded across five sites, with *Pontederia crassipes* being dominant and Nabadwip showing the highest macrophyte diversity and coverage. In the monsoon season, Tehatta displayed the richest diversity with abundant *Hydrilla verticillata*, *Pistia stratiotes*, *Alternanthera philoxeroides*, and *Wolfia*, while Nabadwip was dominated by floating species like *Lemna* minor and *Ipomoea*. Malopara had sparse macrophyte cover, and Islampur was primarily colonized by *Pontederia crassipes* and Vallisneria spiralis. Post-monsoon observations revealed Tehatta again with the highest species richness, including *Potamogeton* sp., while Nabadwip remained dominated by *Cerratophyllum demersum* and *Lemna* minor. Malopara supported *Vallisneria spiralis*, and Islampur was heavily colonized by Pontederia crassipes and *Potamogeton* sp. The widespread presence of fast-growing, nutrientloving species across seasons suggests persistent eutrophic conditions and ongoing nutrient enrichment in the river.

5.1.9.10. Microplastics

The Jalangi River, one of the most polluted tributaries of the Ganga, shows significant accumulation of plastic pollutants, particularly microplastics (MPs) such as polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS). Analysis revealed that river water contained predominantly foam (54%), followed by beads (23%), fragments (15%), and fibres (8%), while sediments were rich in fibres and fragments (35%), with lower proportions of foam (18%) and beads (12%). Macroplastics (particles >5 mm) were also reported. Seasonal variation showed highest MP abundance in the pre-monsoon (69%) and post-monsoon (48%) periods, with reduced levels during the monsoon (21%) due to increased water flow. Foam was mainly found in surface waters, whereas fibres were concentrated in sediments, highlighting the varied distribution and persistence of microplastic pollution in different compartments of the river.

5.1.9.11. Heavy metal contamination

Heavy metal analysis of the Jalangi River revealed seasonal and spatial variations, with water samples generally showing low concentrations of Cd, Cr, Cu, Pb, and As, all within permissible limits, except for Cr, which slightly exceeded the BIS and USEPA guidelines. Higher metal levels were observed during the pre-monsoon due to lower water volume. Sediment samples showed the highest metal concentrations at Nabadwip, likely due to industrial and urban discharges, with Cr exceeding Canadian and USEPA sediment quality guidelines. Fish samples from 16 species showed varying metal accumulation, with *A. mola* and *T. fasciata* exhibiting the highest levels of Cd, Cu, Pb, and As. Despite variability, all metal levels in fish remained within the FAO safety limits; however, continued monitoring is recommended due to potential ecological and health risks.

5.1.9.12. Coliform

This report outlines the levels of bacterial contamination in the Jalangi River, with a focus on the MPN (Most Probable Number) index of coliform bacteria observed at various sites. The Jalangi River exhibits a low to moderate level of bacterial contamination, as indicated by MPN values ranging from 10 to 170. However, the sites at Harirampur and Nabadwip show significantly higher MPN indices compared to other locations, pointing to elevated pollution levels in these areas.

5.1.9.13. Bisphenol A contamination

The analysis of eBPA (environmental Bisphenol A) concentrations in the Jalangi River at four locations, Islampur, Malopara, Tehatta, and Hulor Ghat, shows notable variation in pollution levels. The highest concentration of eBPA was recorded at Malopara (340.6 ng/L), followed by Tehatta (335.25 ng/L) and Hulor Ghat (333.1 ng/L), while the lowest concentration was observed at Islampur (320.45 ng/L). These values suggest that all the sampled locations experience moderate eBPA contamination, with Malopara being the most affected site. Given the potential harmful effects of eBPA on both aquatic ecosystems and human health, these findings highlight the need for monitoring and mitigation efforts in the Jalangi River.

5.1.9.14. Carbon sequestration potential

In the Jalangi river, Dissolved Inorganic Carbon (DIC) was highest in Islampur (76.19 ppm), followed by Tehatta (72.379 ppm), Malopara (70.50 ppm), and lowest in Nabadwip (46.87 ppm), whereas Dissolved Organic Carbon (DOC) was absent in all the areas.

5.1.9.15. Conclusion

The Jalangi River is undergoing a concerning ecological transformation, driven by a combination of natural and anthropogenic pressures. The increased prevalence of Small Indigenous Fish (SIF) diversity was observed throughout all seasons in the river. This is further exacerbated by the rampant growth of macrophytes, which thrive on nutrient enrichment and eutrophication, quietly signalling a dying river ecosystem. Anthropogenic activities such as the construction of bridges, discharge of untreated domestic sewage, rapid agricultural expansion along the banks, and waste from cattle farming significantly contribute to the river's deteriorating health. Jute retting adds another layer of pollution, exacerbating the already insufficient water flow and intensifying ecological stress. While the monsoon influx supports the seasonal availability of Hilsa (*Tenualosa ilisha*), its abundance is threatened by the degradation of habitat quality and water flow dynamics. Without immediate intervention to address pollution, regulate anthropogenic impacts, and ensure sustainable water flow, the river's ecosystem faces an imminent collapse, putting both biodiversity and the livelihoods of dependent communities at significant risk.

Figure 127: A. Assorted catch of River Jalangi, B. Prawn traps operated at Nabadwip, C. Push net operated at Harirampore

5.1.10. KOSI RIVER

Tributaries are critical habitats that transport organic matter, water, and nutrients, shaping conditions for fish survival. They influence biodiversity and introduce contaminants and sediment at confluences. However, limited data on habitat change effects restricts tributary ecological assessment. Fisheries research is essential for eco-restoration and sustainable management.

5.1.10.1. Sampling Sites

Five sampling sites were selected along a 200 km stretch of the Kosi River: Naugachia (site-I), Dumri Ghat (site-II), Baluaha Ghat (site-III), Basbitti (site-IV), and Dubiahi (site-V) across Bhagalpur, Khagaria, Saharsa, and Supaul districts, Bihar (Fig. 128). These sites span a longitudinal gradient, ranging from 25.425561 ° N, 87.097274 ° E to 26.483451 ° N, 86.929835 ° E.

Figure 128: GIS map showing sampling sites of Kosi River

5.1.10.2. Water Quality

Water quality varied across sites and seasons. Temperature ranged from 16.9°C in Dubiahi (post-monsoon) to 32°C in Naugachia (monsoon). Transparency was lowest at Dumrighat (7.3 cm, monsoon) and highest at Dubiahi (67.5 cm, pre-monsoon), indicating sediment influx. Conductivity varied from 119.7 µS/cm (Dubiahi, monsoon) to 242 µS/cm (Dumrighat, monsoon). The river pH remained slightly alkaline (7.4-8.58). Dissolved oxygen ranged 6.8 mg/L (Baluaha, monsoon) to 8.8 mg/L (Dubiahi, pre-monsoon). BOD varied from 0.07 mg/L (Basbitti, post-monsoon) to 5.8 mg/L (Naugachia, pre-monsoon), indicating organic pollution. COD peaked at 100 mg/L (Naugachia, pre-monsoon), dropping to 12 mg/L (monsoon). Total solids ranged 0.08 g/L (Dubiahi, post-monsoon) to 0.368 g/L (Dumrighat, monsoon). Turbidity peaked (438 NTU, Dumrighat, monsoon). Total alkalinity (50-110 mg/L), hardness (48-112 mg/L), chloride (0.0059-0.0999 mg/L), phosphorus (0.0583-0.1794 mg/L), nitrogen (0.0225-0.0827 mg/L), salinity (0.0108-0.01805 ppt), silica (5.67-23.33 mg/L), and chlorophyll varied seasonally.

5.1.10.3. Sediment Quality

Soil properties shifted due to rainfall and sedimentation. The pre-monsoon soils were alkaline (pH 8.24-8.93), with peak conductivity at Basbitti (237 µS/cm). A sand-dominated texture, especially at Naugachia (94%) and Basbitti (93%), was observed, while Dumri Ghat had a higher silt and clay content (88%). $CaCO_3$ peaked at Dumri Ghat (20.75%) and Basbitti (20%). Total Phosphorus reached 28.24 mg/100g, and Nitrogen peaked at Baluaha (210 mg/100g). Organic carbon varied (0.18–0.72%). In monsoon stabilized pH (8.16-8.79) but reduced conductivity due to leaching. Sand increased (99% at Baluaha), while $CaCO_3$ declined at Dumri Ghat (0.5%). Nutrient levels dropped due to dilution and runoff, with OC% reaching lows of 0.03%. In post-monsoon pH remained alkaline, conductivity rose at Naugachia (317 µS/cm), and nutrient replenishment was observed.

5.1.10.4. Plankton Diversity and Density

A total of 42 plankton taxa from 11 classes were identified. Pre-Monsoon Bacillariophyceae peaked at Basbitti (547 cells/L), while Coscinodiscophyceae dominated Naugachia (160 cells/L). Ulvophyceae thrived at Baluaha (1107 cells/L), benefiting from nutrient enrichment. Zygnematophyceae were highest at Baluaha (1640 cells/L). Cyanophyceae showed a remarkable abundance during the monsoon (8660 cells/l). Rotifera and Copepoda occurred in low densities. Monsoon conditions altered plankton distribution: Bacillariophyceae peaked (700 cells/L, Naugachia), Coscinodiscophyceae reached 1320 cells/L (Naugachia) and 1140 cells/L (Dumrighat). Cyanophyceae increased significantly (5460 cells/L, Naugachia), while Rotifera and Copepoda declined. Dubaihi and Basbitti had the highest biodiversity, as indicated by Simpson's Index (0.86 and 0.85) and Shannon Index (2.23). Dumrighat exhibited the lowest diversity (Simpson's Index: 0.52; Shannon: 1.07). Margalef's richness index peaked at Basbitti (2.59), indicating elevated species richness (Fig. 129).

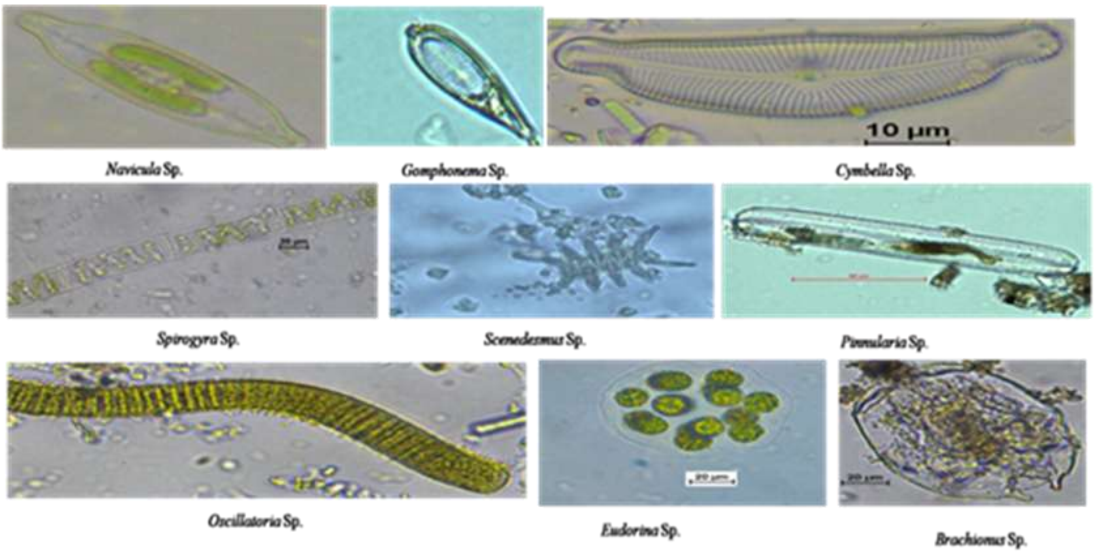


Figure 129: Common planktons of Kosi River

5.1.10.5. Benthic Diversity

The benthic macroinvertebrate community in the Kosi River exhibited distinct patterns of abundance. Viviparidae was the most dominant family (41.54%), followed by Planorobidae (26.15%). Lymnaeidae (9.23%) and Cyrenidae (7.69%) contributed moderately, while Unionidae (3.08%), Pachychilidae, and Bithyniidae (1.54% each) were less prominent. Ampullariidae and Chironomidae shared 4.62%. Pre-monsoon abundance was highest, with Corbicula assamensis (216 ind./m^2) and *Lymnaea acuminata* (130 ind./m^2) dominating (Fig. 130). However, monsoonal disturbances caused significant declines, with some species disappearing altogether, while a few, like *Filopaludina bengalensis* (76 ind./m^2) and *Indoplanorbis exustus* (14 ind./m^2), maintained reduced populations. *Mekongia crassa* was exclusive to the monsoon period. Post-monsoon recovery was partial, with species like *Idiopoma dissimilis* (43 ind./m^2) showing resilience, while others failed to reappear. Seasonal variation showed pre-monsoon dominance at Naugachia (649 ind./m^2) and Basbitti (346 ind./m^2), while monsoon led to sharp declines, with stations like Khagaria and Naugachia recording no organisms. Post-monsoon recovery was significant at Basbitti (562 ind./m^2) and Naugachia (86 ind./m^2), while other sites remained less productive.

Figure 130: Macro benthic diversity of Kosi River

5.1.10.6. Fish diversity

Fish diversity across the Kosi River varied spatially and seasonally, with 45 species from 19 families and nine orders recorded. Pre-monsoon richness ranged from 15 (Dubiahi) to 34 (Khagaria). Monsoon conditions caused a decline, with Dubiahi recording the lowest richness (4 species) and Khagaria the highest (18 species). Post-monsoon recovery was substantial, with Dubiahi recording the highest richness (36 species), attributed to improved ecological conditions (Fig. 131). Hydrological cycles greatly influence fish community structures, highlighting the need for seasonal assessments in conservation and management strategies.

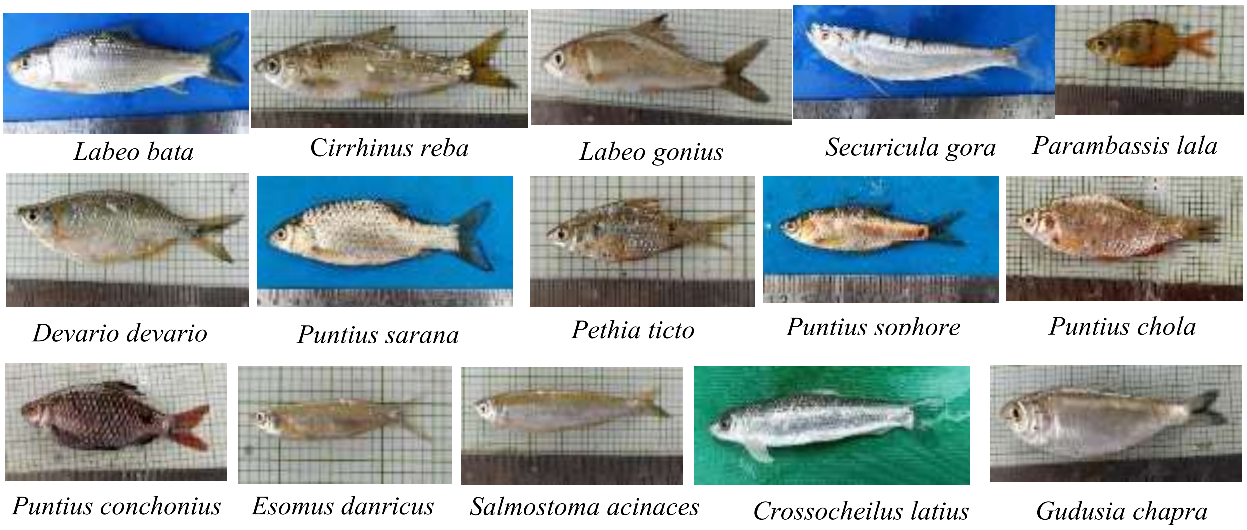


Figure 131: Fish diversity of Kosi River

5.1.10.7. Fishing Craft and Gears

Traditional fishing practices in the Kosi River adapt to dynamic hydrology. Country boats, crafted from wood or bamboo, are manually operated or motorised for manoeuvrability. Fishing gears include gill nets for medium to large fish, cast nets for shallow waters, and drag nets ("bhesal jaal") for broader catches. Seasonal gear selection coincides with increased fish migration post-monsoon.

5.1.10.8. Nutrient Profiling of Fishes

Two species, *Salmostoma acinaces* and *Pachypterus atherinoides*, were analyzed for nutrient profiling.
Salmostoma acinaces: An oil-rich fish with high essential amino acids (glutamic acid, lysine, aspartic acid). Fatty acid analysis identified myristic acid (C14:0), palmitic acid (C16:0), palmitoleic acid (C16:1), and docosahexaenoic acid (C22:6). *Pachypterus atherinoides:* High oil content with significant moisture, crude fat, crude protein, and ash levels. Rich in essential amino acids, glutamic acid and lysine. Fatty acids identified included myristic acid (C14:0), palmitic acid (C16:0), palmitoleic acid (C16:1), and docosahexaenoic acid (C22:6).

5.1.10.9. Microplastics

River Kosi recorded a total microplastic concentration of 12.5 items/L. Khagaria exhibited the highest abundance (6.5 items/L), followed by Dubiahi (2.0 items/L), Baluha Ghat (1.5 items/L), Basbitti (1.0 items/L), and Naugachia (1.0 items/L). Fragments were most dominant, followed by fibers. Site-wise variations highlighted localized pollution trends.

5.1.10.10. Heavy Metal Contamination

Heavy metals detected in river water ranged as follows (mg/L): Cd ND–0.0004, Cr 0.000006–0.01, Cu ND–0.0279, Pb 0.00015–0.0115, As 0.004–0.0125. Monsoon peaks were observed except for arsenic, which peaked post-monsoon. Chromium exceeded BIS (2012) and USEPA (2024) standards. In sediments, metal concentrations (µg/g) varied as follows: Cd ND–0.0171, Cr 0.9–18.26, Cu 0.38–6.13, Pb 0.051–2.38, As 0.097–3.88. Peaks occurred in monsoon, except Cd and Cr, which were highest post-monsoon. Cu, Pb, and As exhibited significant variation, with the highest levels observed near Naugachia, at the confluence of the Ganga. All values remained within Canadian and USEPA guidelines.

5.1.10.11. Coliform

The Most Probable Number (MPN) index showed the highest monsoon coliform levels at Dumari Ghat (94), followed by Baluaha Ghat (84) and Dubiahi (79), indicating increased microbial loads from surface runoff and wastewater discharge. Pre-monsoon values were lower, ranging from 38 MPN at Naugachia and Basbitti to 70 MPN at Dubiahi and Baluha Ghat, reflecting moderate contamination before the rains. Post-monsoon trends varied, with Baluaha Ghat maintaining high levels (84 MPN), while Basbitti (40 MPN) and Dumri Ghat (46 MPN) showed declines.

5.1.10.12. BPA Contamination

Environmental Bisphenol A (eBPA) levels varied seasonally and spatially. During pre-monsoon, high concentrations were recorded: Dubiahi (25.53 ng/L), Baluaha Ghat (25.3 ng/L), Basbitti (24.1 ng/L), and Khagaria (22.75 ng/L), likely due to reduced flow and limited dilution. Naugachia data were unavailable. Monsoon dilution caused declines in Dubiahi (7.41 ng/L) and Baluaha Ghat (15.4 ng/L), while Basbitti saw an increase to 55.2 ng/L due to runoff contamination. Naugachia recorded 8.1 ng/L; Khagaria data were missing. The seasonal hydrology influences BPA distribution, highlighting the need for improved waste management and pollution control during monsoon events.

5.1.10.13. Assessment of Carbon Sequestration Potential from River Kosi

Dissolved Organic Carbon (DOC) concentrations varied across seasons and sites. Khagaria recorded the highest DOC levels, rising from 22.01 mg/L (pre-monsoon) to 27.12 mg/L (post-monsoon). Dubihahi showed the lowest values (9.5–17.41 mg/L). Moderate DOC levels were observed at Baluaha Ghat and Basbitti, with slight seasonal declines. Naugachia remained stable at 10–12 mg/L. These trends reflect local environmental influences on organic carbon distribution. Sediment deposition in Kosi River floodplains aids carbon sequestration and climate change mitigation. Carbon content varied from 7.41 MgC/ha (Naugachia) to 13.15 MgC/ha (Khagaria). Reference sites exhibited lower but consistent storage rates (1.21–2.1 MgC/ha). Variability in tributary sediment suggests differences in environmental conditions affecting carbon retention. Enhancing land and water management can improve carbon storage.

5.1.10.14. Conclusion

The water quality of this river is under the acceptable limit except at the Naugachia site, exceeding the maximum allowable concentration limit of COD during pre-monsoon due to untreated sewage and industrial discharges from near urban areas, indicating a severely polluted condition that is lethal to various aquatic animals. During the monsoon, runoff and high turbidity with decreased transparency generally disrupt the ecological balance in the river. These conditions favour the proliferation of harmful Cyanophyceae growth, with a decline in overall plankton, benthic, and fish populations. Elevated BPA and microplastic concentration in the Kosi River during the monsoon season is considered unsafe for aquatic fauna. An abundance of Coliform and heavy metal concentrations peaked during this period. Post-monsoon conditions showed signs of ecological recovery, with improved water quality and the reappearance of plankton and benthic organisms, particularly at Basbitti and Dubiahi. A total of 45 commercially important fish species were recorded from this river. DOC and sediment carbon levels improved, though some pollutants and microplastics persisted. Effective and sustainable management strategies are urgently needed to control pollution and safeguard the ecological integrity of the Kosi River.

5.1.11. River Matla

The Matla River is a river located in the eastern part of India in Sunderbans of West Bengal. It is a part of the Sundarbans delta, an area famous for its mangrove forests and rich biodiversity. However, like many rivers in the region, the Matla faces challenges such as pollution and the effects of climate change, which threaten its ecosystem. The river's flow is highly affected by tidal variations due to its proximity to the Bay of Bengal.

5.1.11.1. Study sites

Four sampling sites were selected viz., Canning (site-I), Goran Bose I (site-II), Goran Bose II (site-III), and Jharkhali (site-IV). The sampling sites of river Matla covered the only district, South 24 Parganas of West Bengal (Fig. 132). The sampling sites were selected, covering about 200 km. The positional co-ordinates ranged from 22.296522 ºN to 88.682431 ºE.

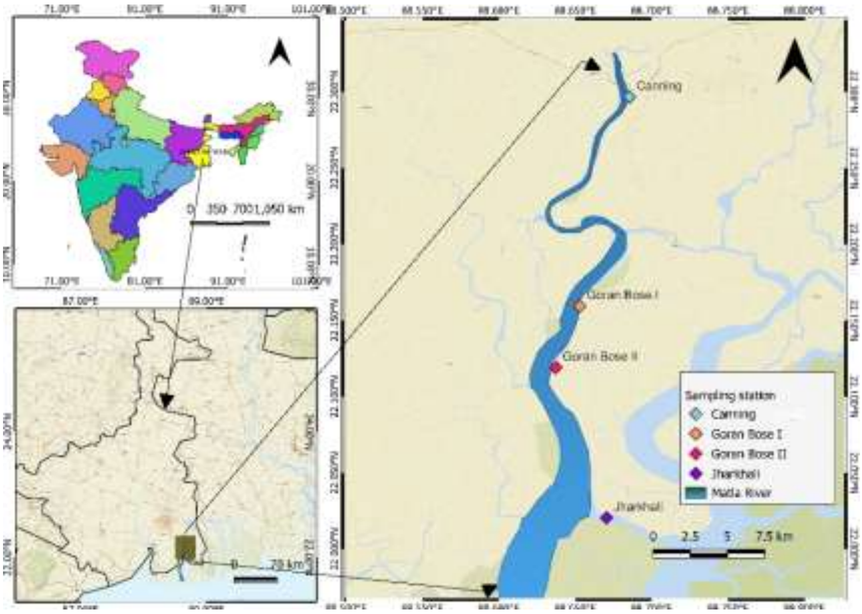


Figure 132: GIS map showing sampling site of river Matla

5.1.11.2. Water quality

The water quality of the River Matla across the sites of Canning, Goran Bose I, Goran Bose II, and Jharkhali exhibits distinct seasonal and spatial variations in multiple parameters. Depth varies most at Jharkhali, peaking at 15 m during the monsoon, while Canning remains the shallowest year-round. Water temperature (20.8 °C) rises steadily from post-monsoon to monsoon (32.8 °C), with Canning consistently recording the highest temperatures and Jharkhali the lowest during winter seasons (21.6 °C). Transparency is best at Goran Bose I and lowest at Jharkhali across all seasons. Specific conductivity (30380 µS/cm), chlorinity (11.13 ppt), and salinity (20.1 ppt) are elevated during post- and pre-monsoon, particularly at Jharkhali, and drop sharply during the monsoon due to dilution by freshwater inflow. pH remains within a alkaline range (7.7–8.39), with Jharkhali consistently showing slightly higher alkalinity across seasons. Dissolved oxygen (DO) levels decrease from post-monsoon (8.4 mg/L) to monsoon (5.4 mg/L), with Canning generally showing the highest levels (5.6-8.4 mg/L), while Jharkhali showed fluctuations (7.2-8.2 mg/L). Turbidity is highest at Jharkhali, peaking during the monsoon (78.9 NTU) and remaining elevated even during pre-monsoon (72.18 NTU), indicating high particulate input, while Canning consistently records the lowest turbidity (44.9-51.6 NTU). Total alkalinity (127 mg/L) and hardness (9200 mg/L) are highest at Jharkhali during post-monsoon and decrease across all sites during the monsoon. The mean BOD and COD are highest during post- monsoon (4.25 mg/L and 1880 mg/L) and pre-monsoon periods (1.80 mg/L and 2510 mg/L), reflecting elevated organic pollution, but decline significantly during the monsoon due to dilution. Total solids, including dissolved (TDS) and suspended fractions (TSS), are highest pre-monsoon, especially at Goran Bose II (48.8 g/L), and decrease notably during monsoon, with Canning showing the lowest values (12.2 g/L). Overall, Jharkhali demonstrates the most dynamic water quality shifts, while Canning reflects more stable, less mineralized conditions.

5.1.11.3. Sediment Quality

The sediment quality of the River Matla shows distinct seasonal and spatial variations across multiple parameters. Sediment pH remained alkaline throughout the year (8.08-8.96), with minor fluctuations, lowest during the monsoon due to freshwater dilution and highest post-monsoon at Canning. Specific conductivity peaked at Jharkhali in the pre-monsoon (12,540 µS/cm) and dropped significantly during monsoon due to dilution, before rising again post-monsoon, particularly at Goran Bose I. Sediment texture varied, with silt-clay content highest at Canning pre-monsoon and Jharkhali post-monsoon. At the same time, Goran Bose II consistently had the highest sand content, especially post-monsoon (89%), indicating tidal influence. Calcium carbonate levels were exceptionally high at Canning pre-monsoon (36%) but decreased sharply during monsoon, reflecting dilution and reduced biogenic input, then moderately rebounded post-monsoon. Total phosphate concentrations were highest at Canning pre-monsoon (32.61 mg/100 g), declined during monsoon due to rainfall dilution, and partially recovered post-monsoon, especially at Goran Bose II. Total nitrogen was highest at Jharkhali pre-monsoon (180 mg/100 g), dropped during monsoon, and spiked dramatically at Goran Bose I post-monsoon (380 mg/100 g), likely from upstream nutrient inputs. Organic carbon levels peaked during the monsoon at Canning and Goran Bose I (1.43% and 1.39%, respectively), then declined post-monsoon, reflecting seasonal organic input followed by decomposition and flushing. Overall, sediment characteristics reflected dynamic interactions between hydrology, land use, and tidal influence across seasons.

5.1.11.4. Plankton and periphyton community

A total of 42 phytoplankton genera belonging to 12 groups were identified from Matla River exhibiting distinct seasonal and spatial variations, reflecting dynamic interactions between hydrological conditions, nutrient availability, and environmental factors. During the pre-monsoon, phytoplankton were dominated by Bacillariophyceae, particularly at Goranbose II (10,290 cells/L). A total of 7 zooplankton genera belonging to 5 groups were recorded. The group Arthropoda was abundant at Goranbose I, indicating favorable conditions for diatom growth and balanced organic loads. In the monsoon season, phytoplankton abundance declined while zooplankton, especially Ciliophora, increased markedly at Goranbose II (1,755 ind/L), with Cyanophyceae also peaking at Goranbose I, likely due to nutrient-rich runoff. Post-monsoon, Coscinodiscophyceae became dominant, particularly at Goranbose II (12,040 cells/L), while Bacillariophyceae rebounded at Goranbose I, reflecting ecosystem recovery following flooding. Zooplankton densities decreased, though Arthropoda and Ciliophora remained present. Overall, Goranbose II consistently showed the highest plankton densities, underscoring its ecological importance, and the seasonal shifts highlight the river's sensitivity to changing environmental and hydrological conditions. The periphyton community of the Matla River shows distinct seasonal and spatial variations, influenced by nutrient availability, hydrological shifts, and substrate conditions. Bacillariophyceae were dominant during the monsoon, peaking at Goranbose II (6,550 cells/cm^2), while post-monsoon dominance was noted at Canning (3,265.7 cells/cm^2). Cyanophyceae also showed significant post-monsoon abundance at Canning (10,026.7 cells/cm^2), suggesting nutrient enrichment following rainfall. Xanthophyceae peaked at Jharkhali during the monsoon (7,500 cells/cm^2), indicating localized environmental inputs. Euglenophyceae and Zygnematophyceae were largely absent, playing a minimal role in community structure. Zooperiphytic groups like Rotifera were scarce, with highest counts post-monsoon at Goranbose I and Jharkhali (30 cells/cm^2), while Arthropoda and Ciliophora were abundant at Goranbose II post-monsoon, with Ciliophora reaching 1,755 cells/cm^2. Overall, Bacillariophyceae and Cyanophyceae dominated periphyton assemblages, with site-specific contributions from other groups, underscoring the ecological impact of monsoonal dynamics and the value of periphyton as indicators of aquatic ecosystem health.

5.1.11.5. Benthic diversity and abundance

A total of seven benthic species were recorded from the Matla River. Potamididae was the most dominant family (45.45%), followed by Cerithidae (21.21%), Ellobiidae (19.7%), and Neritidae (12.12%), indicating a diverse and estuarine environment, with Nassariidae being the least abundant (1.52%). Pre-monsoon benthic diversity was low, with only *Telescopium telescopium* and *Neritia baltaeta* present (43 ind/m^2 each) at Laskarpara and Goran Bose. The monsoon triggered a surge in benthic populations, with Cerithidea cingulata (144 ind/m^2) and Cerithidea obtusa (115 ind/m^2) dominating, alongside *Pirenella alata, Cassidula aurisfelis*, and *Ellobium aurisjudae*. Post-monsoon, the species composition shifted again, with *Ellobium gangeticum* emerging as the dominant species (101 ind/m^2), and Nassarius sp. appearing (14 ind/m^2), while many monsoon-dominant species vanished. Spatially, monsoon abundance peaked at Goranbose I, while post-monsoon dominance shifted to Jharkhali, illustrating the dynamic response of the benthic community to environmental fluctuations (Fig. 133).

Figure 133: Benthic diversity of river Matla

5.1.11.6. Fish diversity

Fish diversity study in different sites of the river Matla has recorded the presence of 66 finfish species belonging to 59 genera, 34 families and 17 orders from four sampling sites. The maximum species richness was observed at site Jharkhali (n = 54), followed by Goranbose II (n = 36), Canning (n = 33), and Goran Bose I (n = 36) respectively. As the river experiences tidal influx, the classification of the piscine environment indicates 67% of marine water-dominated species, 23% as brackishwater species, and 10% as freshwater species. Moreover, 45% of the fish are demersal, 25% pelagic, 22% benthopelagic and 8% reef-associated. As per the IUCN red list 2024, 55 % of the species are Least Concern (LC) category, 5% are Near threatened (NT), 28% are Not Evaluated (NE), and 12% are Data deficient (DD), respectively. The majority of the fish abundance was observed in post-monsoon (37%) compared to the other seasons (pre-monsoon: 35% and monsoon: 28%), likely due to the post-breeding migration and feeding intensity in the estuary. Among the piscine order, fishes belonging to the order Perciformes/Euperca dominated the most (20%), followed by Clupeiformes (17%), Gobiiformes (12%) and Carangiformes (11%) respectively (Fig. 134).

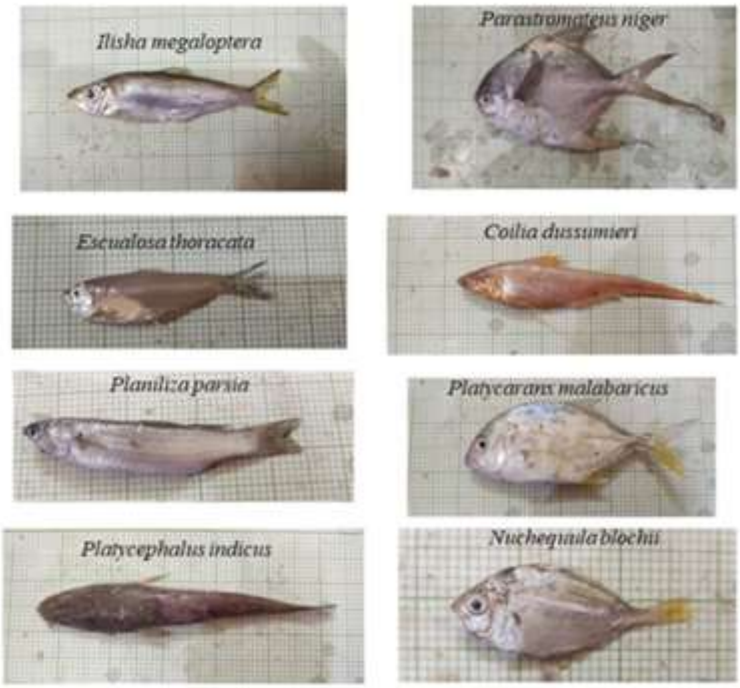


Figure 134: Fish diversity of River Matla

Among the shellfish, the Giant orange mud crab (*Scylla olivacea*) stands out due to its high commercial export value. This species, belonging to the family Portunidae, is extensively harvested and is a significant source of income for local fishers due to its demand in both domestic and international markets. During post-monsoon, the most species-rich family was recorded to be Gobiidae was found to be the dominant group (13%), followed by Sciaenidae (9%), and 4% each for Polynemidae, Ariidae, Pristigaseteridae, Clupeidae, Ophicthidae and others, 1% each. The species *Escualosa thoracata* (RA 51%) was observed to be the dominant species in the river Matla followed by *Arius arius* (RA 30%), *Coilia dussumieri* (11%) and others (8%).

5.1.11.7. Fishing craft and gear

Gill nets, traps, bag nets and Hook and line are among the few main fishing gears in River Matla. The river harbours a variety of fish and shellfish fauna and several fishing gears were observed to operate throughout the year. Information gathered from the local fishermen that the peak fishing time extends from March to September, with maximum operation of bag nets. At present, the bag nets are being operated in the sea mouths due to heavy water currents, which will settle after the new moon of the month. Fishing in the main channel is primarily restricted to seine nets, traps, and hook and line.

5.1.11.8. Nutrient profiling

Six fishes viz. *Pisodonophis boro*, *Parastromateus niger*, *Escualosa thoracata*, *Chelon parsia*, *Anodontostoma chacunda* and *Acanthopagrus datnia* were collected from different stretches of river Matla and nutrient profiling was carried out in terms of gross chemical composition, amino acid and fatty acid composition. The Gross chemical composition revealed that all except *A. chacunda* are protein-rich, while *A. chacunda* is oil-rich. In terms of Amino acid analysis, all species were found to be rich in the essential amino acid's glutamic acid or lysine, with aspartic acid being the dominant non-essential amino acid. Fatty acid composition showed that saturated fatty acids were dominated by either myristic acid (C14:0) or palmitic acid (C16:0), with the order varying by species. Oleic acid (C18:1) was the dominant monounsaturated fatty acid (MUFA) in all except *A. chacunda*, where palmitoleic acid (C16:1) prevailed. Docosahexaenoic acid (DHA, C22:6), a beneficial polyunsaturated fatty acid (PUFA), was consistently the dominant PUFA across all species. These findings highlight the nutritional richness of these fishes, particularly in high-quality proteins and health-promoting fatty acids.

5.1.11.9. Microplastics

Microplastic assessments in the Matla River revealed that fragments were the dominant type in both water and sediments across all sites and seasons. In river water, the highest fragment concentration was at Laskarpara (32 items/L), while Goranbose I and II had the lowest (17 and 13 items/L, respectively). Films were sparsely present at Goranbose I (2 items/L) and Laskarpara (1 particle/L). In sediments, fragments peaked at Goranbose I (100 items/kg), and fibers were most abundant at Goranbose II (93 items/kg). Films were detected at Goranbose II (3 items/kg) and Goranbose I (1 particle/kg), confirming localized variability in microplastic pollution.

5.1.11.10. Heavy metal contamination

Heavy metal assessments in the Matla River revealed seasonal and spatial variations across water, sediment, and fish samples. In river water, fragment concentrations ranged for Cd (ND–0.00032 mg/L), Cr (0.0038–0.063 mg/L), Cu (0.0032–0.113 mg/L), Pb (ND–0.0069 mg/L), and As (0.0026–0.0093 mg/L), with copper and chromium peaking post-monsoon. Cadmium and lead were undetected at Goranbose II post-monsoon. Cr levels slightly exceeded BIS and USEPA guidelines. In sediments, metal concentrations ranged from Cd (0.0087–0.0817 µg/g), Cr (1.302–47.83 µg/g), Cu (ND–31.01 µg/g), Pb (0.158–16.16 µg/g), and As (0.48–14.069 µg/g), with the highest Cr and Cu in Jharkhali during monsoon, and Pb and As at Goranbose I in pre-monsoon. As exceeded the Canadian sediment quality guideline (>7.24 µg/g). In fish, heavy metals ranged from Cd (0.0017–0.078 µg/g), Cr (0.071–0.674 µg/g), Cu (0.107–8.314 µg/g), Pb (ND–0.521 µg/g), and As (0.147–1.738 µg/g). *A. arius* showed the highest accumulation across all metals, while *J. belangerii* and *T. lepturus* had high arsenic levels. All fish samples remained within FAO (1983) permissible limits.

5.1.11.11. Coliform contamination

The MPN index of coliform bacteria in the Matla River exhibited seasonal variations, with the highest contamination observed during the monsoon. Laskarpara recorded the highest MPN (47) in the monsoon, followed by Goranbose II (40) and Jharkhali (38), indicating an increase in bacterial loads due to surface runoff and rainfall. Pre-monsoon levels were relatively low, ranging from 11 MPN at Jharkhali to 25 MPN at Goranbose II. Post-monsoon values declined but remained above pre-monsoon levels at most sites.

5.1.11.12. Bisphenol A contamination

Environmental Bisphenol A (eBPA) levels in the Matla River show clear spatial and seasonal variations across Laskarpara, Goranbose I, Goranbose II, and Jharkhali. Concentrations peak during the pre-monsoon, notably at Jharkhali (259 ng/L), and decline during the monsoon due to dilution, with Goranbose II still showing elevated levels (220.5 ng/L). Post-monsoon levels rise again, especially at Jharkhali (224.6 ng/L), suggesting persistent or accumulating contamination. These trends reflect the combined impact of seasonal hydrology and localized pollution sources on BPA distribution.

5.1.11.13. Carbon sequestration potential

The dissolved inorganic carbon (DIC) concentrations in river water across Jharkhali, Garan Bose I, Garan Bose II, and Laskarpara exhibit apparent seasonal variations. DIC levels are highest during the pre-monsoon period, with Laskarpara recording the peak at 30.375 mg/L, followed by Garan Bose II (27.481 mg/L), Jharkhali (24.474 mg/L), and Garan Bose I (24.042 mg/L). During the monsoon, concentrations decrease significantly due to dilution from rainfall and runoff, with Jharkhali showing the lowest value at 18.14 mg/L and others ranging from 17.44 to 19.7 mg/L. Postmonsoon levels rise slightly, ranging from 20.1 mg/L at Garan Bose I to 22.8 mg/L at Laskarpara, likely due to reduced flow and increased evaporation. In river sediments, carbon sequestration varies across the Matla tributaries, with Sonakhali showing the highest value at 202.86 Mg C/ha, followed by Goran Bose II (112.1 Mg C/ha), Jharkhali (101.20 Mg C/ha), and Laskarpara (95.55 Mg C/ha). All values are substantially higher than their respective reference values, highlighting the strong carbon storage potential of these tributaries and their significant role in regional carbon sequestration and climate change mitigation.

5.1.11.14. Conclusion

The comprehensive study of the Matla River reveals a dynamic, ecologically sensitive estuarine system characterised by distinct seasonal and spatial variations. Jharkhali emerged as both the most biodiverse and environmentally stressed site. Water and sediment quality show monsoonal dilution and increased pollution during pre- and post-monsoon. The river supports 66 finfish species, with the highest abundance in post-monsoon. No evidence of Hilsa was observed in the river. High plankton, benthic, and fish diversity reflect rich biodiversity. Nutritional profiling confirms protein- and PUFA-rich fish with significant socioeconomic value. However, threats from heavy metals, microplastics, coliforms, and BPA are widespread. Sediment carbon sequestration highlights its potential for climate mitigation. Persistent pollution demands strong conservation efforts. Integrated, sustainable management is crucial to protect the Sundarbans biodiversity hotspot.

5.1.12. Nayar river

Nayar River flows as a non-glacial perennial waterway through the Pauri Garhwal District in Uttarakhand, India. The Nayar River serves as a crucial resource for the inhabitants of the Nayar Valley, providing essential water for consumption and agriculture. The river source lies in the Dudhatoli Reserved Forest within the Garhwal Hills of the Pauri District. Two primary tributaries, Nayar East and Nayar West, converge near Satpuli to form the main river. The Nayar River drainage basin encompasses 1,956.33 square kilometers, bordered by the districts of Tehri Garhwal, Chamoli, Almora, Nainital, and Dehradun.

5.1.12.1. Study areas

Two sampling sites were selected along the Nayar river viz. Satpuli and Vyas Ghat (Fig.135).

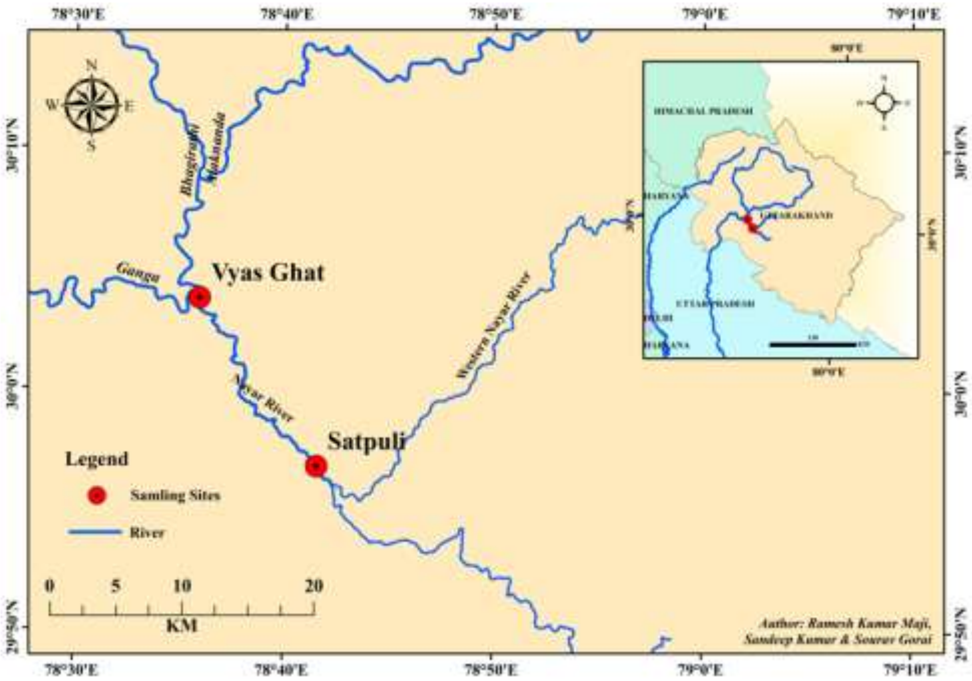


Figure 135: GIS map showing the study sites in River Nayar

5.1.12.2. Water quality

The water quality of River Nayar was assessed during the pre-monsoon (PRM), monsoon (MON), and post-monsoon (POM) seasons, revealing significant spatial and temporal differences in physical, chemical, and biological parameters. During PRM temperature peak was observed at 27.2°C (Vyas Ghat) and declined during POM (12.4°C) at Vyas Ghat due to cold weather conditions. Transparency was found highest (87.4 cm) at Satpuli and lowest (38 cm) at Vyas Ghat, with turbidity ranging from 4.74 NTU to 40.8 NTU (Satpuli). Maximum conductivity (223 µS/cm) was seen during PRM and minimum (90.8 µS/cm) during MON due to dilution. The pH of the river ranged from slightly alkaline (7.7) to alkaline (9) in nature. Dissolved oxygen was found maximum (11.2 mg/L) in POM at Vyas Ghat and minimum in MON (7.4 mg/L) at Satpuli, suggesting seasonal influences. A total alkalinity value of 98 mg/L during PRM (Vyas ghat) and 58 mg/L during POM (Satpuli) was obtained. Total hardness was recorded at 48 mg/L at Satpuli during MON and 110 mg/L at Vyas Ghat during PRM. Lower and higher values of chlorinity and salinity were obtained during POM and PRM, respectively. Nutrient parameters varied, with the highest phosphorus (0.136 mg/L) and nitrogen (0.56 mg/L) levels at Satpuli during PRM, and the maximum silicate concentration (10.024 mg/L) at Vyas Ghat during MON. High BOD value of 1.6 mg/L (PRM) and COD (86.48 mg/L) during MON were obtained at Satpuli and Vyas Ghat, respectively. TS and TSS also reported high during PRM at Satpuli. Overall water quality of the Nayar River was found under the national and international standard limits except for turbidity.

5.1.12.3. Sediment quality of River Nayar

The sediment quality of river Nayar shows greater seasonal and spatial differences among different parameters. The sediment pH ranged from slightly alkaline to alkaline in nature (7.5–8.48), increasing during MON and POM due to runoff and dilution effects. Specific conductivity was found to be highest (421 µS/cm) during POM and lowest (55 µS/cm) during MON. Calcium carbonate content decreases during MON and increases during PRM, with a range of 1.5 – 13%. Sand content (81.60–94%) dominated the sediment texture throughout all seasons, with a slight rise in silt and clay content during MON. Total phosphorus and available nitrogen concentration were found highest at 45.52 and 18.48 mg/100 g, respectively, during PRM and POM. Organic matter also varied seasonally (0.03-0.37%), reflecting changes in organic input, runoff and decomposition. Overall, these patterns indicate the strong relationship between water and sediment interaction in the river.

5.1.12.4. Plankton and periphyton community

The phytoplankton and periphyton analysis of the Nayar River revealed significant seasonal variations (n = 24). In the pre-monsoon season, the phytoplankton group Bacillariophyceae was most abundant (822600 cells/L), especially at Satpulli (954000 cells/L), but lowest during the monsoon period, with the highest value at Satpulli (292800 cells/L). Chlorophyceae were absent during post-monsoon and present both during pre-monsoon and monsoon. During the monsoon season, phytoplankton density dropped (232800 cells/l), but in periphyton, especially Bacillariophyceae, it increased sharply in pre-monsoon due to stable and favourable conditions. The post-monsoon season recorded the highest total periphyton density (13950000 cells/cm²). The zooplankton analysis of the Nayar River revealed marked seasonal variations in both species' diversity and population density. Rotifera were the most dominant group, with 4 species recorded during the post-monsoon season. In contrast, zooplankton density (n=2) decreased during the monsoon. The post-monsoon period also recorded the highest overall zooplankton density, reaching 4 ind/litre. In general, there were more zooplankton after the monsoon season. In contrast, the monsoon season had fewer types of species but still allowed zooplankton to grow because of the extra nutrients and pollution from surface runoff.

5.1.12.5. Benthic diversity and abundance

During the study period, we recorded a total of 30 benthic fauna, belonging to 7 orders and 23 families. Benthic species distribution in the Nayar River varied across Satpuli and Vyasghat, reflecting favourable environmental conditions (Fig. 136). The highest average total abundances of the benthic species were recorded from Vyasghat (733 ind/m²), followed by Satpuli (400 ind/m²). The benthic community of the river Nayar, among the 23 families, the families Baetidae and Heptageniida primarily dominated, accounting for 10% of the total abundance. This indicates their strong flexibility to the river's ecological conditions. Leptophlebiidae, Perlidae and Polycentropodidae (6.66%) also contribute significantly, representing the favourable conditions for the Trichoptera in the river Nayar. Benthic diversity and abundance were increased during the post-monsoon season. *Heptagenia* sp. and *Baetis* sp. were observed at all the sampling sites, ranging from 11 to 238 ind/m² and 22 to 76 ind/m², respectively. *Antocha* sp. was more evenly spread, ranging from 22 ind/m² at Vyasghat to 310 ind/m². *Tabanus* sp. was observed only at Satpuli during the monsoon (10 individuals/m²) and post-monsoon (43 ind/m²), representing the possible seasonal habitat preferences. *Simulium* sp. and *Baetis* sp. were the most dominant benthic species during the post-monsoon season (346 ind/m² and 238 ind/m², respectively) at the Vyasghat. During the post-monsoon season, *Chironomus* sp. was the most dominant (346 ind/m²) at Vyasghat, followed by the monsoon (30 ind/m²) at Satpuli and the pre-monsoon (14 ind/m²) at Vyasghat, respectively.

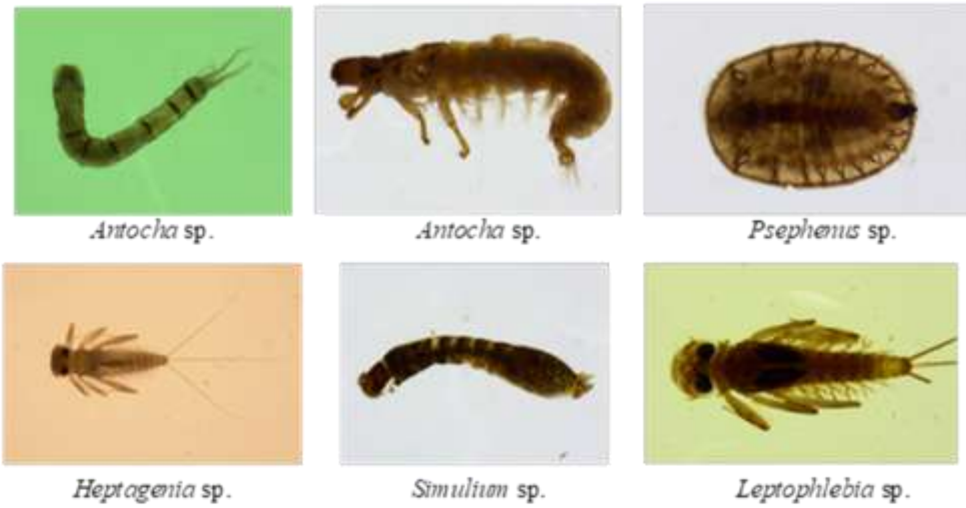


Figure 136: Macro-benthic diversity of river Nayar

5.1.12.6. Fish diversity

In the Nayar River, 17 fish species from 13 genera, 6 families, and 3 orders during the pre-monsoon, monsoon, and post-monsoon sampling in 2024 were recorded. *Labeo dero*, *Tariqilabeo latius*, *Garra gotyla gotyla*, *Tor putitora, Schizothorax richardsonii, Schizothorax plagiostomus*, *Naziritor chelynoides*, *Barilius vagra* and *Puntius sophore* were the dominant fish species at both sampling sites. The highest 17 fish species were dominant in pre-monsoon sampling at Vyasghat and the lowest was 12 during the monsoon sampling in 2024 (Fig. 137). The order Cypriniformes was dominant (88%), followed by the Siluriformes (6%) and Synbranchiformes (6%). Cyprinidae was the most dominant fish family (70%), followed by Danionidae (12%), Cobitidae (06%), Sisoridae (06%), and Mastacembelidae (06%).

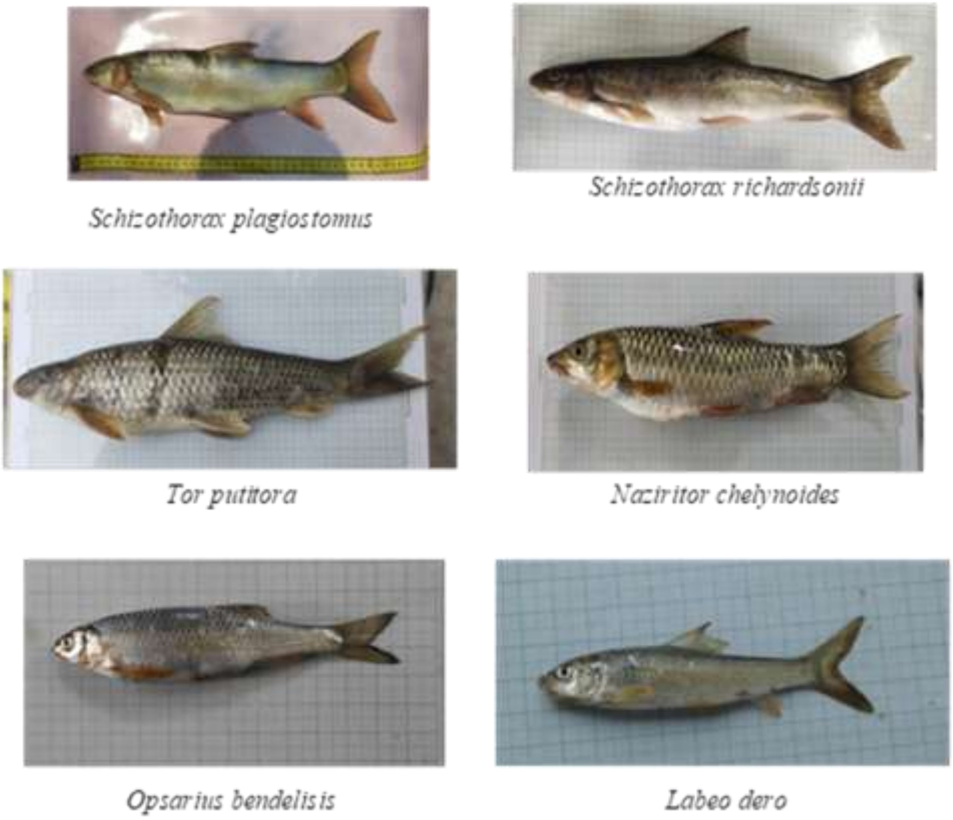


Figure 137: Fish Diversity of river Nayar

5.1.12.6. Fishing crafts and gears

Because the Nayar is narrow, shallow, and fast-flowing, large or motorised boats are rarely used. Instead, fishers employ small-scale, locally adapted gears to target cold-water species. The gears used to target cold water fishes are gill nets, cast nets, hook and line, fish traps and traditional harpoons.

Figure 138: Activities and habitat status of river Nayar

5.1.12.7. Conclusion

The study of the Nayar River highlights a dynamic non-glacial, perennial freshwater system with distinct seasonal and spatial variations in water, sediment, and biological parameters. Water quality remains within acceptable standards, though turbidity and nutrient levels fluctuate seasonally. Sediment composition is dominated by sand, with seasonal variations in nutrient and organic content reflecting runoff and decomposition. Plankton and periphyton communities, especially Bacillariophyceae, show clear seasonal shifts, indicating ecological responsiveness. Benthic fauna diversity is high, with post-monsoon abundance peaks at Vyasghat. A total of 17 cold-water fish species were recorded, dominated by Cypriniformes, reflecting the river's ecological richness. Overall, the Nayar River supports a diverse aquatic ecosystem with strong ecological integrity. Continued monitoring and sustainable management are essential to preserve its biodiversity and ecological balance.

5.1.13. Ramganga river

The Ramganga River originates from "Diwali Khal" in Gairsain Tehsil, at an altitude higher than the town of Gairsain. The river flows through the Almora district in Kumaon, passing through a deep and narrow valley in Chaukhutia tehsil. It forms part of the boundary between Almora and Pauri Garhwal districts after crossing the Marchula Bridge. The river enters the Bhabar region and flows westward, passing through Patli Dun before entering Jim Corbett National Park. The Ramganga River, with a total length of 596 km, descends from the hills of Uttarakhand and enters the plains at Kalagarh in Bijnor district, Uttar Pradesh. The Ramganga River flows through the Bareilly district primarily in a southeastern direction. It receives the combined stream of Bhakra and Kichha (also called Baigul) from its left. It receives the combined stream of Bhakra and Kichha (also called Baigul) from its left. The Gagan River joins it from the right. Near Bareilly city (located about 10 km to its left), it is further joined by the Deoranian and Nakatiya rivers, both of which flow through Bareilly. Additionally, an annual fair is held on the river banks in Chaubari village near Bareilly during Ganga Dussehra (September–October), celebrating the cultural and religious significance of the river.

5.1.13.1. Study area

Five sampling sites, viz. Chaukhutiya, Marchulla, Kalagarh, Moradabad and Hullapur, were selected along the entire Ramganga River (Fig. 139).

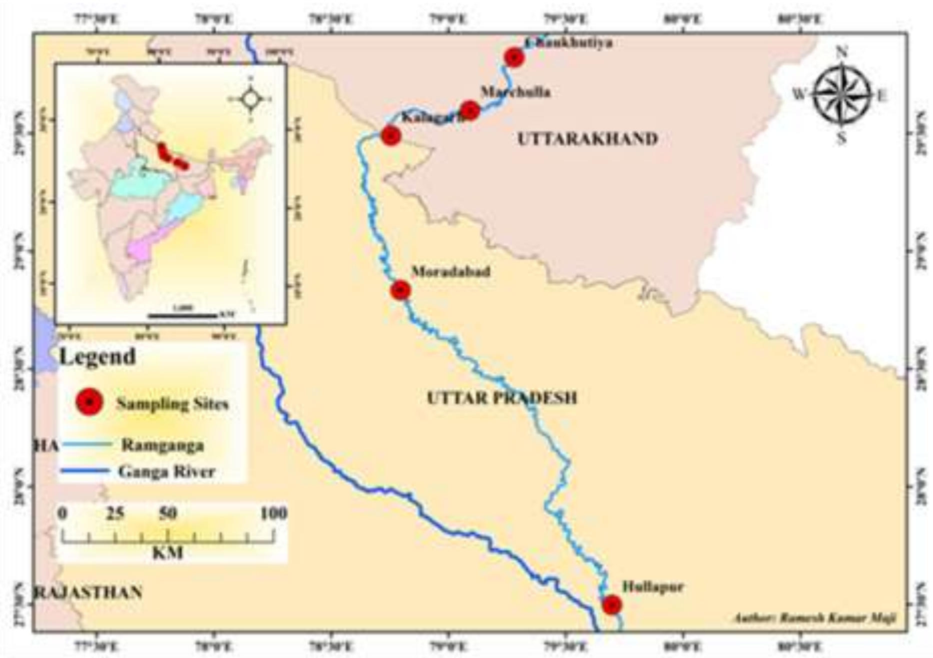


Figure 139: GIS map showing the study sites in river Ramganga

5.1.13.2. Water quality

Pre-monsoon (PRM), post-monsoon (POM) and monsoon (MON) samplings were conducted at five different sites along the Ramganga River by the ICAR-CIFRI Prayagraj team from April 2024 to January 2025. The variation of different water quality variables during the year is elaborated below. The lowest depth of 0.48 m was observed during PRM at Chaukhutiya, whereas the highest depth of 6.4 m was observed at Hullapur during the POM season. The water temperature varied from 13.2°C (Chaukhutiya, POM) to 34.2°C (at Kalagarh, MON). The highest transparency value of 103 cm was observed at Kalagarh (PRM) and the lowest transparency value (10 cm) was observed at Moradabad (MON). Very high values of turbidity (1065 NTU) were obtained during MON (Moradabad) and a low (1.09 NTU) during POM (Marchula). The conductivity during the POM was reported as 529 µS/cm (Hullapur) and 93.7 µS/cm (Chaukhutiya) during the MON, indicating a dilution effect. The pH ranges between 7.7 and 9.0 during PRM. Higher DO values (12.8 mg/L, Kalagarh) were obtained in POM compared to MON (3.2 mg/L, Moradabad). In the POM, a higher value of 260 mg/L was recorded at Hullapur and in MON lower value of 44 mg/L at Chaukhutiya. During N, Chaukhutiya recorded a reduced hardness value of 52 mg/L, while during POM, Chaukhutiya recorded an increased value of 238 mg/L. Chlorinity (2 – 41 mg/L) and salinity (0.03 – 0.07 g/L) were reported highest during PRM and lowest during POM. A maximum value (2.311 mg/L) of total phosphorus was observed at Chaukhutiya (PRM), while a minimum value (0.008 mg/L) was observed at Moradabad (MON). Total nitrogen (TN) concentration during PRM ranged from 0.003 mg/L at Kalagarh to 2.134 mg/L at Moradabad. The highest value of available silicate (13.911 mg/L, Hullapur) was obtained during POM, while the lowest value (1.418 mg/L at Moradabad) was during MON. BOD of the river during PRM was found 10.2 mg/L (at Moradabad) and during MON 0.8 mg/L (Chaukhutiya). COD value of 108.1 mg/L was obtained at Kalagarh (MON) and 8 mg/L at Chaukhutiya (PRM). TS and TSS were reported to be maximum during MON at Hullapur. Overall, the water quality of the Ramganga River was found mostly degraded at the Moradabad and Hullapur sites.

5.1.13.3. Sediment quality of the River Ramganga

The seasonal and spatial variation among different sediment quality parameters is described as follows. The sediment texture of the Ramganga River was dominated by sand with a range of 92 – 57.34%. Although the content of silt (0.18 – 22.85%) and clay (6 – 40.72%) increased during the MON due to eroded soil. The sediment pH of the river during POM was found mostly alkaline (8.79, Hullapur) and slightly alkaline (7.5, Moradabad) during PRM. The specific conductance during PRM was estimated minimum (0.017 mS/cm) at Moradabad and maximum (0.897 mS/cm) during POM at Kalagarh. In the PRM and POM, the organic carbon (OC) was found very low (0.03%) and high (1.68%) at Chaukhutiya, respectively. The minimum (0.94 mg/100g) and maximum (71.83 mg/100g) values of phosphorus were reported at Hullapur during PRM and POM, respectively. During MON value of nitrogen was found to be minimum (3.92 mg/100g, Chaukhutiya) and maximum (19.04, Kalagarh). In the PRM and POM, the value of calcium carbonate ($CaCO_3$) was reported as minimum (0.5%) and maximum (12.5%) at Moradabad, respectively.

5.1.13.4. Plankton and the Periphyton community

Analysis of phytoplankton and periphyton communities in the Ram Ganga River (n = 57) revealed pronounced seasonal variations. During the pre-monsoon season, Bacillariophyceae (diatoms) and Chlorophyceae (green algae) dominated the phytoplankton assemblage, particularly at Hullapur. In the monsoon, Cyanophyceae grew the most, reaching a high of 598,000 cells/L at Hullapur, due to increased water flow and nutrient pollution from runoff. These cyanobacterial populations then declined in the post-monsoon period, as water currents stabilised and nutrient inputs decreased. During the monsoon, phytoplankton density decreased (428160 cells/L). The periphyton, especially Bacillariophyceae, exhibit a reduction in density, while Cyanophyceae increased during pre-monsoon due to nutrient availability, favourable conditions and substratum. The pre-monsoon season exhibits the highest total periphyton density (9132000 cells/cm²), while the monsoon revealed minimum density due to high flow and lack of substratum. There were notable seasonal fluctuations in the species composition and population density of the zooplankton. With nine species identified, rotifera were most prevalent in the post-monsoon season. In contrast, only five species of zooplankton were found during the pre-monsoon, indicating a decline in diversity. With a total zooplankton density of 9 ind./L, the post-monsoon season also had the highest density. More zooplankton abundance was generally supported throughout the post-monsoon period, most likely as a result of more stable hydrological conditions and higher nutrition availability.

5.1.13.5. Benthic diversity and abundance

During the 2024 sampling, 23 benthic macro-invertebrate species were recorded from the Ramganga River, representing 9 orders and 21 families (Fig. 140). Taxa in the class Insecta overwhelmingly dominated the community. Seasonal analysis indicated that both benthic diversity and overall abundance peaked during the pre-monsoon season. During the pre-monsoon season in the Ramganga River, the dominant species included *Indoplanorbis exustus*, *Gyraulus convexiusculus*, *Lymnaea acuminata*, *Baetis* sp., *Hydropsyche* sp., *Platybaetis* sp., and *Heptagenia* sp. *Enallagma* sp. and *Stenopsyche* sp. were recorded during the post-monsoon season from the Chaukhutiya while absent in the monsoon and the pre-monsoon seasons at all the sampling sites. The dominant benthic faunawere as follows: (Gastropods) *Physella acuta,* (Insects) *Chironomus* sp., and *Leptophlebia* sp. in the entire stretches of the river Ramganga. The highest average total abundances (ind/m²) of the benthic species were recorded from

Muradabad (393 ind/m^2), followed by Chaukhutiya (277 ind/m^2), Marchula (120 ind/m^2), Klagarh (130 ind/m^2), and Hullapur (60 ind/m^2), respectively. During the pre-monsoon season the highest benthic abundance was observed at 620 ind/$m^2$from Muradabad, followed by 440 ind/m^2 and 120 ind/m^2 during the monsoon and post-monsoon seasons, respectively. During the post-monsoon season the least 20 ind/m^2 benthic abundance was observed from Hullapur, followed by 60 ind/m^2 and 100 ind/m^2 during the monsoon and pre-monsoon seasons. *Stenopsyche* sp. (20 ind/m^2) belongs to Class-Insecta, Order-Trichoptera, family-stenopsychidae, *Polycentropus* sp. (20 ind/m^{22}), *Tabanus* sp. (10 ind/m^2) were recorded from Chaukhutiya and Muradabad, respectively.

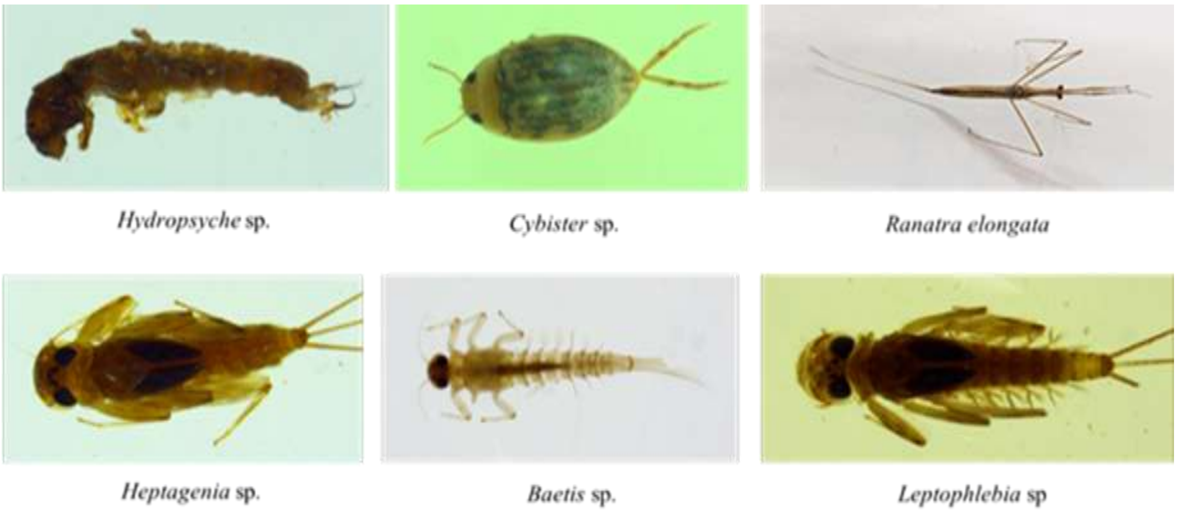


Figure 140: Benthic Diverisity of river Ramganga

5.1.13.6. Fish diversity

During three seasonal surveys in 2024, a total of 71 fish species were recorded from the Ramganga River. Spatially, the highest species richness was observed at Hullapur (n = 32), followed by Moradabad (n = 24), while the lowest diversity occurred at Kalagarh (n = 3) during the pre-monsoon sampling. Seasonally, the monsoon supported the greatest fish diversity (n = 66), followed by the pre-monsoon (n = 47) and post-monsoon (n = 45). *Labeo bata*, *Labeo rohita*, *Cirrhinus mrigala*, *Tor putitora*, *Wallago attu*, *Mystus cavasius*, *Mystus vittatus*, *Sperata seenghala*, *Channa punctata*, *Mastacembelus armatus*, *Pethiaticto*, *Pethia conchonius, Puntius sophore, Barilius vagra, Opsarius bendelisis* and *Salmostoma bacaila* were found to be the frequent fish species from different stretches of the Ramganga. At the order level, Cypriniformes dominated the fish community, accounting for 48% of total abundance, followed by Siluriformes at 27% (Fig. 141).

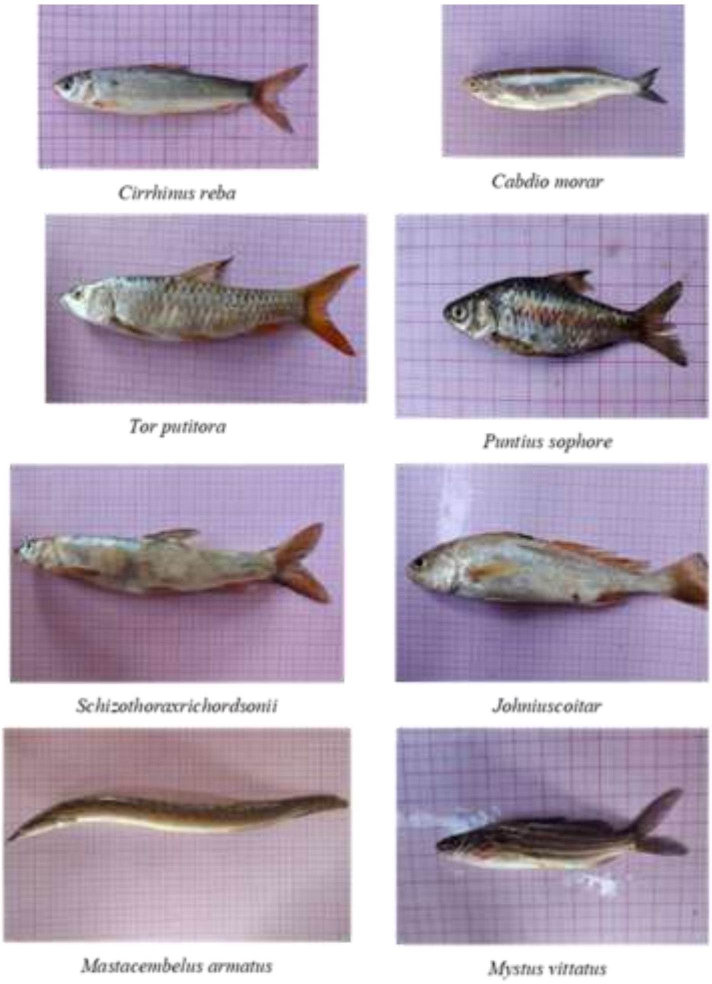


Figure 141: Fishes of river Ramganga

5.1.13.7. Fishing crafts and gear

A variety of traditional and small-scale fishing gears are used by local fishermen in the Ramganga River, adapted to the river's hydrology and target species. The most commonly used gears include gill nets – these are the most widely used fishing gears in the Ramganga River, particularly for capturing medium- to large-sized fish; cast nets, drag nets and hook and line (Fig. 142).

Figure 142: Field activities and habitat status of river Ramganga

5.1.13.8. Conclusion

The ecological assessment of the Ramganga River reveals significant spatial and seasonal variability across its longitudinal gradient, with water quality degradation most evident at Moradabad and Hullapur. High turbidity, elevated BOD and COD, and reduced DO during the monsoon indicate severe pollution stress, particularly in urban and downstream stretches. Nutrient enrichment, especially total phosphorus and nitrogen, peaked during the pre-monsoon at Chaukhutiya, suggesting localized anthropogenic inputs. Sediment quality showed increased siltation and organic enrichment post-monsoon, reflecting runoff impacts and soil erosion. Seasonal phytoplankton dynamics were driven by flow regimes and nutrient influx, with

Cyanophyceae proliferating during the monsoon and Bacillariophyceae dominating in post monsoon periods. Periphyton density peaked during pre-monsoon, while zooplankton diversity was highest in post-monsoon, aligned with stable hydrological conditions. Benthic macroinvertebrate communities were dominated by insect taxa, with highest densities in Moradabad during the pre-monsoon, suggesting local habitat suitability despite pollution. The fish fauna was highly diverse, with 71 species recorded, peaking during the monsoon. However, upstream stretches like Kalagarh showed alarmingly low diversity. The dominance of Cypriniformes and widespread traditional fishing practices reflect the river's fisheries significance. Overall, the study underscores urgent need for catchment-scale management, pollution mitigation, and ecological flow maintenance to safeguard the Ramganga River's biodiversity and restore its environmental integrity.

5.1.14. Rupnarayan river

The river Dwarakeswar, originally named Dhaleswari (Dhalkiswar), flows into the city of Bankura in West Bengal state after coming out of the Chota Nagpur plateau foothills northeast of Purulia. The river originating from Bankura meanders through the plain till it reaches the city of Ghatal, where it converges with the Silai River and is then called Rupnarayan. After covering a distance of approximately 240 kilometers, the river subsequently merges with the Hooghly River. The river Rupnaryan serves as a western outlet of the river Ganga and is significant due to its capacity for irrigation and Hilsa fishery.

5.1.14.1. Study area

Nine sampling locations were selected namely Kashipur (site-I), Rajogram (site-II), Bishnupur (site-III), Arambag (site-IV), Bandar (site-V), Kolaghat (Site-VI), Tamluk (Site -VI), Geonkhali (Site -VII) and Gadiara (Site -VIII) (Fig 143). The sampling locations encompassed the districts of Purulia, Bankura, Hooghly, West Midnapore, East Midnapore and

Figure 143: Survey sites of Rupnarayan River

Howrah in the state of West Bengal. The sampling sites were selected to encompass approximately 200 km along the longitudinal gradient of the river Rupnaryan. The positional coordinates spanned from 23.424643º N, 86.680456º E to 22°13'08.40"N, 88°02'50.41"E.

5.1.14.2. Water quality

Water depth in the Rupnarayan River varied significantly, ranging from 0.963 m at Kashipur to 16.2 m at Geonkhali in post monsoon with deeper sections observed downstream (e.g., Geonkhali and Tamluk). Water temperature across the river basin fluctuated between 16.3°C and 33°C. Specific conductivity generally decreased during the monsoon season, with lowest value at Kolaghat (192.3 µS/cm). Specific conductivity values in post-monsoon ranged from 198.1 µS/cm at Kashipur to 273 µS/cm at Bishnupur, reflecting reduced ion concentration from increased rainfall. pH levels during the post-monsoon period remained primarily alkaline, ranging from 8.01 at Bishnupur to 8.92 at Bandar. Dissolved oxygen concentrations followed a seasonal trend: highest in the post-monsoon period (5.4 mg/L at Gadiara to 10.4 mg/L at Bandar), moderately reduced during the pre-monsoon season, and further declining in the monsoon season (3 mg/L at Tamluk to 7.2 mg/L at Arambag), indicating the influence of temperature and organic matter on oxygen dynamics. Turbidity peaked in the post-monsoon season, particularly at Kolaghat, Tamluk, and Geonkhali, exceeding 200 NTU due to sediment inflow from monsoonal runoff. In contrast, pre-monsoon turbidity levels were substantially lower, with Geonkhali showing a minimum of 1.3 NTU, indicative of clearer water and reduced sediment input. Alkalinity in the post-monsoon period ranged from 100 mg/L at Kolaghat to 162 mg/L at Geonkhali. Water hardness exhibited spatial variation, peaking at 350 mg/L in Geonkhali and dipping to 96 mg/L at Bandar. Salinity increased progressively downstream, from 0.0234 ppt at Kashipur to 3.5016 ppt at Gadiara. This gradient reflects the river's increasing proximity to the Hooghly River confluence and the Bay of Bengal, influencing estuarine conditions an important factor for brackish water fisheries. Chlorophyll concentrations, indicative of algal biomass and primary productivity, were relatively low post-monsoon, with the highest recorded at Bishnupur (19.28 mg/m^3), and followed by Geonkhali (13.22 mg /m^3) and Bandar (12.60 mg /m^3). In contrast, pre-monsoon chlorophyll levels were substantially higher, particularly at Arambag (120.54 mg/m^3), suggesting a seasonal peak in phytoplankton growth. Other notable concentrations were recorded at Gadiara (18.02 mg/m^3) and Geonkhali (17.44 mg/m^3), aligning with enhanced nutrient availability before the monsoon. These variations in physicochemical parameters across seasons and locations significantly influence fishery conditions along the Rupnarayan River. Brackish water fisheries in downstream areas benefit from higher salinity and nutrient levels post-monsoon, while upstream freshwater fisheries respond more directly to changes in turbidity, DO, and chlorophyll concentrations across seasons.

5.1.14.3. Sediment quality

In the pre-monsoon period, the pH level varied from 7.51 in Arambag to 9.00 in Tamluk, indicating somewhat alkaline conditions. In monsoon season specific conductivity shows a significant decrease, with lowest at 67.3 µS/cm to 50.8 µS/cm at Bishnupur due to heavy rainfall diluting the effect. In the pre-monsoon period, calcium carbonate varied from 2% in Kashipur to 17% in Geonkhali, indicating greater carbonate buildup in downstream areas. In th lower streat of Rupnarayan sediment is generally sandy but during monsoon there was an increase in river discharge that led to elevated silt and clay fractions, ranging from 2% to 13%. total phosephate and total nitrogen concentrations reached their highest levels in monsoon at lower strech of Rupnarayan (26.80 mg/kg TP in Geonkhali and 140 mg/kg TN at Kolaghat) probably as a result of agricultural runoff and the resuspension of sediments. The organic carbon of the river strech varies from 0.09% to 0.35% deoending on organic matter deposition, and site-specific anthropogenic activities.

5.1.14.4. Plankton and periphyton community

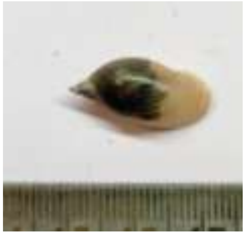
A total of 93 genera of plankton from 14 distinct groups were documented in the Rupnarayan river. In the study of zooplankton, Rotifera emerged as the dominant group with a density of 1525 ind/L, closely followed by Arthropoda at 1049 ind/L. The significant presence of Cyanophyceae, especially in areas such as Bishnupur, Arambag, and Rajogram, indicates a surplus of nutrients entering the water bodies, probably as a result of human activities. In the pre-monsoon season, Cyanophyceae showed increased densities, peaking at Arambag with 560,000 cells/cm^2 and demonstrating notable abundance at Bandar with 221,500 cells/cm^2. In the post-monsoon season, Coscinodiscophyceae was notably prevalent at Bandar, with a density of 4,500 cells/cm^2. In contrast, Cyanophyceae exhibited significantly lower densities at all stations, with the highest recorded in Geokhali at 9,950 cells/cm^2. Chlorophyceae exhibited notable presence in Geokhali with a density of 4,100 cells/cm^2 and in Arambag with 2,100 cells/cm^2.

5.1.14.5. Benthic diversity and abundance

A total of 12 species were recorded from this river belonging from 7 families. In this river Thiaridae (54.00%) and Viviparidae (43.00%) as the predominant families. Lymnaeidae (17.00%) and Unionidae (11.00%) play a notable role, reflecting their capacity to thrive in various environmental conditions (Fig .144). Planorobidae (8.00%) and Neritidae (7.00%) exhibited moderate representation, whereas Assimineidae (2.00%), Stenothyridae (1.00%), and Bithyniidae (1.00%) were observed in lesser proportions. The pre-monsoon and monsoon period saw a dominance of *Tarebia granifera* (260 and 225 ind/m²) and *Filopaludina bengalensis* (108 and 69 ind/m²). The post-monsoon period exhibited striking trends, with a surge in *Filopaludina bengalensis* (260 ind/m²) and *Parreysia caerulea*, which was completely absent earlier but peaked at 260 ind/m². *Indoplanorbis exustus* also experienced a massive increase (151 ind/m²), indicating a preference for post-monsoon conditions.


Filopaludina bengalensis


Idiopoma dissimilis


Lymnaea acuminata


Tarebia granifera


Melanoides tuberculata


Parreysia corrugata

Figure 144: Benthic community of Rupnarayan River

5.1.14.6. Fish diversity

The comprehensive survey documented 60 fish species across 46 genera, 28 families, and 11 orders from nine sampling locations throughout the river stretch (Fig. 145). The lower section of the river (Bandar to Gadiara), influenced by tidal input, is habitat to various brackish-water fish species, including *Arius maculatus, Polynemus paradiseus, Chelon parsia, Anodontostoma chacunda, Sillago sihama,* and *Sardinella* sp., observed downstream of Kolaghat. The river also hosts *Tenualosa ilisha* (Hilsa) during the peak winter and monsoon seasons; however, the population of Hilsa is on a diminishing trajectory. The station-specific study demonstrated the highest number of fish species at Bishnupur (n = 36) in Bankura district, West Bengal, followed by Kolaghat (n = 29), Tamluk (n = 27), and Arambagh (n = 26) respectively. The percentage representation of the piscine order indicates an increased abundance of cypriniformes (33%), predominantly in the upper portions of the river. Siluriformes has demonstrated a prevalence of 22% across all sites, indicating a stable population of catfish throughout the river system.

Figure 145: Fish species diversity of river Rupnarayan

5.1.14.7. Fishing craft and gears

The conventional fishing devices, including various bamboo traps such as Ghuni, Jhuri, and Atal, along with additional gear like Behundi jaal (Bottom set bagnet) and Thela jaal (Push net), have been used by the marginal fishers in Tamluk, Kolaghat, and Geonkhali of Purba Midnapore (Fig. 146). The Dungi boat is utilised for small-scale fishing in this region, and a large wooden boat was employed by the large-scale fishers. In the upper stretch, where the water depth was relatively shallower, the application of cast nets for fishing was predominantly observed.

Figure 146: Fishing activities in different sites of river Rupnarayan

5.1.14.8. Nutrient profiling of fish

A total of three fishes *Systomus sarana, Notopterus notopterus* and *Barillius barila* were collected from different stretches of river Rupnarayan. *S. sarana* and *B. barila* were found to be rich in essential amino acids glutamic acid followed by lysine and leucine and non-essential amino acid aspartic acid. *N. notopterus* was found to be rich in essential amino acids lysine followed by threonine and non-essential amino acid aspartic acid. The crude protein in *N. notopterus* in highest with 19% followed by *P. sarana* 18% and *B. barila* 13%.

5.1.14.9. Microplastic

In the Rupnarayan River, the highest concentrations of fragments (53 items/L) and fibers (29 items/L) were observed at Bishnupur. The lowest fragment concentration was recorded at Bandar (4 items/L) and at Gadiara and Geonkhali (5 items/L each). Films (3 items/L) were detected only at Kolaghat, while beads (1 particle/L) were observed exclusively at Kashipur. In the sediment samples of the Rupnarayan River during the pre-monsoon sampling, the highest concentration of fragments was recorded at Tamluk (99 items/kg), while the lowest was observed at Kolaghat (39 items/kg). During the monsoon sampling, fragments remained the dominant microplastic type, with the highest concentration at Bishnupur (123 items/kg) and the lowest at Gadiara (33 items/kg). Beads were absent at all sites except Kashipur, where a concentration of 1 particle/kg was recorded.

5.1.14.10. Heavy metal contamination

Among all the heavy metals copper and lead concentration (ND to 0.0267 ± 0.003 mg/L and ND to 0.0152 ± 0.001 mg/L) was undetected at all the sampling sites during post-monsoon (POM) season. The maximum concentration of chromium, arsenic and cadmium was higher at Gadiara during POM season which is mainly due to the confluence of the river Hooghly and Rupnarayan. In sediment maximum concentration of cadmium, copper and lead (0.0017 ± 0.00014 to 0.944 ± 0.0941 µg/g; 0.239 ± 0.040 to 56.245 ± 2.815 µg/g; 0.289 ± 0.035 to 25.835 ± 2.923 µg/g) was found in the post-monsoon season while chromium in monsoon season. The highest concentration of cadmium, chromium and arsenic were found in *Puntius conchonius* while copper in *Macrognathus pancalus* and lead in *Channa punctata* (Fig .147).

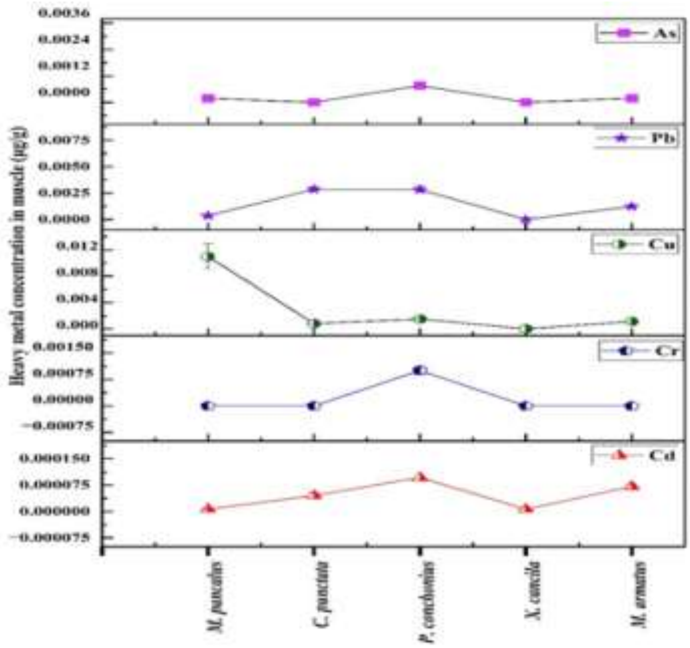


Figure 147: Seasonal variations heavy metals in fishes of river Rupnarayan

5.1.14.11. Coliform contamination

The MPN index of coliform bacteria in the Rupnarayan River Showed moderate seasonal variations, with the highest contamination observed during the monsoon. Arambag recorded the highest MPN (63) in the monsoon, followed by Rajogram (39) and Kashipur (34), indicating an increase in bacterial loads due to surface runoff and rainfall. Pre-monsoon levels were generally lower, ranging from 8 MPN at Bishnupur to 38 MPN at Arambag. Post-monsoon values showed a decline compared to the monsoon, but some sites, such as Bishnupur (25 MPN) and Arambag (31 MPN), remained elevated.

5.1.14.12. Bisphenol A contamination

The analysis of eBPA concentrations across multiple sampling sites along the Rupnarayan River reveals significant spatial variability, with values ranging from a mean of 118.06 ng/L at Kashipur to a maximum of 300.22 ng/L at Kolaghat. This variability likely reflects differences in local anthropogenic influences, industrial activity, and land-use patterns near each site. Upstream sites, such as Kashipur (118.06 ± 8.44 ng/L) and Rajogram (142.84 ± 24.84 ng/L), show comparatively lower levels of eBPA. Interestingly, Gadiara, located near the river's confluence with the Bay of Bengal, still exhibits a high eBPA concentration (228.87 ± 11.05 ng/L), suggesting limited dilution or persistent inputs even in downstream regions.

5.1.14.13. Carbon sequestration potential

The dissolved inorganic carbon content in the Rupnarayan River shows that the highest concentration was recorded at the Bandar Site (38.4±4.65 mg/L), followed closely by Rajogram (38.12±6.22 mg/L), while the lowest level was observed in Kolaghat (31.87±10.22 mg/L). Dissolved organic carbon (DOC) was not present at any of the sites. In the sediment sample of Kolaghat (144.37 MgC/ha) and Geokhali (131.70 MgC/ha) appear to facilitate greater carbon storage owing to their more expansive floodplains and vegetation, despite their reference values being 1.01 and 0.97, respectively (Fig. 148). Tamluk (189.12 MgC/ha) and Gadiara (139.26 MgC/ha), with lower reference values of 0.78 MgC/ha, appear to have constrained sequestration potential.

Figure 148: Habitat profile of different sites in river Rupnarayan

5.1.14.14. Conclusion

The Rupnarayan River is experiencing significant ecological stress due to various anthropogenic activities, including the construction of hydraulic structures, water extraction, sand mining, and the installation of check dams. These interventions have led to reduced flow velocities, particularly in the upper stretches, altering the river's ecological balance. A comprehensive study documented 60 fish species across 46 genera, 28 families, and 11 orders from nine sampling locations along the river. Notably, the river hosts *Tenualosa ilisha* (Hilsa) in the tidal zone during peak winter and monsoon seasons; however, the Hilsa population is on a declining trajectory. Additionally, there has been a discernible drop in the abundance of major carps, with a notable increase in exotic carps, likely due to the altered habitat conditions.

In the lower stretches of the river, tidal effects are more pronounced, and water flow remains relatively normal. However, water and sediment quality exhibit varied ranges across different sites, with a clear distinction between tidal and non-tidal zones. These variations in physico-chemical parameters across seasons and locations significantly influence fishery conditions along the Rupnarayan River, highlighting the need for region-specific management strategies to sustain aquatic biodiversity and local livelihoods. The study also utilized the presence of small indigenous fishes (SIF) as indicators of aquatic habitat condition, revealing a significant presence of SIFs in the upper sections of the river. This underscores the importance of focusing on their conservation and population sustainability. The presence of major pollutants such as microplastics, bisphenol A (BPA), and coliform contamination in river water and sediment at low to moderate levels is concerning and calls for concentrated attention on river health in order to protect the Rupnarayan River's ecological health and maintain its diminishing biodiversity. The regulation of industrial and domestic effluents discharge to the river may help in maintaining the biotic integrity of this river.

5.1.15. SARYU RIVER

The Karnali River of Nepal is known as the Ghaghara River and is also referred to as the Saryu River in the Awadh region of India. It is a perennial transboundary river that originates from the northern slopes of the Himalayas in the Tibetan Plateau. The river cuts through the Himalayas in Nepal before joining the Sharda River at Brahma Ghat in India, forming the Ghaghara River, a major left-bank tributary of the Ganges. With a length of 507 km, the Karnali is the longest river in Nepal, while the total length of the Ghaghara River up to its confluence with the Ganges at Revelganj, Bihar, is 1,080 km. It is the largest tributary of the Ganges by volume and the second longest after the Yamuna. Several important towns are situated along its banks, including Bahraich, Barabanki, Sitapur, Gonda, Akbarpur, Ayodhya, Basti, Deoria, Barhalganj, Gorakhpur, and Tanda in Uttar Pradesh, as well as Chapra, Siwan, and Sonepur in Bihar.

5.1.15.1. Study area

Six sampling sites, viz. Girjapuri, Chahlari Ghat, Elgin Bridge, Ayodhya, Dohri Ghat and Manjhi Ghat, were selected along the entire river Saryu (Fig. 149). The sampling sites of the Saryu River cover Bahraich, Sitapur, Ayodhya, Mau (Uttar Pradesh), and Chapra (Bihar) in India.

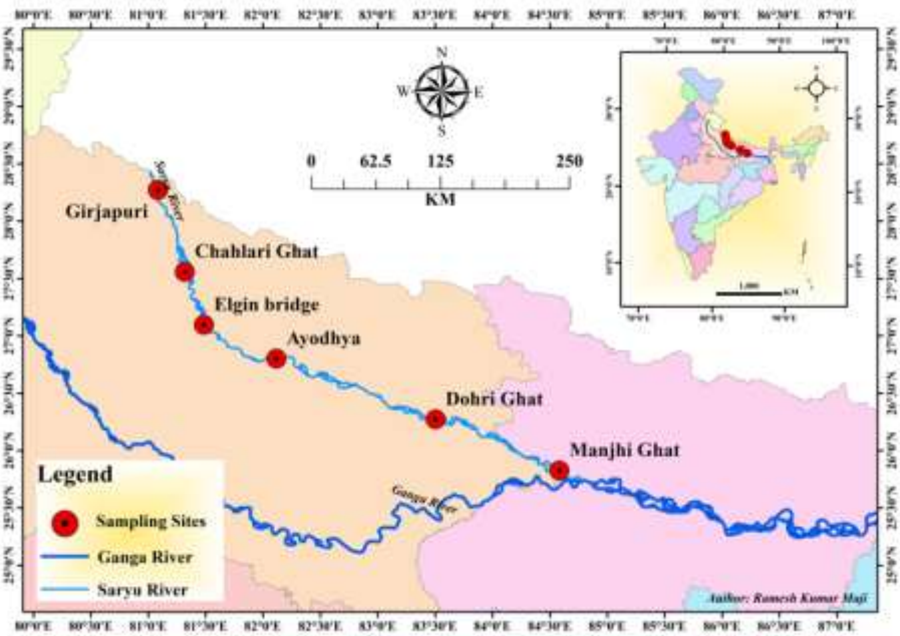


Figure 149: GIS map showing the study sites in river Saryu

5.1.15.2. Water quality

Pre-monsoon (PRM), post-monsoon (POM) and monsoon (MON) samplings were conducted at seven different sites of the Saryu River during the year 2024-25. The variation of different water quality variables during the year is elaborated below. The water temperature varied from 16.7°C (Girija AB) during POM to 31.8°C (Manjhi ghat) during MON. The lowest depth of 1.2 m (Chahlari ghat), whereas the highest depth of 5.6 m was observed at Girija AB during the PRM and POM seasons, respectively. Transparency during MON gets reduced to a great extent due to the flow contained by the river. The lowest transparency value of 5 cm (Dohri Ghat), while the highest, 260 cm, was observed during POM (Girija AB). Very high values of turbidity were obtained during MON (1097 NTU, Guptar ghat) and a low value (4.85 NTU, Girija AB) during POM. The pH of the river was found to be slightly alkaline to alkaline in nature, with a maximum value of 9.23 (Dohri ghat) during POM. The highest DO concentration of 12.4 mg/L was observed at Dohri Ghat (POM) and the lowest, 6.0 mg/L, at Manjhi Ghat (PRM). During the pre-monsoon period, a higher value of 190 mg/L was recorded at Dohri Ghat, and a lower value of 124 mg/L was recorded at Girija BB. During PRM, maximum alkalinity (180 mg/L) was obtained at Dohri Ghat, which gets reduced by dilution (104 mg/L) in MON at Girija AB. A similarly reduced hardness value (98 mg/L, Manjhi Ghat) in MON and a peaked value (154 mg/L, Guptar Ghat) in PRM were observed. The conductivity of the river during MON was reported as minimum (218 µS/cm) at Girija AB and maximum (344 mg/L) during POM at Girija BB. A maximum value (0.287 mg/L) of phosphorus was observed at Dohri Ghat (PRM), while a minimum value (0.018 mg/L) was observed at Dohri Ghat (MON). The river's flood discharge during the MON reported a notable rise in the level of nitrogen (0.919 mg/L) at Manjhi Ghat and in PRM a reduced value (0.434 mg/L) at Girija AB. During MON, the highest value of available silicate (10.52 mg/L) was found at Chahlari Ghat, while during PRM, the lowest value (5.96 mg/L) was at Dohri Ghat. Chlorinity of the river Saryu ranges from 0.5 mg/L (MON) to 6.5 mg/L (PRM). The pollution parameter BOD crosses the limit at Dohri Ghat (3.6 mg/L) during POM. During the POM, the minimum COD value of 7.55 mg/L was obtained at Chahlari ghat, and in MON, the maximum value of 94.73 mg/L was obtained at Dohri Ghat. TS and TSS were reported to be high during MON at Chahlari Ghat. Overall, the water quality of the Saryu River was under the national and international norms, except in the case of BOD and turbidity parameters at a few sites.

5.1.15.3. Sediment quality of the River Saryu

Sediment samples were collected from seven different sites of the Saryu River during April 2024 to January 2025. The seasonal variation among different sediment quality parameters is described below. The highest and lowest sand content was reported at Girija AB during the MON and in PRM, respectively. The sand proportion decreased during MON due to an increase in silt (0.28 – 29.85%) and clay (10.86 – 20.96%) content. The pH was found slightly acidic to alkaline, with the highest value of 9.54 at Chahlari Ghat (PRM) and the lowest, 6.3, at Manjhi Ghat (POM). The specific conductance during PRM was estimated at 0.066mS/cm (Elgin Bridge, POM) and 0.467mS/cm (Girija AB, PRM). The minimum value of organic carbon was 0.03% and the maximum was 0.48% at Dohri Ghat (POM). Total phosphorus during PRM was found minimum of 0.09 mg/100g at Girija AB and a maximum of 83.08 mg/100g during POM at Elgin Bridge. During PRM lowest value of available nitrogen, 1.68 (Chahlari ghat) and the highest, 20.72 mg/100g (Dohri Ghat) during POM were recorded. The calcium carbonate ranged from 7 to 17.5 % at Dohri Ghat during MON and POM, respectively. The river Saryu demonstrated a strong interaction between water and soil.

5.1.15.4. Plankton and the Periphyton Community

An analysis of the phytoplankton and periphyton communities in the Saryu River revealed significant seasonal variations (n=56). During the post-monsoon season, Bacillariophyceae and Chlorophyceae were the most abundant phytoplankton groups, with notable dominance at Manjhighat. In contrast, the Cyanophyceae group saw a sharp increase during the monsoon season, reaching their highest density at Chalharighat (288,000 cells/L). This surge is likely attributed to increased water flow. However, the abundance of Cyanophyceae declined in the post-monsoon period. Phytoplankton density overall decreased during the monsoon (5,413,714.286 cells/L), which was also reflected in the periphyton community. The pre-monsoon season recorded the highest total periphyton density (18,320,000 cells/cm²). However, this density dropped significantly during the monsoon, mainly due to strong water currents and the lack of stable substrata. The diversity and abundance of zooplankton populations in the Saryu River showed notable seasonal variations. Notably, members of the phyla *Rotifera* and Arthropoda exhibited peak abundance during the post-monsoon season, with 5 and 3 species identified, respectively. In contrast, zooplankton density declined during the monsoon period, with only 3 species recorded. The Manjhighat site recorded the highest zooplankton density during the post-monsoon phase, with a density of 11 no./l. Overall, post-monsoon conditions appeared to support greater zooplankton abundance, likely due to increased water stability and nutrient availability.

5.1.15.5. Benthic diversity and abundance

Identification of twenty macro-benthic species, belonging to seven orders and eleven families, from the Saryu River, including 13 gastropods, 5 bivalves, and 2 insects were identified. The location with the most macro-benthic species was 600 Elgin Bridge, followed by 397 individuals/m² at Chalhari Ghat, 361 individuals/m² at Ayodhya, 311 individuals/m² at Girjapuri AB, 297 individuals/m² at Dohrighat, 261 individuals/m²at Girjapuri BB, and 225 individuals/m² at Manjhi Ghat. The pre-monsoon season showed an increase in benthic diversity and richness along the Saryu River. During the post-monsoon season, the highest 389 individuals/m² gastropods were observed at Girjapuri AB, followed by 217 individuals/m² bivalves at Ayodhya and 130 individuals/m² insects at Elginbridge. On the other hand, during the pre-monsoon, the highest 433 individuals/m² of bivalves were observed at Chalhari Ghat, followed by 325 individuals/m² of gastropods at Elginbridge and 238 individuals of insects at Elginbridge. The dominated bivalves were 433 individuals/m², followed by 261 individuals/m² of gastropods and 65 individuals/m² of insects from Elgin Bridge during the monsoon season. Macro benthic diversity of the river Saryu exhibits seasonal variations from all the sampling sites. *Gyraulus convexiusculus*, *Bellamya bengalensis* and *Corbicula striatella* remained the most widespread species while species diversity shifted slightly with seasonal changes. Macro benthic diversity of the river Saryu exhibits seasonal variations from all the sampling sites. *Gyraulus labiatus* (22 individuals/m²) was observed during the monsoon season at Girjapuri BB. *Mekongia crassa* (22-43 individuals/m²) was recorded from Manjhi Ghat, Dohrighat and Elginbridge during the pre-monsoon and monsoon seasons, respectively (Fig. 150).

Figure 150: Macro-benthos Diversity of river Saryu

5.1.15.6. Fish diversity

Across pre-monsoon, monsoon, and post-monsoon surveys in 2024 in the Saryu River, 84 fish species were recorded. Spatially, Dohri Ghat recorded the richest assemblage during the post-monsoon season (n = 47), followed by Girijapuri Barrage in the pre-monsoon (n = 40). In contrast, the lowest species counts were observed in the post-monsoon period at Elgin Bridge (n = 11) and Ayodhya (n = 14). Seasonally, fish diversity peaked in the post-monsoon (n = 64), closely followed by both pre-monsoon and monsoon (n = 63 each), indicating fairly uniform richness outside the monsoon flush. At the order level, Cypriniformes, constituting 40% of total abundance, dominated (Fig. 151). Siluriformes accounted for 28%, underscoring the ecological role of catfish in the Saryu fish community.

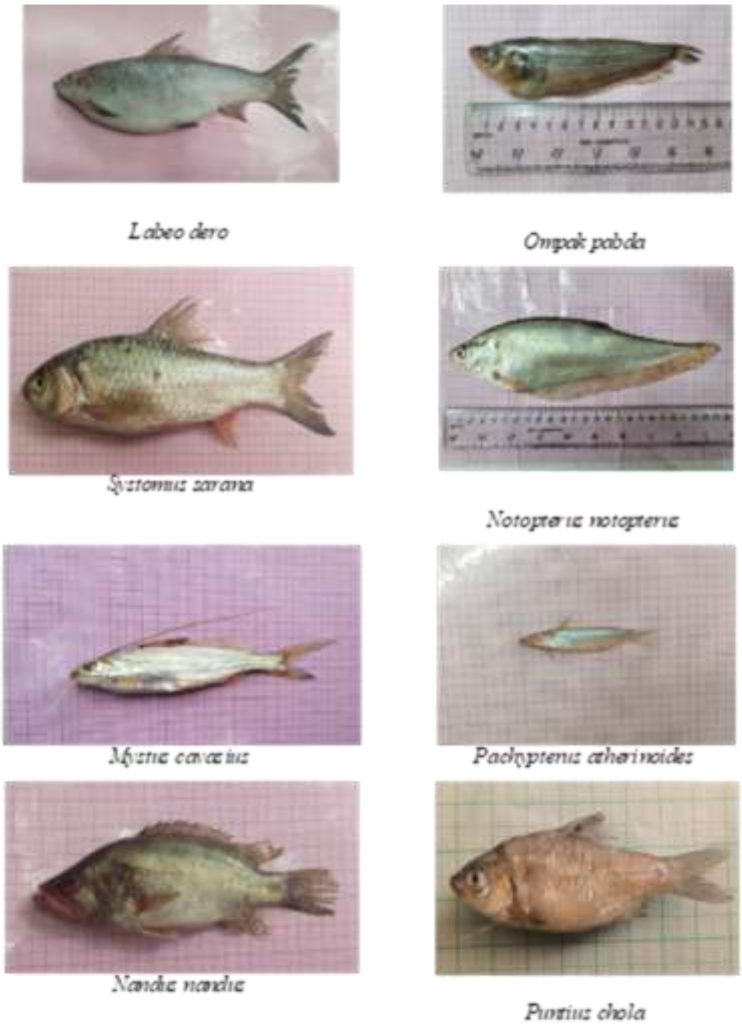


Figure 151: Fish diversity of river Saryu

5.1.15.7. Fishing crafts and gear

In the Saryu River, ranging from its mountainous upper reaches to the plains before Ayodhya, local fishers employ a variety of traditional, non-mechanised crafts and gears adapted to the river's flow regimes and target species. Gill nets are widely used in the Saryu River, especially for targeting fish species such as cyprinids. Hook and line are also a popular and straightforward method for catching individual fish. Drag nets are used in deeper areas of the Saryu River (Fig. 152).

Figure 152: Field activities and habitat status of river Saryu

5.1.15.8. Conclusion

The ecological appraisal of the Saryu River reveals moderate to significant seasonal fluctuations in water quality, biotic communities, and sediment dynamics across its longitudinal stretch. While overall water parameters remain within permissible limits, monsoon-driven turbidity and elevated BOD and COD values at sites like Dohri Ghat signal episodes of pollution stress. Reduced transparency and increased nutrient concentrations during monsoon and pre-monsoon seasons further indicate catchment runoff and anthropogenic influence. Sediment analysis shows increased silt and clay fractions during monsoon, with a rise in organic carbon, nitrogen, and phosphorus in the post-monsoon, highlighting sediment-bound nutrient transport. Planktonic and periphytic communities' exhibit pronounced seasonal trends, with Cyanophyceae dominance in monsoon and Bacillariophyceae flourishing post-monsoon. Periphyton density was highest in pre-monsoon, while zooplankton richness peaked post-monsoon due to improved water stability and nutrient levels. Macro-benthic fauna was dominated by gastropods and bivalves, with seasonal shifts in composition and density, particularly at Elgin Bridge and Chahlari Ghat. A total of 84 fish species were recorded, with peak richness during the post-monsoon, especially at Dohri Ghat, and Cypriniformes and Siluriformes forming the dominant orders. However, some sites such as Elgin Bridge showed notably reduced post-monsoon diversity. Overall, the findings highlight the ecological resilience of the Saryu River, yet underscore the need for targeted habitat protection and pollution control to ensure the long-term health of its aquatic ecosystems.

5.1.16. YAMUNA RIVER

The Yamuna River is the second-largest tributary of the Ganges by discharge and the longest tributary in India. The Yamuna originates from the Yamunotri Glacier at an altitude of about 4,500 meters (14,800 feet) on the southwestern slopes of the Bandarpunch Peaks in the Lower Himalayas of Uttarakhand. The river has a length of 1,376 kilometres (855 miles) and covers a drainage area of about 366,223 square kilometres (141,399 square miles), which makes up 40.2% of the entire Ganges Basin. The Yamuna River plays a crucial role in supporting the livelihoods of nearly 57 million people, making it one of the most vital water sources in northern India. The river provides drinking water and irrigation to 57 million people across multiple states. The river Yamuna, particularly in Delhi, is one of the most polluted rivers in India. Two major stretches that highlight the severity of pollution are ITO and Wazirabad, both critically impacted by untreated sewage, industrial effluents, and solid waste. The Yamuna River holds immense religious and mythological significance in Hinduism, similar to the Ganges. According to Hindu mythology, the Yamuna originated in heaven and descended to Earth due to the penance of the Seven Sages. The Rig Veda includes Yamuna among the seven sacred rivers, alongside the Ganges, Saraswati, and Godavari.

5.1.16.1. Study area

Ten sampling sites were selected along the entire river Yamuna, viz. Barkot (Uttrakhand), Dakpathar (Uttrakhand), Yamunanagar (Haryana), Sonia Vihar, ITO (New Delhi), Agra, Pachnada, Hamirpur, Chilaghat and Prayagraj (Uttar Pradesh) (Fig. 153).

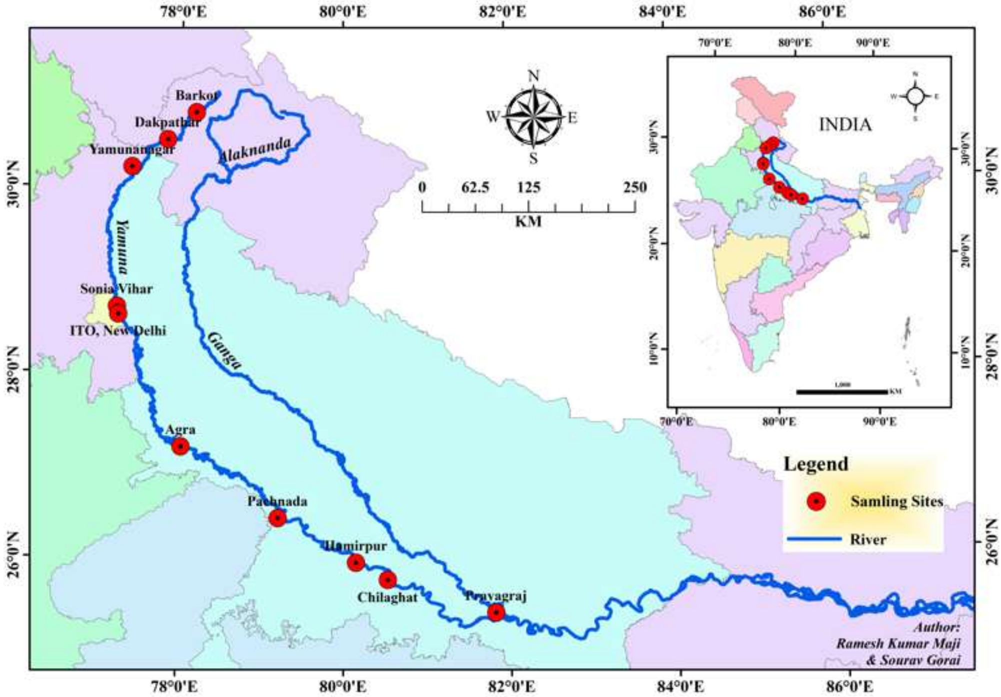


Figure 153: GIS map showing the study sites in river Yamuna

5.1.16.2. Water quality

The water quality of the river Yamuna was assessed during the pre-monsoon (PRM), monsoon (MON) and post-monsoon (POM) seasons, showing significant spatial and temporal differences among physical, chemical and biological parameters. The shallower depth of 0.45 m was recorded at Dakpathar during the POM and the deeper of 19.5 m at Pachnada during MON. The PRM temperature peak of 33.1°C was recorded at Prayagraj and decreased during POM (9.5°C) at Barkot due to climate conditions. Transparency was found to be highest (83.3 cm) at Prayagraj and lowest (7 cm) at ITO, with turbidity ranging from 3.22 to 835 NTU (Dakpathar), indicating monsoonal runoff impact. Very high conductivity (1961 µS/cm) was seen at ITO during PRM and reduced (104.7 µS/cm) during MON at Dakpathar due to dilution. The pH of the river ranged from slightly alkaline (7.4) to alkaline (9.31) in nature. Dissolved oxygen was found to be highest (14.8 mg/L) in POM at Dakpathar and lowest (0 mg /L) in PRM at ITO, suggesting sewage influences. Total alkalinity peaked (480 mg/L) during POM at ITO and dropped (36 mg/L) at Barkot during MON. Total hardness was recorded at 52 mg/L at Barkot and 392 mg/L at ITO during PRM. Lower and higher values of chlorinity and salinity were obtained during POM and PRM, respectively. Nutrient levels vary with phosphorus highest during PRM at ITO (8.487 mg/L), maximum nitrogen (4.371 mg/L) at ITO during POM and silicate concentration highest (19.868 mg/L) at Agra during PRM. Pollution-indicating parameters show elevated BOD levels of 31.8 mg/L and COD 118.8 mg/L during POM and PRM at ITO and Agra, respectively. TS and TSS were reported to be high during MON at Dakpathar. Highly degraded water quality of the river Yamuna was found from Sonia Vihar to Agra, which creates a serious threat to aquatic biota.

5.1.16.3. Sediment quality of the River Yamuna

The sediment quality of the river Yamuna represented greater spatial and seasonal differences, as described below. The sediment pH ranged from slightly alkaline to alkaline in nature (6.77 - 9.31), increased during POM and decreased during PRM. Specific conductivity was found highest (2.76 mS/cm) during PRM and lowest (0.073 mS/cm) during POM. Calcium carbonate content increasing (12%) during PRM and decreasing (2%) during POM. Sand content (58.84-89.59%) dominated the sediment texture throughout all seasons, with a slight rise in silt and clay content during MON. Total phosphorus and available nitrogen concentration were found highest at 131.79 and 33.6 mg/100 g, respectively, during POM and PRM. Organic matter also varied seasonally (0.03-2.25%), reflecting changes in organic input, runoff and decomposition. Overall, these patterns indicate a strong relationship between water and sediment interaction in the river.

5.1.16.4. Plankton and the Periphyton Community

The analysis of phytoplankton and periphyton communities in the Yamuna River revealed marked seasonal variations (n=81). During the post-monsoon season, phytoplankton groups such as Bacillariophyceae and Chlorophyceae were the most dominant, particularly at the Railway Bridge in Agra. This dominance can be attributed to warmer temperatures, adequate sunlight penetration, nutrient-rich conditions, and stable water currents. Cyanophyceae peaked during the pre-monsoon season, reaching the highest density of 6,864,000 cells/L at Hamirpur. However, their abundance declined during the post-monsoon season, as water flow stabilised and eutrophication levels decreased. Overall, phytoplankton density dropped significantly during the monsoon (recorded at 1,282,020 cells/L), a trend also observed in the periphyton community. The highest total periphyton density was observed during the pre-monsoon season (12,874,000 cells/cm²), whereas densities dropped substantially during the monsoon, primarily due to strong water currents. The zooplankton community structure in the Yamuna River exhibited pronounced seasonal fluctuations**.** Among the observed taxa, members of the class *Rotifera* were most prevalent during the post-monsoon period, with a total of 17 species recorded. In contrast, zooplankton diversity and density declined markedly during the monsoon season, with only six species identified. The post-monsoon phase registered the highest zooplankton density, reaching 848 ind/l. Overall, the post-monsoon period was characterised by elevated zooplankton abundance. However, the rain during the monsoon seemed to boost the growth of zooplankton by adding nutrients and causing eutrophication from water runoff, even though there were fewer types of species.

5.1.16.5. Benthic diversity and abundance

28 macro-benthic species belonging to 11 orders and 21 families were documented across 10 sampling sites along the Yamuna River, spanning from Barkot to Prayagraj during the 2024 sampling period (Fig. 154). The highest macro-benthic density was observed at the Barkot site during the post-monsoon season, with 1,472 ind/m²; in the pre-monsoon season, density reached 801 individuals/m². The dominant benthic species were recorded during the pre-monsoon season, such as *Lymnaea acuminata*, *Physella acuta*, *Indoplanorbis exustus*, *Bellamya bengalensis* and *Gyraulus convexiusculus,* while some species, mostly insects (*Brachycentrus* sp., *Leptocella* sp., *Simulium* sp. and other species, were absent. The maximum abundance of the *Chironomus* sp. was observed at 87 inds/m² at Yamuna Nagar and the minimum at 22 ind/m² at Dakpathar. *Lymnaea acuminata* and *Physella acuta* 152 ind/m² and 130 individual/m² were recorded only from Prayagraj (Fig. 154). *Caenis* sp., belonging to the class Insecta, order Ephemeroptera, and family Caenidae, and *Thraulodes* sp., class Insecta, order Ephemeroptera, and family Leptophlebiidae, was observed only from Barkot. Macro benthic diversity of the river Yamuna exhibits seasonal variations at all the sampling sites. The benthic diversity dominated in the pre-monsoon and post-monsoon seasons, with 607 ind/m² only at the Prayagraj site, while at Dakpathar, ITO and Soniavihar, the least benthic species were observed during the pre-monsoon season.

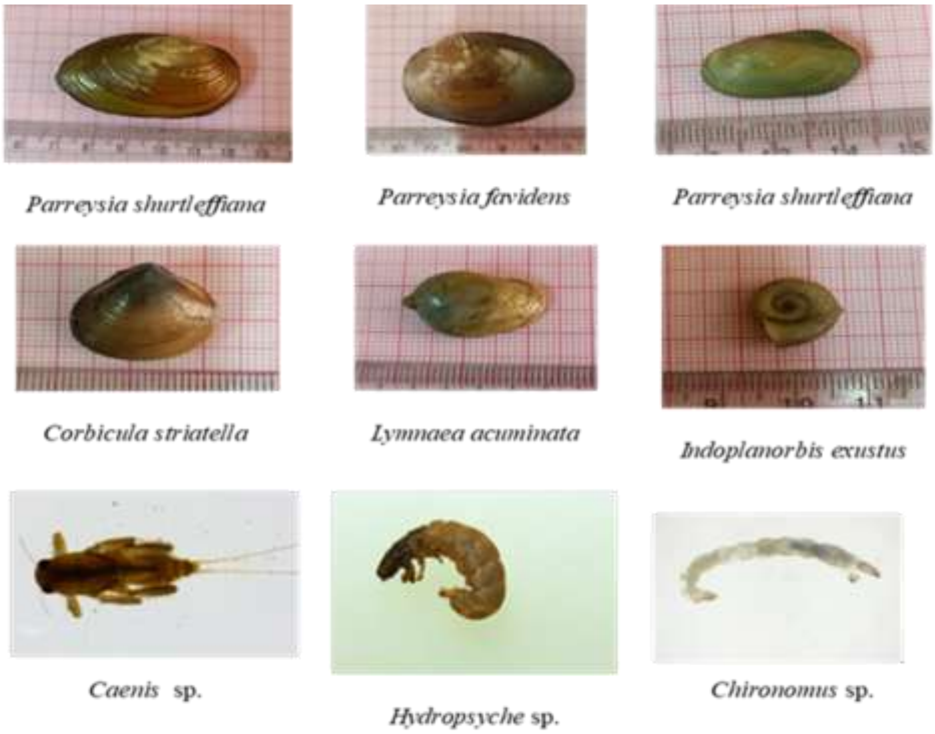


Figure 154: Macro-benthos of river Yamuna

5.1.16.6. Fish Diversity

A total of 85 species were identified from River Yamuna. Site Hamirpur (n = 32) has the highest reported fish diversity, followed by Yamunanagar (29) and Sonia Vihar (28) (Fig. 155). During the pre-monsoon, no fish species were reported from ITO, New Delhi, due to extremely poor water quality, primarily due to the discharge of untreated domestic sewage, industrial effluents, and solid waste from multiple drains. Seasonally, the highest fish diversity was reported during post-monsoon (n = 53), followed by pre-monsoon (n=51) and monsoon (n=45). The order-wise taxonomic composition revealed that Cypriniformes was the most dominant fish order in the Yamuna River, accounting for 40% of the total fish abundance, followed by Siluriformes, which contributed 28%, indicating their significant presence in the river's fish community. A remarkable observation during the monsoon sampling at the ITO stretch of the Yamuna River was the presence of Nile tilapia fish species. Despite the generally degraded water quality and absence of native fish fauna in this stretch due to low DO and high pollution load, the increased water flow and dilution effect during the monsoon likely improved water quality temporarily, enabling the occurrence of Tilapia.

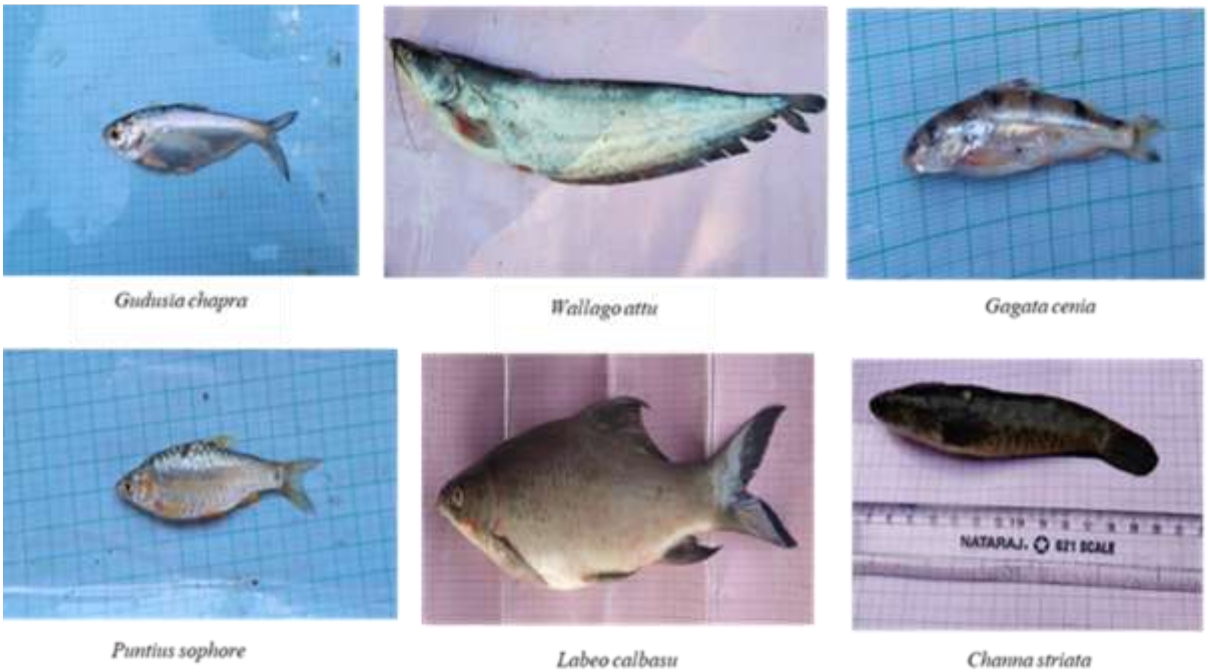


Figure 155: Fishes of River Yamuna

5.1.16.7. Fishing crafts and gear

In the upper and middle reaches of the Yamuna, local fishers rely on small, non-mechanised crafts and artisanal gears adapted to the river's depth, flow, and target species. Fishing crafts used are dugout canoes and plastic rafts. The fish gears used are gill nets, cast nets, drag nets, scoop nets and hook and line (Fig. 156).

Figure 156: Field activities and habitat status of river Yamuna

5.1.16.8. Conclusion

The Yamuna River exhibits significant spatial and seasonal variations in water and sediment quality, biological diversity, and pollution levels. Pre-monsoon and post-monsoon seasons show higher biological productivity compared to the monsoon due to stable conditions and reduced runoff. Water quality is severely degraded at urban stretches, especially from Sonia Vihar to Agra, marked by high BOD, COD, and low DO levels. Sediment characteristics reflect the influence of seasonal runoff and pollution inputs. Plankton and benthic communities display seasonal shifts, with diversity peaking during less turbulent seasons. Zooplankton density increases in post-monsoon due to nutrient influx. Fish diversity is highest at less polluted sites, while stretches like ITO show absence of native fish. Artisanal fishing methods dominate, with adaptations to river conditions. Overall, pollution and anthropogenic pressures pose serious threats to aquatic ecosystems. Conservation and pollution mitigation are urgently needed to restore ecological balance.

5.2. OBJECTIVE II: CHARACTERIZING THE FISH STOCK IN IMPORTANT FISH IN THE SELECTED TRIBUTARIES AND WETLANDS OF GANGA RIVER BASIN

5.2.1. Stock assessment based on fish morphometrics in the selected tributaries of Ganga River Basin

Morphometric variation of three fish species viz. *Puntius conchonius* (Rosy Barb), *Ailia coila* (Gangetic Ailia), and *Setipinna phasa* (Long hairfin Anchovy) was carried out from three distinct locations of the Gangetic Basin. Specimens were collected from the main channel of the river Ganga, the river Jalangi, and the river Damodar, respectively, in West Bengal. The results illustrated significant differences in the morphometric characters of the three fishes across the three rivers. For *Puntius conchonius*, seven characters (TW, TL, SL, MBD, ED, IOL, and CPL) showed significant variation. For *Setipinna phasa*, a single character (SNL) exhibited significant differences. In contrast, for *Ailia coila*, 14 characters (TW, TL, SL, HL, MBD, SNL, ED, IOL, PPeL, PPvL, PAL, CD, CFL, and CPL) varied significantly across locations. A major variation in the morphometrical changes was also revealed by the Linear Discriminant Analysis (LDA) between the characters (Fig. 157). The difference can be linked to the variations in ecological status and feeding habits of these fish in different river systems.

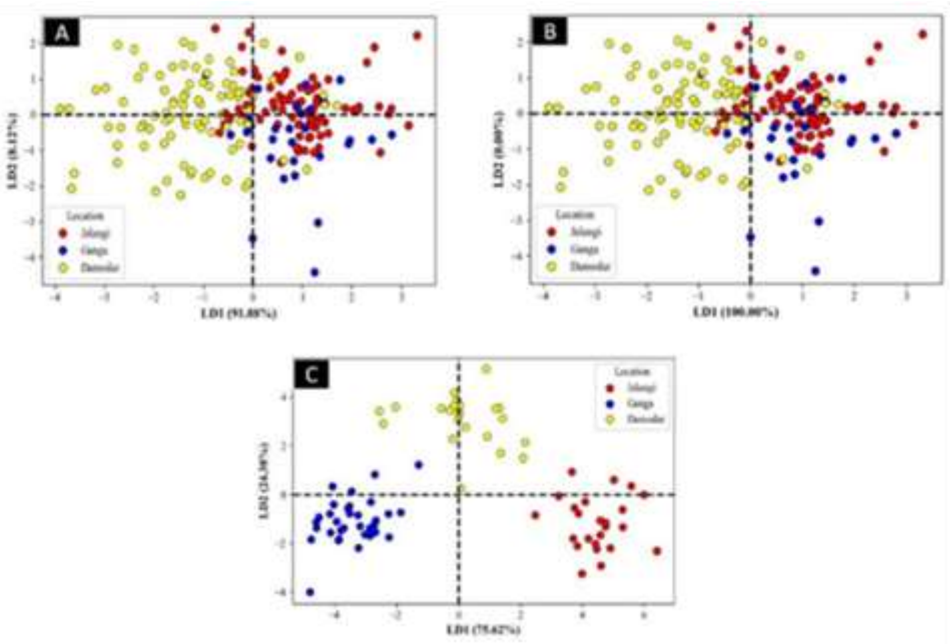


Figure 157: Linear Discriminant Analysis Analysis (LDA) between the morphometric values of three fishes

Significant differences were observed in the morphometric characters of the three fish species across the three locations—Jalangi, Ganga, and Damodar—based on the Kruskal-Walli's test ($p < 0.05$).

Table 13: Details of morphometric characterstics of three fishes from Gangetic tributaries according to the Kruskal-Wallis Statistic test

Morphometric Characters	*Setipinna phasa*	*Ailia coila*	*Puntius conchonius*
Total weight (TW)	15.515	64.327*	15.515*
Total length (TL)	16.340	62.931*	16.340*
Standard length (SL)	17.917	62.12*	17.917*
Head Length (HL)	2.306	47.018*	2.306
Mean Body Depth (MBD)	6.860	55.179*	6.860*
Eye diamter (ED)	17.942	60.154*	17.942*
Pre Dorsal length (PDL)	2.7674	--	2.767
Inter Orbital Length (IOL)	15.6102	50.786	15.610*
Snout Length (SNL)	4.1823*	41.627*	4.182
Pre Pelvic Length (PpeL)	2.9281	58.536*	2.928
Post Pelvic Length (PPvL)	5.1896	61.993*	5.189
Pre Anal Length (PAL)	5.3318	63.831*	5.331
Caudal Depth (CD)	4.1785	54.776*	4.178
Caudal Fork Length (CFL)	0.475	60.524*	0.475
Caudal Peduncle Length (CPL)	28.307	30.643*	28.30*

*Significant at p<0.05 TW-g

5.2.2. Stock status of two commercially important catfishes, *Mystus gulio* (Hamilton 1822), and *Mystus cavasius* (Hamilton 1822) from River Ganga

Mystus gulio and *Mystus cavasius* are small indigenous catfish species (SIFs) found throughout the year at various stretches of the river Ganga and contribute significantly to the commercial fishery. The current study was conducted with a total of 609 specimens of *M. gulio* with a total length ranging from 84 to 190 mm and 377 specimens of *M. cavasius* of total length ranging from 51 to 232 mm, collected from eight selected sites of lower stretches of the river Ganga to analyze the growth, mortality, and exploitation status. The sample specimens' length-frequency distribution, primarily taken from bag nets and set barrier nets used in artisanal fisheries, was assessed using the FiSAT II programme (Fig. 158). For *M. gulio*, the estimated asymptotic length ($L\infty$), growth coefficient (K), and initial condition factor (t_0) were 183.23 mm, 0.31 yr^{-1} and -0.486 years and for *M. cavasius*, 246.23 mm, 0.19 yr^{-1} and -0.302 years, respectively. The estimates for the total (Z), natural (M), and fishing (F) mortality rates were 1.78, 0.49, and 1.29 yr^{-1}, for *M. gulio* and 0.68, 0.33 and 0.35 yr^{-1}, for *M. cavasius*, respectively. A single spawning peak was observed for both *M. gulio* (May to July) and *M. cavasius* (June to August). The estimated exploitation ratio (E) for was 0.72, indicating overexploitation, as E is considerably higher than *M. gulio* the optimum level of exploitation (E_{opt}) and maximum exploitation level (E_{max}), whereas, the E value for *M. cavasius* was 0.52, showing an optimum level of exploitation. The fishing pressure was found to be slightly excessive for the current stocks of *M. gulio*, which should be considered for proper management of the fishery in the river Ganga. The present study, highlights the stock status of these two commercially important species and the management measures taken to revive the stock along the lower stretches of the Ganga in India. The environmental parameters of the lower stretches of the river Ganga exhibited favourable conditions for the optimum growth of *M. gulio* and *M. cavasius* (Fig. 159).

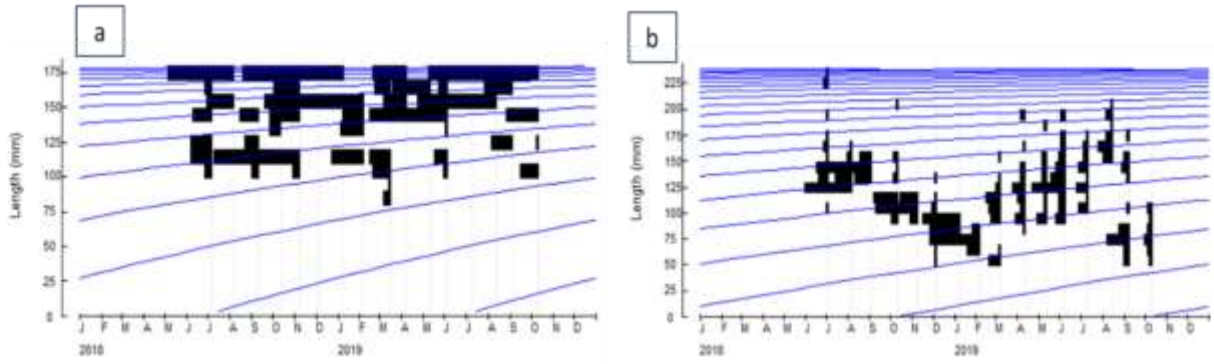


Figure 158: Length-frequency distribution and seasonal occurrence of *M. gulio* (a) and M. *cavasius* (b) along the lower stretches of the river Ganga

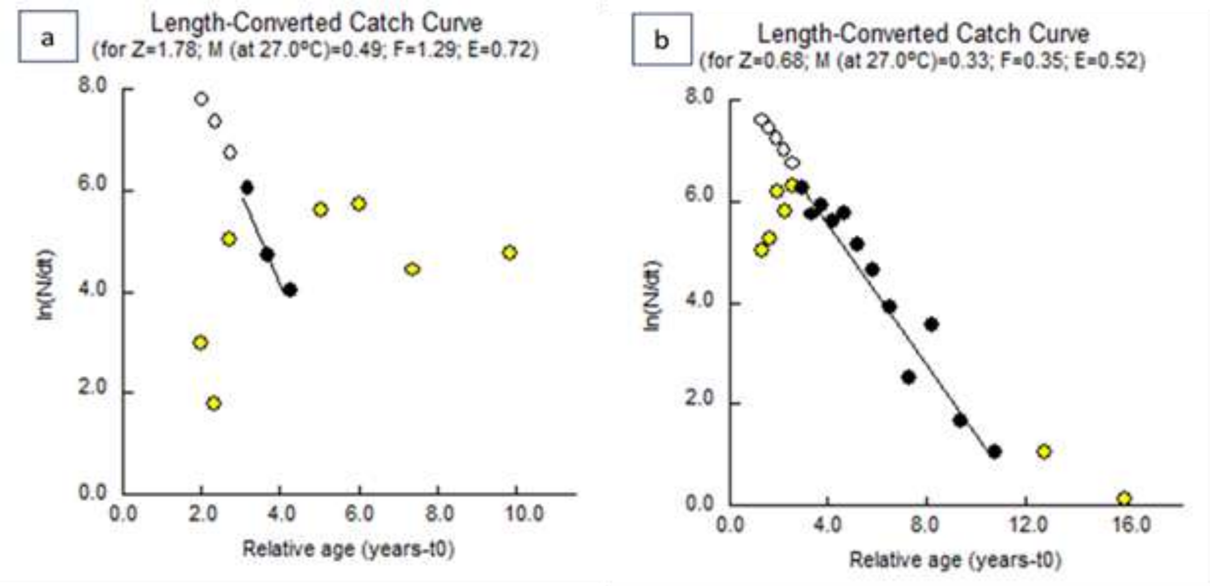


Figure 159: Length converted catch curve for estimation of total mortality (Z) for *M. gulio* (a) and *M. cavasius* (b) along the lower stretches of river Ganga

5.3. OBJECTIVE III: CHARACTERIZING DIFFERENT HABITAT TYPES BASED ON QUANTITATIVE AND QUALITATIVE ATTRIBUTES IN THE SELECTED TRIBUTARIES AND WETLANDS OF GANGA RIVER BASIN

5.3.1. Ecological survey in selected wetlands of River Ganga

Wetland contributes adversely to the livelihood of millions of people. Wetland ecology plays a crucial role in maintaining the health and functionality of river ecosystems. Wetlands, which include marshes, swamps, and bogs, serve as buffers between land and water, helping to filter pollutants, regulate water quality, and prevent soil erosion. By absorbing excess nutrients and contaminants, wetlands improve the water quality flowing into rivers and protect aquatic life from harmful substances. Furthermore, wetlands act as vital habitats for a diverse range of species, contributing to biodiversity and supporting food chains in river ecosystems. Additionally, wetlands provide carbon storage, helping mitigate climate change. In summary, wetlands are integral to the health of river systems, supporting biodiversity, improving water quality, regulating water flow, and offering crucial ecosystem services that benefit both the environment and human populations. Six different floodplain wetlands are selected, four in the state West Bengal (Akaipur, Bijpur, Kundipur and Maniknagar), and two in Uttar Pradesh (Haiderpur and Alwar Tal) (Table 14) (Fig. 160).

Table 14: Details of the wetland surveyed under NMCG phase III (2024)

Particulars	Akaipur	Bijpur	Maniknagar	Kundipur	Haiderpur	Alwar Tal
State	West Bengal	West Bengal	West Bengal	West Bengal	Uttar Pradesh	Uttar Pradesh
Site	Bongaon	Kanchrapara	Char Maniknagar,	Bongaon	Bijnor	Manjhanpur
District	North 24 Parganas	North 24 Parganas	Nadia	North 24 Parganas	Hastinapur	Kaushambi
GPS	23.5473 N, 88.4244E	22.5812 N, 88.25 48 E	23.3136 N, 88.3268E	23.1424 N, 88.8170 E	29.374945	25.415991
River Connectivity	Closed	Closed	Regularly opened (Khari)	Periodically opened (Ichhamati)	Regularly opened (Ganga)	Periodically opened (Yamuna)
Avg. water Area (Ha)	54.63	24.28	12.73	123.27	6908	168.68
Avg. depth (m)	3.47	1.53	0.8	9.75	3.6	2.1
Fishermen (no.)	80	59	44	315	22	18

Figure 160: View of different wetlands A. Bijpur, B. Kundipur, C: Maniknagar, D: Akaipur, E: Haiderpur, F: Alwar Tal

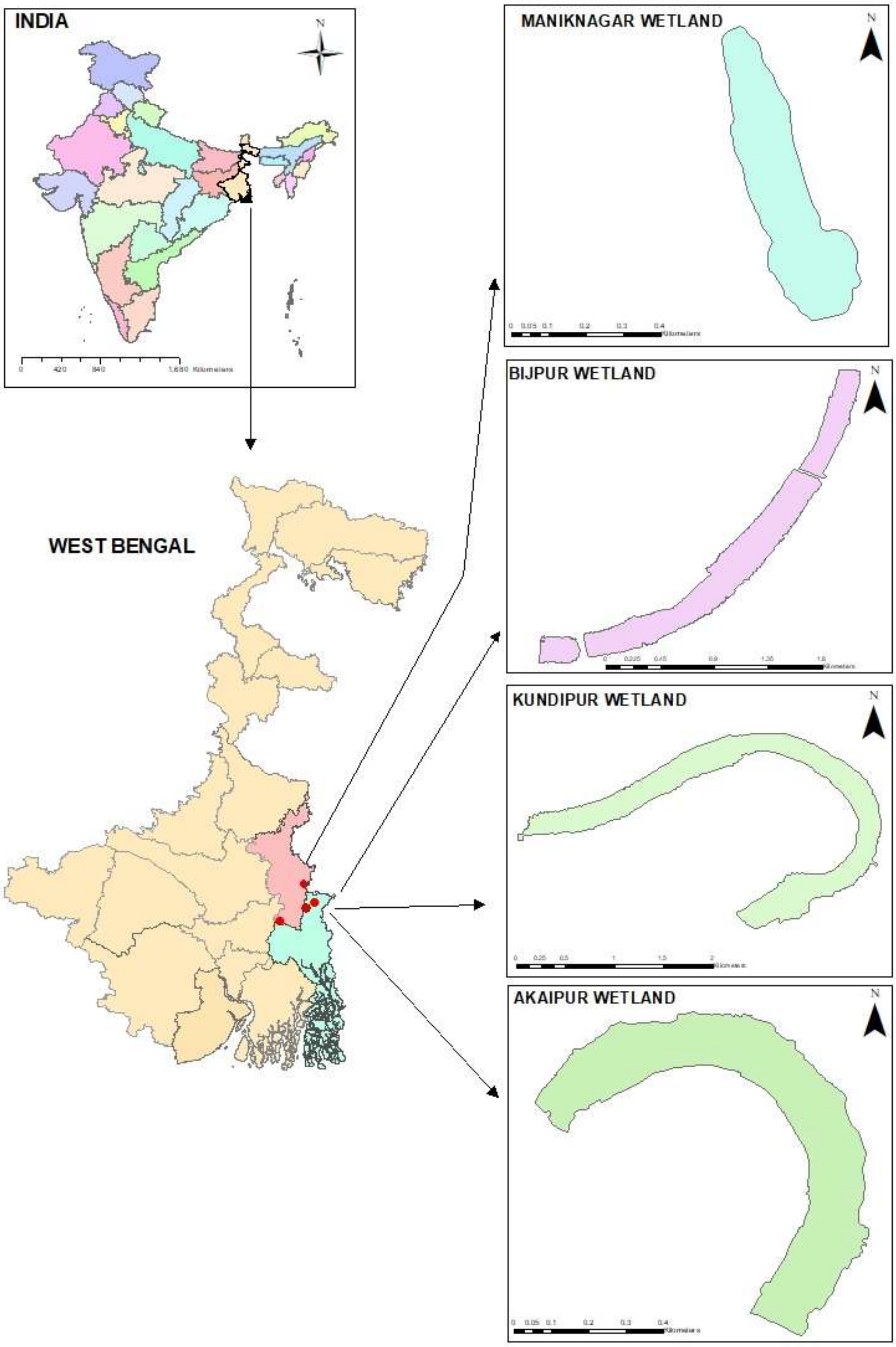


Figure 161: GIS map of the studied wetlands of West Bengal

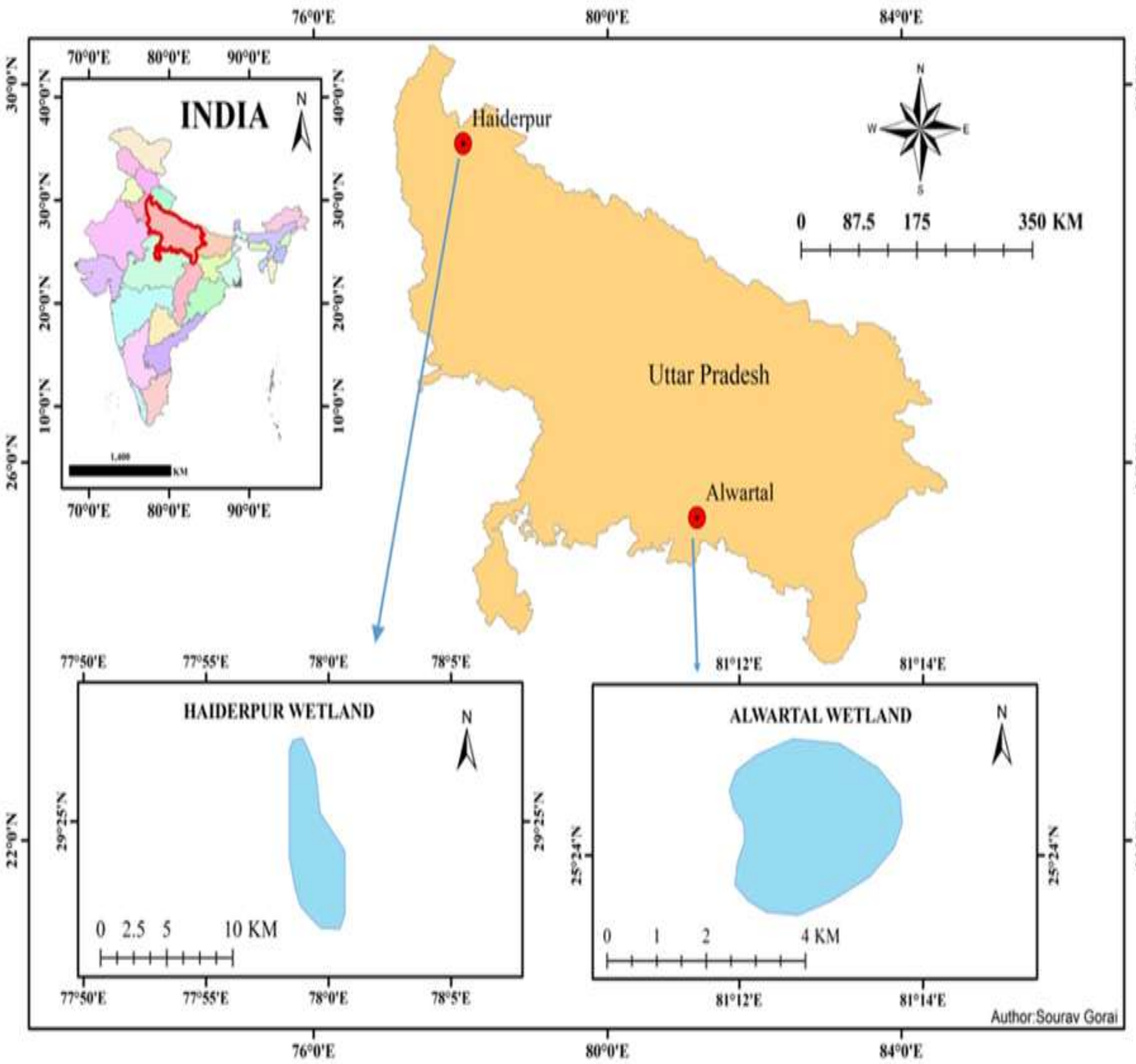


Figure 162: Study area map of Alwara and Haiderpur Wetland of Uttar Pradesh

5.3.1.1. AKAIPUR WETLAND

Akaipur wetland (23.594ºN, 88.431ºE) is an oxbow lake type and ecologically distinct floodplain wetland. It is situated in the North 24 Parganas district of West Bengal (Fig.163). It is a closed wetland with no exchange of water. It has an average area coverage of 32 ha. It receives allochthonous inputs, especially during the rainy season, from surrounding agricultural fields, jute retting, animal husbandry, domestic effluents, etc., but there is no industrial or city waste inflow. These wetlands are utilised for culture-based fisheries and provide livelihood and food support to 500 and 300 households, respectively. Akaipur Dwarbasini Fisheries Cooperative Society manages it. The society comprises 80 members, with a notable presence of two female members, and all belong to the SC category.

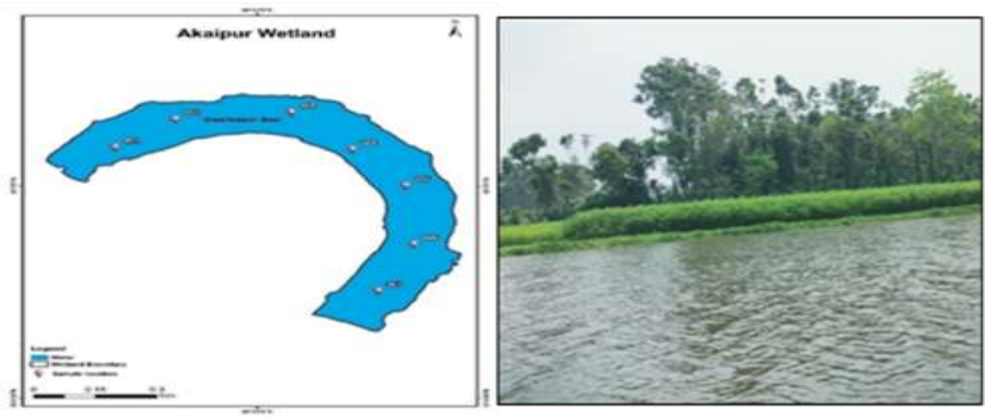


Figure 163: Study area map of Akaipur Wetland

i. Water quality

The Akaipur wetland exhibits notable seasonal variations in its physicochemical parameters, reflecting the dynamic interplay of climatic and hydrological factors. Water temperature ranges from a low of 24.5°C during the post-monsoon period to a high of 36.5°C in the pre-monsoon season, indicating significant thermal fluctuations. Water depth varies from 0.5 m to 2 m, highlighting seasonal hydrological fluctuations. pH levels fluctuate between 4.9 to 8.76, transitioning from slightly acidic to alkaline conditions. Dissolved oxygen (DO) concentrations range from 3.4 mg/L to 8.4 mg/L. Specific conductivity ranges from 175.7 µS/cm to 250 µS/cm, reflecting changes in ion concentration resulting from dilution and evaporation. Turbidity levels range from 6.2 NTU to 41.4 NTU, influenced by suspended particles and organic matter. Total alkalinity fluctuates between 42 mg/L to 64 mg/L at the same site in the pre-monsoon, indicating variations in the buffering capacity of the water. Total hardness ranges from 24 mg/L to 60 mg/L, reflecting changes in mineral content. These seasonal variations underscore the complex and dynamic nature of the Akaipur wetland's ecosystem, influenced by climatic and environmental factors.

ii. Sediment

Sediment pH varied from 6.19 in pre-monsoon to 5.46 in monsoon and slightly increased to 6.08 in post-monsoon. Conductivity was lowest in the monsoon season (327.25 µS/cm) and highest in the post-monsoon season (598.45 µS/cm). Silt-clay content increased during monsoon (18.25%) but dropped post-monsoon, while calcium carbonate rose from 5.1% in premonsoon to 7.83% in post-monsoon. Phosphate levels were consistently high, peaking at 28.35 mg/100g in postmonsoon. Total nitrogen reached 400 mg/100g in monsoon and declined slightly to 350 mg/100g in post-monsoon. Organic carbon remained stable in pre-monsoon (5.19%) and monsoon (5.047%) but decreased to 1.09% in post-monsoon.

iii. Pollution status

Biochemical oxygen demand (BOD) levels range from 0.4 mg/L to 4 mg/L at S5 and S6 in the same period, indicating varying levels of organic matter decomposition. Chemical oxygen demand (COD) fluctuates between 12 mg/L and 40 mg/L, reflecting changes in organic pollutants. Total solids, total dissolved solids (TDS), and total suspended solids (TSS) levels exhibit seasonal variations, with maximum values observed during the pre-monsoon period and minimum values during the monsoon, indicating changes in sediment load and water clarity.

iv. Heavy metal contamination

The analysis of heavy metal contamination revealed distinct seasonal variations in both water and sediment. In water, metal concentrations followed the trend Cu > Cr > As > Pb > Cd, with levels generally increasing from the pre-monsoon to post-monsoon seasons. Copper and Chromium peaked in the post-monsoon season, while Arsenic exceeded the USEPA (2024) limit (>0.01 mg/L) during the monsoon but remained within BIS (2012) standards. In sediment, the highest metal concentrations were recorded during the monsoon due to runoff, following the trend monsoon > pre monsoon > post monsoon. Chromium and Copper showed significant increases in monsoon, while levels declined in post-monsoon, likely due to dilution or sedimentation.

v. Fish diversity

20 fish species belonging to 16 genera, 12 families, and 8 orders were recorded at Akaipur wetland (Table 1). The order Cypriniformes constitutes the largest share in this wetland species diversity, followed by Anabantiformes and Perciformes (Fig. 164). The wetland dominance with SIF's like *Parambassis ranga* (39%), *Puntius conchonius* (15%), *Salmostoma* spp. (14%), *Glossogobius giuris* (10%), *Puntius sophore* (7%), *Macrognathus pancalus* (6%) etc (Fig 2). Air-breathing catfish *Heteropneustes fossilis* were abundant only during the pre-monsoon. In monsoon, only 10 species were observed, with major dominance of SIF *Amblypharyngodon mola* (77%), *Glossogobius giuris* (5%), etc. The abundance of carps like *Cirrhinus mrigala, Labeo rohita, Labeo catla* during monsoon were about 4%.

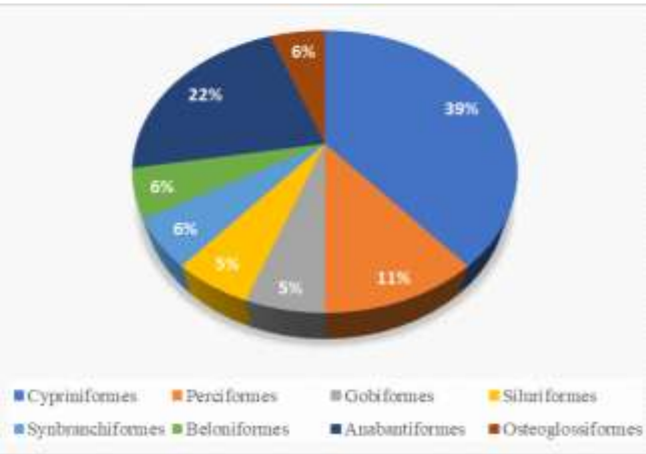


Figure 164: Piscine order (%) in Akaipur wetland

Table 15: Indigenous fish species diversity in Akaipur Wetland

Order	Family	Species
Cypriniformes	Danionidae	*Amblypharyngodon mola*
		Salmostoma acinaes
	Cyprinidae	*Cirrhinus mrigala*
		Labeo rohita
		Labeo catla
		Puntius chola
		Puntius conconius
		Puntius sophore
	Cobitidae	*Lepidocephalichthys guntea*
Anabantiformes	Channidae	*Channa puntata*
	Nandidae	*Nandus nandus*
	Osphronemidae	*Trichogaster fasciata*
		Tricogaster lalius
Perciformes	Ambassidae	*Chanda nama*

		Parambassis ranga
Gobiiformes	**Gobiidae**	*Glossogobius giuris*
Siluriformes	**Heteropneustidae**	*Heteropneustes fossilus*
Synbranchiformes	**Mastacembelidae**	*Macrognathus pancalus*
Osteoglossiformes	**Notopteridae**	*Notopetrus notopetrus*
Beloniformes	**Belonidae**	*Xenentodon cancila*

vi. Plankton and Periphyton Diversity

In phytoplankton and zooplankton communities across seven sites during the pre-monsoon, monsoon, and post-monsoon periods. During the pre-monsoon season, Cyanophyceae (3,900 cells/L) dominated the phytoplankton community, supported by suitable temperature, pH, alkalinity, and nutrient levels, followed by Trebouxiophyceae (1,740 cells/L), Bacillariophyceae (1,704 cells/L), and other minor groups (Fig. 165). The Dinophyceae group was represented solely by *Peridinium* sp. (24 cells/L), thriving under favourable light and nutrient conditions. Zooplankton during this time was dominated by Rotifers (1,344 ind/L), with Arthropoda and Ciliophora also present. During the monsoon season, phytoplankton abundance surged, particularly that of Cyanophyceae (522,880 cells/L), driven by nutrient-rich runoff and favourable environmental conditions. Other prominent groups included Coscinodiscophyceae (106,940 cells/L) and Chlorophyceae (13,080 cells/L). Zooplankton density also increased, with Rotifers (8,940 ind/L) remaining dominant, alongside higher Arthropoda and Ciliophora counts and a minimal presence of Amoebozoa (80 ind/L). Post-monsoon, Euglenophyceae (3,440 cells/L) and Chlorophyceae (3,160 cells/L) were the most abundant phytoplankton, while overall phytoplankton density declined due to nutrient depletion. In contrast, zooplankton populations peaked, especially Rotifers (18,840 ind/L) and Arthropods (3,720 ind/L), as stabilized water conditions and residual monsoon nutrients created favourable conditions for their proliferation (Fig.165)

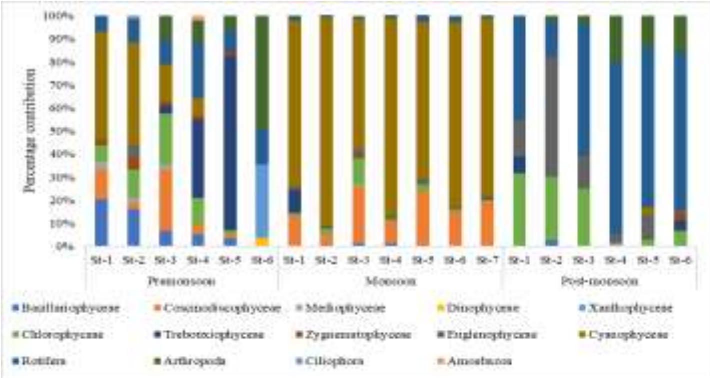


Figure 165: Variation of Plankton (%) abundance in Akaipur wetland

vii. Enhancing Wetland Fisheries through Pen Culture: A Climate-Resilient Strategy in Akaipur Wetland

NMCG showcased innovative techniques like in situ seed raising in pen enclosures to enhance local fish seed production and boost fish productivity (Fig. 166). As part of the NMCG project, ICAR-CIFRI provided HDPE pens, and an outboard engine fishing boat to local stakeholders, stocked 150 kg of indigenous fish seed (*Labeo rohita*, *Labeo catla*, and *Labeo bata*). *Labeo rohita* (5155 nos), *Labeo bata* (9804 nos.) and *Labeo catla* (4941 nos.) were stocked in the HDPE Pen system (0.1ha) in two pens. Over a four-month culture period, the initial stocking size of Labeo *bata* (5.1g), *Labeo rohita* (9.7 g), *Labeo catla* (10.12g) attained 47.49±12.41g, 182.3g, and 239g, respectively. The total harvested biomass reached 375 kg, showcasing the success of CBF practices in enhancing fish production. Over 50 local fishers attended in fish Harvest Mela, gaining insights into sustainable practices and the positive impact on their livelihoods. ICAR-CIFRI continues to promote sustainable aquaculture and community empowerment.

Figure 166: Pen system in Akaipur Wetland

viii. Benthic Diversity

Eight species of macro-benthic fauna from six families were recorded, with Viviparidae being the most dominant (73%), followed by Planorbidae (9%), Thiaridae (7%), Bithyniidae (5%), Insecta (4%), and Lymnaeidae (2%). *Filopaludina bengalensis* (Fig.167) showed the highest abundance in the pre-monsoon season (476 individuals/m²), while *Idiopoma dissimilis* dominated during the monsoon (390 individuals/m²), and a more even distribution was noted post-monsoon, with *Filopaludina bengalensis* still prominent (303 individuals/m²). Dominant species included *Idiopoma dissimilis, Indoplanorbis exustus, Lymnaea luteola, Chironomid* *larvae, Melanoides tuberculata, Gyraulus convexiusculus*, and *Gabbia orcula*. Macro-benthic diversity and abundance peaked in the pre-monsoon season and gradually declined through the monsoon and post-monsoon periods.

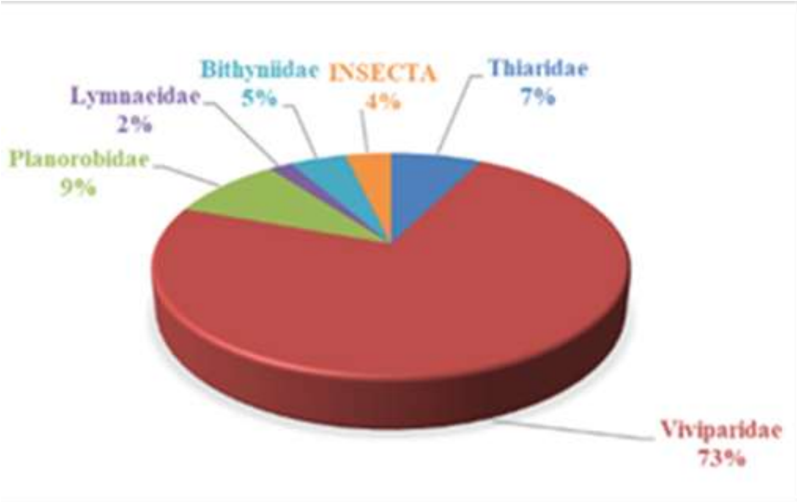


Figure 167: Family-wise (%) distribution of benthos

ix. Assessment of Carbon Sequestration Potential

The dissolved Inorganic Carbon was highest in the monsoon season (8.61±1.72 mg/L) and lowest in the pre-monsoon season (6.41±2.08 mg/L). In contrast, the Dissolved Organic Carbon was highest in the pre-monsoon season (10.83±0.78mg/L) and lowest in the monsoon season (1.76±0.59mg/L. The amount of C deposited in sediment up to a 30 cm layer (99.71 Mg C/ha), whereas in the corresponding reference upland sites, the C accumulation (24.62 Mg C/ha) up to a 0-30 cm layer, respectively. The variation in carbon accumulation was greater in wetland sites than in the corresponding upland sites.

x. Analysis of eBPA Concentrations

BPA concentration decreases from 123.10 ng/L in Pre-Monsoon to 116.69 ng/L in Monsoon, followed by a slight increase to 118.07 ng/L in Post-Monsoon. The fluctuations are minimal, indicating consistent sources of pollution.

xi. Nutrient profiling of Food Fishes

The nutrient profiling of *Amblypharyngodon mola* was carried out from Akaipur wetland. Gross chemical composition identified *Amblypharyngodon mola* as a protein-rich fish. Amino acid analysis revealed that the fish was rich in essential amino acids, such as lysine (0.613 g/100 g) and threonine (0.463 g/100 g), and non-essential amino acids, including aspartic acid (0.224 g/100 g).

Fatty acid composition revealed myristic and palmitic acids as dominant saturated fatty acids. Oleic acid was the most common MUFA, while docosahexaenoic acid (DHA, C22:6) was the dominant PUFA.

xii. Microplastic abundance in Akaipur wetland

Microplastic analysis of the wetland across different seasons revealed notable trends in both water and sediment samples. In the pre-monsoon period, water samples showed a moderate presence of fragments (21 items/L) and fibres (17 items/L), along with traces of foams (1 particle/L); sediment samples exhibited higher concentrations with fibres (41 items/kg) and fragments (35 items/kg), and minor occurrences of films (1 particle/kg) and foams (2 items/kg) (Fig. 168). During the monsoon season, water samples recorded a significant rise in fragments (41 items/L) and fibres (22 items/L), with the only detection of beads (1 particle/L) in the entire study; sediment samples reflected stable fragment levels (40 items/kg) but reduced fibre content (15 items/kg), along with a slight increase in films (2 items/kg) and foams (2 items/kg). The post-monsoon period showed the highest levels of fibres (36 items/L) and fragments (45 items/L) in water, accompanied by minimal presence of films and foams (1 particle/L each). Sediment samples during this season also registered the highest overall microplastic load, with fragments (72 items/kg), fibres (25 items/kg), and increased detection of films (3 items/kg) and foams (3 items/kg). Beads remained largely absent in sediment throughout all seasons.

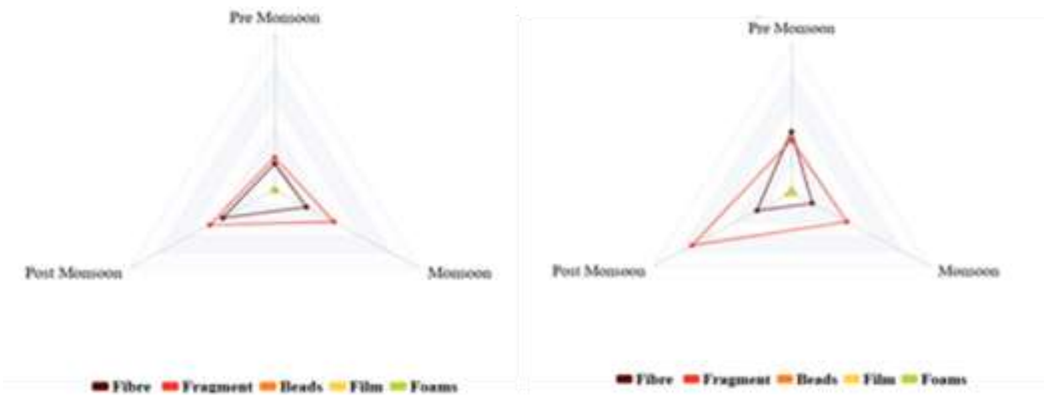


Figure 168: The graph describes the microplastics abundance in water and sediment, respectively

Challenges include poaching, weed infestation, siltation, water depletion, and ecological threats. Low incomes, inadequate training, and conflicts further strain livelihoods. Addressing these requires focused efforts in education, infrastructure, and wetland conservation.

xiii. Coliform bacteria count in different wetlands of West Bengal

The Most Probable Number (MPN) index of coliform bacteria in the wetlands showed notable seasonal variations, with the highest contamination occurring during the monsoon. Kundipur and Bijpur recorded the highest MPN levels (170) in the monsoon, followed by Maniknagar (140) and Akaipur (110), indicating a significant increase in microbial pollution due to surface runoff and increased water flow. Pre-monsoon levels were relatively lower, ranging from 21 MPN at Kundipur to 47 MPN at Bijpur, suggesting reduced contamination before the rainy season. Post-monsoon values declined across all sites but remained above pre-monsoon levels, particularly at Bijpur (48 MPN) and Kundipur (39 MPN), indicating sustained microbial presence (Fig.169).

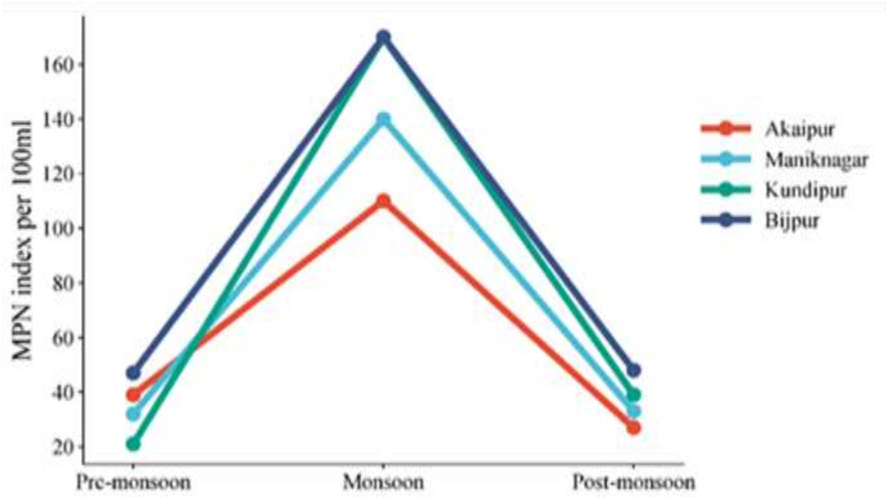


Figure 169: Seasonal variation in the MPN index of coliforms in different wetlands

xiv. Conclusion

Akaipur wetland is a vital oxbow lake ecosystem in West Bengal, supporting rich biodiversity and providing crucial livelihood and food security to local SC communities. It exhibits significant seasonal variations in water and sediment quality, with notable fluctuations in physicochemical parameters, heavy metals, and biological communities such as fish, plankton, and benthos. While the wetland maintains moderate ecological health, increasing levels of microplastics, organic pollutants, coliform bacteria, and heavy metals, especially during the monsoon, raise concerns. The successful implementation of the pen culture initiative has enhanced fish productivity and demonstrated the potential for climate-resilient, community-based aquaculture. Additionally, the wetland shows high carbon sequestration capacity, emphasising its role in climate mitigation. However, challenges like poaching, siltation, pollution, and the low socio-economic status of fishers demand integrated management strategies focusing on education, habitat restoration, and sustainable resource use.

5.3.1.2. ALWARA WETLAND

Alwara Lake "Wetland" (Eco tourism site) located in Kaushambi district of Uttar Pradesh state of India, spreads over an area of about five hundred hectares in Alwara village (Fig. 170). The Alwara wetland gets its connection with the river Yamuna during the monsoon. The wetland has a great diversity of fish, aquatic animals, plants and birds.

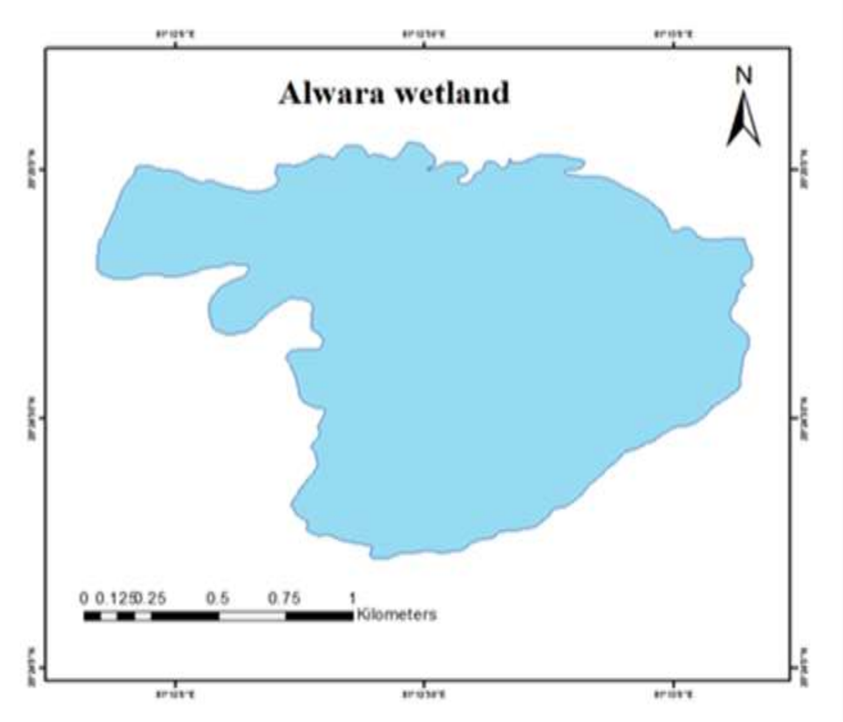


Figure 170: Study area map of Alwara Wetland

i. Fish diversity

A total 37 fish species belonging to 24 genera, 13 families and 4 orders were recorded in Alwara wetland during the 2024 sampling. Indian Major Carps (*Labeo rohita, L catla, C. mrigala*), two exotic carps viz. *Cyprinus carpio* and *Ctenopharyngodon idella*, Catfish (*Wallago attu, Mystus cavasius, M. vittatus, Ailia coila, Sperata aor,* and *S. seenghala*) were found dominant. 32 fish species were Least Concern (LC), 3 species were Near threatened (NT), and two were Vulnerable (VU).

ii. Water quality

The Alwara wetland showed seasonal changes in hydrology and water quality. Pre-monsoon water temperature reached 39.46°C and dropped to 33.46°C during monsoon, while depth increased from 1.56 m to 2.098 m due to rainfall. Transparency and turbidity decreased, indicating clearer water in the monsoon. The pH shifted from alkaline to near neutral, and dissolved oxygen declined from 8.12 to 3.48 mg/L. Both total alkalinity and hardness dropped, reflecting dilution. TDS and conductivity also decreased, suggesting reduced pollution. Nutrient analysis showed high total phosphorus pre-monsoon, while total nitrogen rose in the monsoon due to runoff. Sulphate, silicate, and chlorophyll levels declined, indicating lower productivity during the pre-monsoon season.

iii. Sediment

In Alwara wetland, sediment pH increased significantly from 6.9 to 7.7 during the monsoon, shifting from slightly acidic to moderately alkaline conditions. Specific conductance also rose from 0.401 to 0.424 mS/cm, indicating a small increase in ion concentration. Calcium carbonate content remained relatively stable, with a slight increase from 9.5% to 9.9%. Sediment texture in Alwara consistently showed high sand content, with a noticeable increase in silt during the monsoon, reflecting changes in sediment deposition patterns. Available phosphorus showed a sharp increase from 14.0 to 32.4 mg/100g, and total phosphorus rose from 23.4 to 37.8 mg/100g, indicating nutrient enrichment during the wet season. In contrast, available nitrogen declined significantly from 45.4 to 22.7 mg/100g. Organic carbon content, which was high in the pre-monsoon period (2.56%), dropped in the monsoon, likely due to decreased organic matter accumulation or increased microbial utilisation under wetter conditions.

iv. Pollution status

Alwara wetland exhibited significant seasonal changes in chloride and COD levels, indicating fluctuating water quality conditions. The pre-monsoon chloride concentration was notably high at 210.4 mg/L, suggesting potential contamination or higher mineral input, but dropped sharply to 27.54 mg/L during the monsoon, likely due to dilution from rainfall. In contrast, chemical oxygen demand (COD) increased from 30.64 mg/L pre-monsoon to 48.12 mg/L in the monsoon, pointing to elevated levels of organic pollution, possibly from surface runoff carrying organic matter into the wetland during heavy rains.

v. Plankton and Periphyton Density and Diversity in Alwara

In Alwara Taal, 43 phytoplankton species from 6 phyla and 8 classes were recorded in 2024. Bacillariophyceae (18 species) was the most represented group, followed by Chlorophyceae (12), Cyanophyceae (5), and others, including Cosinodiscophyceae, Euglenophyceae, Zygnematophyceae (2 each), and Cryptophyceae, Mediophyceae (1 each). During pre-monsoon, Cyanophyceae showed the highest density (1.5×10^6 cells/L at Alwara-3), followed by Chlorophyceae (7.7×10^5) and Bacillariophyceae (5.9×10^5). In monsoon, Cryptophyceae dominated (1.5×10^5 cells/L at Alwara-5), while other groups like Bacillariophyceae, Cyanophyceae, Chlorophyceae, Euglenophyceae, and Cosinodiscophyceae showed lower densities. Cryptophyceae were absent in pre-monsoon, and Zygnematophyceae were not recorded in monsoon, indicating their sensitivity to seasonal changes (Fig. 171). In Alwara Wetland, six zooplankton species belonging to 2 phyla and 3 classes were also recorded, comprising 4 species of Rotifera and 2 of Arthropoda. The zooplankton abundance ranged from 5 ind/L (minimum at Alwara-2 during pre-monsoon) to a maximum at Alwara-4 during the monsoon. Rotifera dominated in both seasons, with 4 ind/L during pre-monsoon and increasing to 6 ind/L during monsoon, followed by Arthropoda with 3 ind/L in monsoon. The dominance of Rotifera reflects their adaptability and key role in nutrient cycling and energy transfer in wetland ecosystems. Their higher abundance during monsoon suggests a positive response to increased nutrient input and primary productivity, while their pre-monsoon presence indicates a preference for stable conditions. Arthropoda, though fewer in species, also contributed notably to the community, particularly during monsoon.

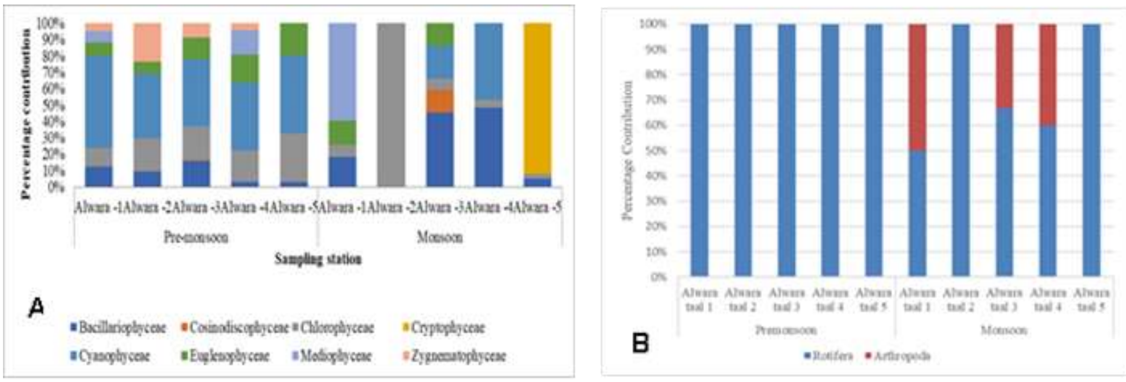


Figure 171: Percentage (%) contribution of (A), Phytoplankton and zooplankton groups in Alwara Wetland (B)

These seasonal variations in abundance and diversity highlight the influence of environmental factors such as water temperature, nutrient availability, and hydrodynamics. The study emphasises the ecological importance of Rotifera as primary consumers and the need for continued seasonal monitoring to understand zooplankton community responses to environmental and anthropogenic changes. Rotifera contributed the highest density among all zooplankton groups, as illustrated in Fig.172.

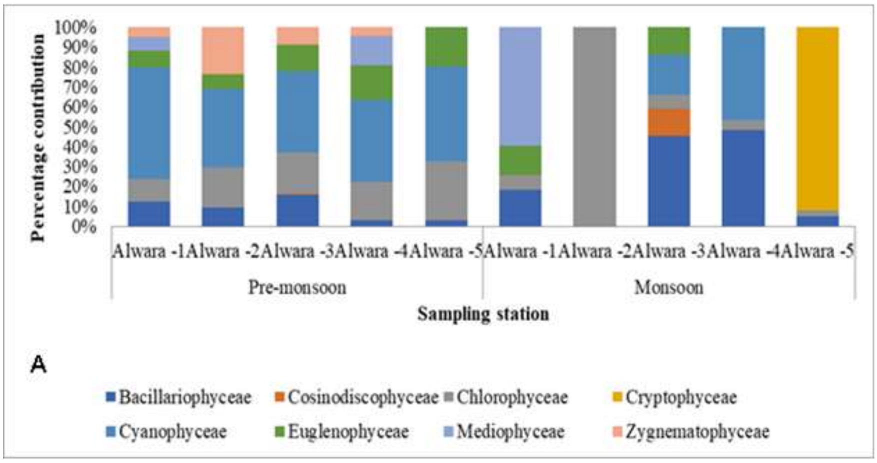


Figure 172: Seasonal percentage (%) of phytoplankton in Alwara wetland

In 2024, a total of 55 algal species belonging to 5 phyla and 7 classes were recorded in Alwara Tal. The major algal groups included Bacillariophyceae (28 species), Chlorophyceae (10), Cyanophyceae (7), Cosinodiscophyceae (3), Zygnematophyceae (3), Mediophyceae (2), and Euglenophyceae (2). Periphyton abundance ranged from 1.8×10^5 to 1.9×10^6 cells/cm^2, with a maximum at Alwara-4 during pre-monsoon and a minimum during monsoon. In the pre-monsoon, Bacillariophyceae showed the highest abundance (6.9×10^5 cells/cm²) at Alwara-3, followed by Cyanophyceae (4×10^5) at Alwara-2, and Chlorophyceae (1.3×10^5) at Alwara-1. Cosinodiscophyceae, Zygnematophyceae, Mediophyceae, and Euglenophyceae also showed notable but lower abundances. During the monsoon, Bacillariophyceae remained dominant (3.4×10^5 cells/cm²) at Alwara-5, while Cyanophyceae, Chlorophyceae, and Euglenophyceae showed moderate presence (Fig.173). However, Cosinodiscophyceae, Zygnematophyceae, and Mediophyceae were absent, likely due to their lower tolerance to high-flow and turbid conditions, unlike Bacillariophyceae, which thrived in such environments due to their adaptability to increased water turbulence and lower eutrophication.

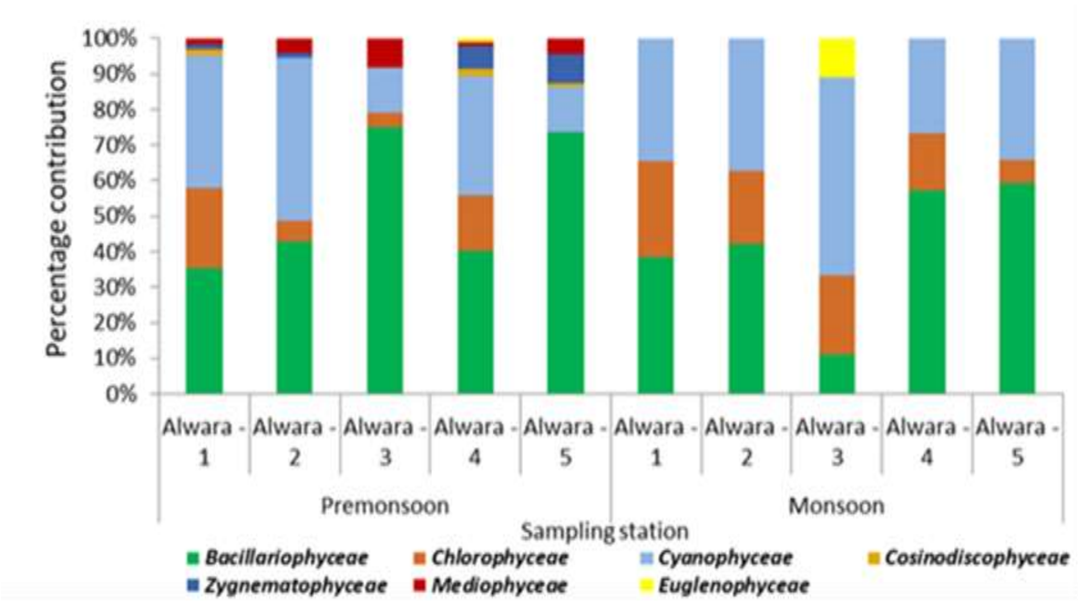


Figure 173: Percentage (%) contribution of periphyton in Alwara Wetland Uttar Pradesh

vi. Benthic diversity

In 2024, 11 macro-benthic species were recorded from Alwara Tal, Kaushambi, including 7 Gastropods, 3 Insects, and 1 Clitellata, across 5 orders and 6 families. Dominant species included *Bellamya bengalensis*, *Gyraulus convexiusculus*, *Indoplanorbis exustus*, *Lymnaea acuminata*, *Physella acuta*, *Pila globosa*, *Ranatra elongata*, *Nepa* sp., and *Hirudinaria* sp., while bivalves were absent. The highest abundance was 463 ind/m², and the lowest was 8. Gastropods were more abundant in the monsoon (251 ind/m²) than in summer (212 ind/m²), while Clitellata remained at 4 ind/m² in both seasons. Planorbidae was the dominant family (28%) followed by Nepidae (18%), with other families including Lymnaeidae, Viviparidae, Ampullariidae, Hirudinidae, and Physidae (Fig.174).

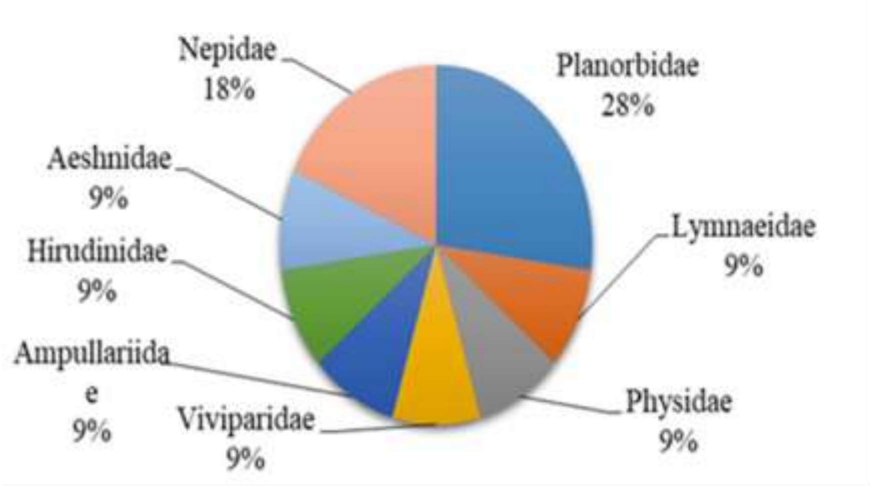


Figure 174: Family distribution of benthic fauna (%) in Alwara Wetland

vii. Conclusion

Alwara Wetland in Kaushambi district is a seasonally connected aquatic ecosystem with notable biodiversity and ecological significance. It supports 37 fish species, including Indian major carps and several catfishes, with a few species falling under threatened categories. Plankton communities showed rich diversity, with Bacillariophyceae dominating phytoplankton and periphyton groups across seasons. Rotifera were the most abundant zooplankton, reflecting their adaptability and ecological role in nutrient cycling. The wetland contributes 11 macro-benthic species, mostly gastropods, indicating moderate benthic diversity. Physico-chemical parameters fluctuated seasonally, with high temperatures, DO, and nutrient loads during pre-monsoon. Signs of organic pollution were evident, particularly in elevated chloride and COD levels. Sediment analysis revealed increased phosphorus during monsoon, but declining nitrogen and organic carbon suggest reduced soil fertility. Alwara showed signs of eutrophication and contamination risks, highlighting the need for restoration. Regular ecological monitoring and pollution control are essential for sustaining its biodiversity and ecosystem health.

5.3.1.3. BIJPUR WETLAND

Bijpur wetland (22° 58' 12" N & 88° 25' 48" E) is situated in Kanchrapara, North 24 Parganas district of West Bengal (Fig.175). It is managed by ‘Bijpur Fisherman’s Co-operative Society Ltd.’, having 59 members, all belonging to the SC category. It consists of members from six villages: Jonepur, Milan Nagar, Gokulpur, Chatrapara, Malibagan, and Upendranagar. It is a closed wetland. These wetlands are utilized for culture-based fisheries and provide livelihood and food support to people. It has an average area coverage of 32 ha.

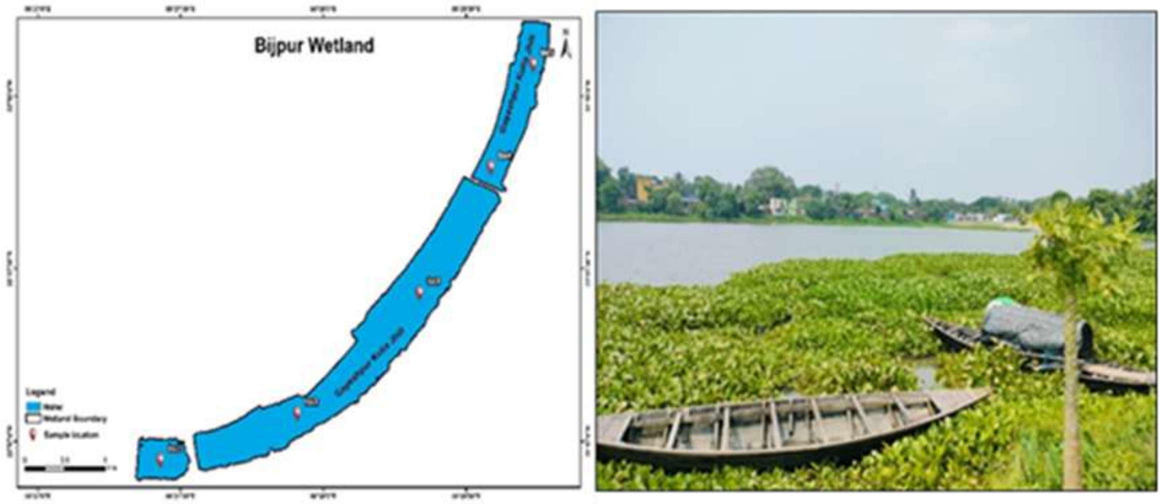


Figure 175: Study area of Bijpur Wetland

i. Physico-chemical characteristics

The Bijpur wetland exhibits significant seasonal variations in key physico-chemical parameters across sampling sites S-1 to S-8. Water temperatures ranged from 31.2°C to 35.2°C, with higher values during the pre-monsoon period. Water depth varied widely, ranging from 0.6 to 8 meters pre-monsoon and from 1.4 to 2.1 meters during the monsoon, influenced by rainfall and evaporation. pH values remained slightly alkaline, ranging from 7.84 to 8.9, while dissolved oxygen (DO) levels showed seasonal shifts, peaking at 6.4 mg/L during monsoon and dropping to 2.6 mg/L. Specific conductivity was higher in the pre-monsoon (515–530 µS/cm) and lower during monsoon (317–370 µS/cm), indicating dilution from rainfall. Turbidity varied significantly, with pre-monsoon levels reaching up to 47.1 NTU, and lower monsoon values resulting from sediment settling. Total alkalinity ranged from 126 to 154 mg/L pre-monsoon and dropped to 92-94 mg/L in monsoon, while total hardness followed a similar trend (130-150 mg/L pre-monsoon and 110-132 mg/L during monsoon). The chlorinity and salinity were also higher in the pre-monsoon period (up to 0.0749 ppt and 0.1354 ppt, respectively), decreasing significantly with monsoon inflow. These seasonal changes underscore the dynamic nature of the wetland ecosystem and its sensitivity to climatic and hydrological factors.

ii. Sediment

The pH ranged from 6.63 in pre-monsoon to 7.90 in post-monsoon, while conductivity peaked at 1611.33 µS/cm post-monsoon. Sand content remained above 91% throughout, and calcium carbonate increased from 3.2% in monsoon to 13.88% in post-monsoon. Phosphate levels rose sharply from 15.14 mg/100g in pre-monsoon to over 24 mg/100g in monsoon and post-monsoon. Nitrogen increased progressively to 320 mg/100g in post-monsoon, while organic carbon decreased drastically from 4.9% in pre-monsoon to 1.09% in post-monsoon.

iii. Pollution status

The Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels show significant seasonal variations, reflecting changes in organic pollution and water quality. BOD levels peaked at 2 mg/L during the pre-monsoon period at sites S3 and S5, indicating moderate organic pollution. In contrast, the lowest value of 0.6 mg/L was recorded at S2 during the monsoon, suggesting improved water quality due to dilution by increased rainfall. Pre-monsoon BOD values ranged from 1.5 to 2 mg/L, whereas monsoon values ranged from 0.6 to 1.2 mg/L. COD levels were highest during the pre- and post-monsoon periods, reaching up to 100 mg/L at S1, with other stations, such as S2 to S5, showing elevated values between 68 and 84 mg/L. These variations in BOD and COD highlight the influence of seasonal factors such as rainfall, runoff, and reduced water flow on the organic and chemical load of the wetland, emphasizing the need for continuous monitoring to manage water quality effectively.

iv. Heavy metal contamination

The analysis of heavy metal concentrations in water, sediment, and fish from the Bijpur wetland across three seasons- pre-monsoon (PRM), monsoon (MON), and post-monsoon (POM)—revealed notable seasonal and biological variations. In water samples, metals followed the decreasing order As > Pb > Cu > Cr > Cd, with the highest concentrations in PRM and a general decline during MON and POM, except for arsenic, which peaked during MON, possibly due to runoff or geochemical changes. All water metal levels remained within USEPA (2024) limits, except for arsenic, which exceeded the standard but complied with the BIS (2012) limit. In sediment, heavy metal concentrations were highest in PRM, decreased during MON due to dilution or lower inputs, and rose slightly in POM, following the trend PRM > POM > MON. All sediment metals remained within the Canadian Interim Sediment Quality Guidelines (2011), except for arsenic in PRM. Fish tissue analysis across seven species showed species-specific accumulation, with *O. niloticus* and *G. chapra* recording higher levels of Cr and Cu, while *N. notopterus, L. bata, S. seenghala*, and *P. japonicus* exhibited generally lower or undetectable metal concentrations. Despite the variations, all fish metal concentrations were within FAO (1983) safety limits, suggesting no immediate risk to aquatic life or human consumers.

v.Fish diversity

In Bijpur wetland, 11 species belonging to 9 genera, 6 families and 5 orders were recorded from Bijpur wetland (Table 16). Cypriniformes, Siluriformes and Osteoglossiformes are major contribution orders (Fig. 176). The study recorded 55% fish abundance during the monsoon season, compared to 45% during the pre-monsoon season. Species like *Gudusia chapra* (56%) and *Labeo bata* (18%) dominated during monsoon. During pre-monsoon, the fish in the wetland were found *Notopterus notopterus* (36%) and *Gudusia chapra* (24%). Large riverine catfish, such as *Sperata seenghala*, were found to be available during the onset of the monsoon. Availability of exotic Nile tilapia (*Oreochromis niloticus*) and *Puntius japonicus* was also observed.

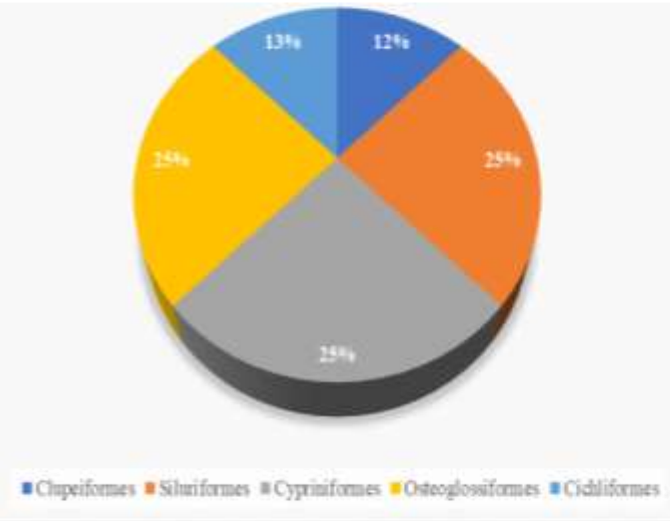


Figure 176: Piscine order (%) in Bijpur wetland

Table 16: Fish diversity in Bijpur wetland

Order	Family	Fish species
Cypriniformes	Cyprinidae	*Cirrhinus mrigala*
		Labeo rohita
		Labeo catla
		Labeo bata
		Puntius japonicus
Clupeiformes	Clupeidae	*Gudusia chapra*
Siluriformes	Heteropneustidae	*Heteropneustes fossilis*
	Bagridae	*Sperata seenghala*
Osteoglossiformes	Notopteridae	*Notopterus notopterus*
		Chitala chitala
Cichliformes	Cichlidae	*Oreochromis niloticus*

vi. Adaptive Aquaculture in Action: Pen Culture as a Resilience Strategy for Bijpur Wetland

National Mission for Clean Ganga implemented a culture-based fisheries (CBF) initiative in Bijpur Wetland, a floodplain ecosystem affected by unscientific practices and pollution, to enhance fish productivity (Fig. 177). As part of the NMCG project, ICAR-CIFRI provided HDPE pens, quality fish seed, and an outboard engine fishing boat to local stakeholders. A pen culture demonstration was conducted using 150 kg of fish seed, comprising *Labeo rohita* (5051 nos.), *Labeo catla* (4840 nos.), and *Labeo bata* (9091 nos.). Over a four-month culture period, it yielded 310 kg of fish. The harvested fish were released into the wetland to support sustainable CBF practices, showcasing pen aquaculture as a climate-friendly practice.

Figure 177: Pen culture system in Bijpur wetland

vii. Plankton and Periphyton diversity

Plankton diversity in the Bijpur wetland exhibited pronounced seasonal variations, influenced by environmental factors such as temperature, nutrient availability, and rainfall. During the pre-monsoon season, phytoplankton communities were dominated by Chlorophyceae (green algae) with 4416 cells/L at Site S1 (39.5%), followed by Bacillariophyceae (diatoms) at 3888 cells/L at Site S5 (33.3%), while Cyanophyceae (cyanobacteria) were minimally present (1.1%) (Fig.178). Zooplankton was composed mainly of Rotifera, peaking at 4208 ind/L at Site S3 (78.1%), with Arthropoda and Ciliophora contributing 10.3% and 3.2%, respectively. Monsoon season saw a substantial increase in both phytoplankton and zooplankton populations, particularly Cyanophyceae, which surged to 25960 cells/L at Site S1 (76.8%), overtaking other groups. Chlorophyceae and Bacillariophyceae contributed 9.2% and 4.8%, respectively. Rotifera again dominated the zooplankton with 25960 ind/L at Site S1 (87.4%). Post-monsoon season experienced a sharp decline in plankton abundance; Chlorophyceae (260 cells/L at Site S3) and Bacillariophyceae (20 cells/L at Site S1) remained dominant but in reduced numbers, while Cyanophyceae decreased to 900 cells/L (11.4%). Zooplankton counts also dropped, with Rotifera still prevailing at 1080 ind/L at Site S1 (63.5%). These dynamic seasonal changes reflect the sensitivity of plankton communities to fluctuating ecological conditions in the wetland.

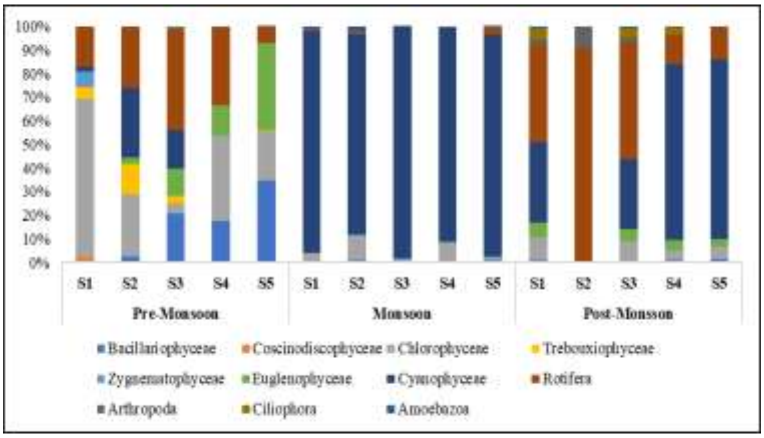


Figure 178: Seasonal percentage (%) of phytoplankton in Bijpur wetland

viii. Benthic diversity

A total of 11 macro-benthic fauna species from 7 families were recorded, with Thiaridae being the most dominant (81%), followed by Planorbidae (7%), Chironomidae (5%), and others in lesser proportions (Fig.179). *Tarebia granifera* showed the highest abundance across all seasons, peaking at 2,303 individuals/m² in the pre-

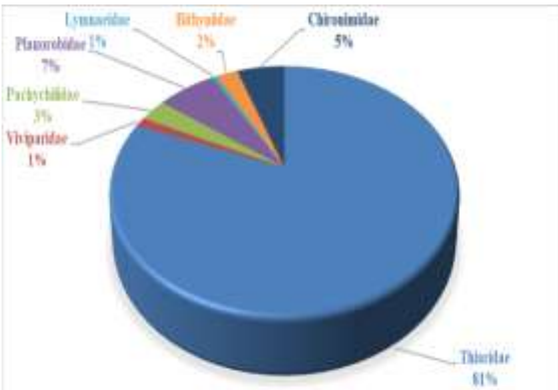


Figure 179: Family-wise (%) distribution of benthic diversity

monsoon, then decreasing in the monsoon (801/m²) and post-monsoon (433/m²). Other notable species included *Filopaludina bengalensis*, *Idiopoma dissimilis*, *Melanoides tuberculata*, *Brotia costula*, *Mekongia crassa*, *Indoplanorbis exustus*, *Lymnaea luteola*, *Gabbia orcula*, and *Chironomus* sp. Macro-benthic diversity and abundance were highest in the pre-monsoon and declined through the monsoon and post-monsoon seasons, indicating a strong seasonal influence on benthic community structure.

ix. Analysis of eBPA Concentrations

Highest BPA levels are recorded among the wetlands, with values increasing from 161.46 ng/L in Pre-Monsoon to 167.70 ng/L in Monsoon and then slightly decreasing to 162.13 ng/L in Post-Monsoon. The Monsoon peak suggests increased pollutant runoff from surrounding areas.

x. Assessment of carbon sequestration potential

Bijpur wetland demonstrated the highest carbon sequestration potential among the studied sites, with significantly elevated levels of both dissolved inorganic and organic carbon. DIC was highest in the pre-monsoon season (38.83 ± 3.44 mg/L) and decreased during the monsoon (28.54 ± 3.24 mg/L), reflecting seasonal dilution by rainfall and runoff. DOC reached its peak during the monsoon (11.03 ± 3.33 mg/L), likely due to influxes of organic-rich water, and was lowest in the post-monsoon season (2.71 ± 0.73 mg/L), possibly due to microbial activity and sedimentation. Averaging 32.25 ± 4.03 mg/L in DIC and 7.46 ± 3.02 mg/L in DOC, Bijpur exhibited the highest levels of both forms of dissolved carbon, highlighting its strong potential as a carbon sink.

xi. Microplastic abundance in Bijpur wetland

Seasonal assessment of microplastics in the wetland revealed distinct patterns across water and sediment samples (Fig. 180). During the pre-monsoon period, fragments (13 items/L) and fibres (8 items/L) were predominant in water samples, with a small amount of foam (1 particle/L), while in sediment, fibres (31 items/kg) and fragments (24 items/kg) dominated along with minor presence of films (1 particle/kg) and foams (2 items/kg). In the monsoon season, water samples showed a sharp increase in fibre content (18 items/L) and fragments (16 items/L), while no beads, films, or foams were detected; sediment samples reflected reduction in fibre (12 items/kg) and stable fragment levels (22 items/kg), with no presence of other types. During the post-monsoon period, water samples continued to show elevated levels of fibres (19 items/L) and moderate fragments (12 items/L), along with a small amount of foam (1 particle/L). Sediment samples showed an increase in fibre content (22 items/kg) with consistent fragment levels (19 items/kg), and small amounts of films (1 particle/kg) and foams (1 particle/kg). Microbeads were not detected in any samples across all three seasons.

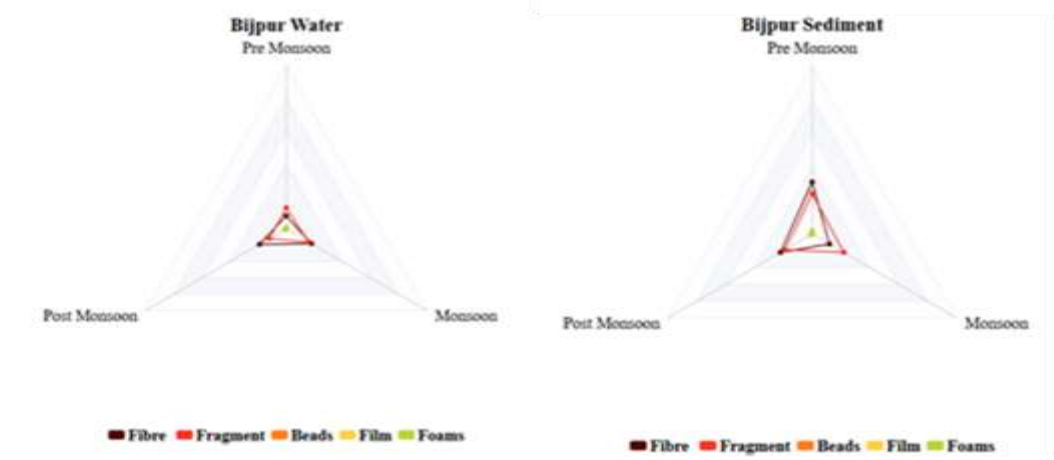


Figure 180: The graph described the microplastics abundance in water and sediment of Bijpur wetland respectively

xii. Nutrient profiling of food fishes

The nutrient profiling of *Labeo bata* and *Oreochromis niloticus* was carried out from the Bijpur wetland. Gross chemical composition identified *Labeo bata* and *Oreochromis niloticus* as protein-rich fishes. Amino acid analysis showed the fish to be rich in essential amino acids such as glutamic acid and glycine, and non-essential aspartic acid. Fatty acid composition revealed myristic (C14:0) and palmitic acids (C16:0) as dominant saturated fatty acids. Oleic acid was the most common MUFA, while docosahexaenoic acid (DHA, C22:6) was the dominant PUFA.

xiii. Conclusion

The Bijpur Wetland is a vital floodplain ecosystem that supports biodiversity, aquaculture, and marginalized communities. Seasonal fluctuations in physico-chemical parameters reflect its ecological dynamism and sensitivity to climatic influences. Although heavy metal concentrations in water, sediment, and fish tissues remain mostly within safety limits, elevated arsenic levels raise concern. Nutrient-rich fish species and successful pen culture initiatives highlight its aquaculture potential. However, increasing microplastic contamination and high eBPA levels pose emerging environmental risks. Plankton and benthic communities exhibit strong seasonal responses, indicating ecological health and stress. The wetland shows high carbon sequestration potential, emphasizing its role in climate regulation. Social profiling reveals low education, modest incomes, and dependence on fishing among SC-dominated communities. Integrated conservation, sustainable fisheries, and community engagement are essential for the conservation of Bijpur Wetland's ecological and socio-economic functions.

5.3.1.4. HAIDERPUR WETLAND

Haiderpur Wetland is a UNESCO Ramsar site located near the Bijnor Ganga Barrage within the Hastinapur Wildlife Sanctuary in Uttar Pradesh, India (Fig. 181). It is one of the largest human-made wetlands, formed in 1984 after the construction of the Madhya Ganga Barrage. The region is fed by the Ganges and its tributary, the Solani River, constituting an area of 6,908 hectares within the Hastinapur Wildlife Sanctuary in Muzaffarnagar and Bijnor districts. Haiderpur was designated as the 47th Ramsar site, a wetland of international importance, in April 2021.

Figure 181: Study area of Haidarpur Wetland

i. Fish diversity

A total of 74 fish species belonging to 56 genera, 27 families, and 10 orders were recorded at Haiderpur wetland (Fig.182). The commercially dominant, impotent carp and catfishes such as *Cirrhinus mrigala, Labeo rohita, L. calbasu, L. gonius, L. bata, C. reba, Wallago attu, Sperata seenghala, S. aor, Rita rita, Bagarius bagarius, Clupisoma garua, Eutropiichthys vacha*, and *Ailia coila* were recorded from the Haiderpur wetland. There was a rich abundance of the snakehead fish *Channa sp.* and stinging catfish *Heteropneustes fossilis* in this wetland. Among the 10 orders, Cypriniformes (46%) were dominant, followed by Siluriformes (27%), Anabantiformes (11%), Synbranchiformes (4%), and Osteoglossiformes (3%). Higher abundance of fish diversity was observed in summer (pre monsoon) compared to the monsoon season.

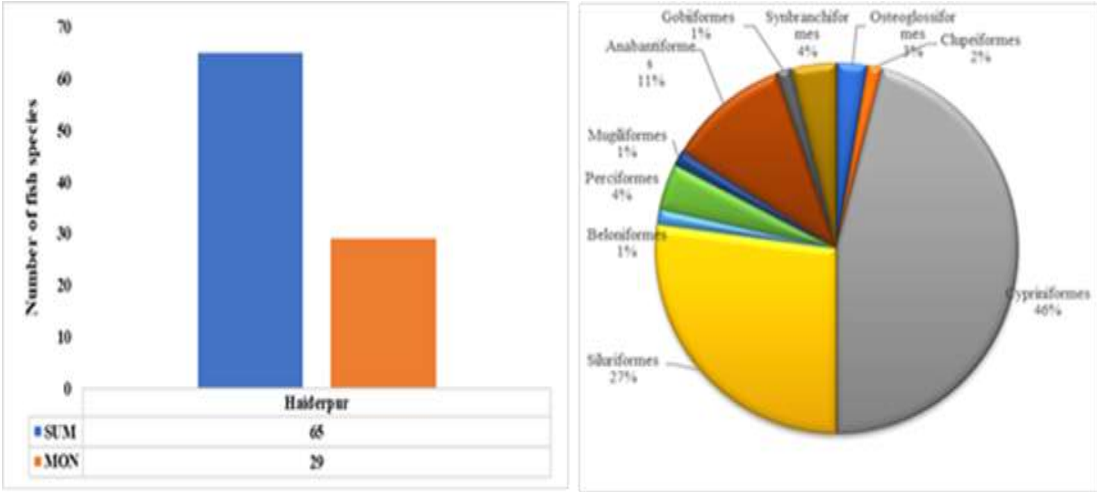


Figure 182: A. Number of fish species (seasonal) and B. Piscine order distribution (%) in Haiderpur Wetland

ii. Water quality

The Haiderpur wetland exhibited notable seasonal variations in hydrology and water quality. Pre-monsoon water temperature was 32.1°C, decreasing to 28.26°C during the monsoon, while water depth increased from 1.2 m to 2.8 m due to rainfall. Transparency declined from 50 cm to 33.56 cm, and turbidity rose sharply from 11.98 NTU to 91.14 NTU, likely due to increased sediment inflow. The pH remained stable and nearly neutral (7.48–7.58). Dissolved oxygen levels improved from 2.8 to 4.36 mg/L, and biological oxygen demand decreased, suggesting reduced organic pollution. Total alkalinity and hardness declined from 205 to 98.4 mg/L and 165 to 116.8 mg/L, respectively, reflecting dilution. Nutrient analysis showed a lower total phosphorus concentration (0.22 mg/L) pre-monsoon, while total nitrogen increased during monsoon to 0.792 mg/L due to runoff. Available sulphate and silicate levels rose from 12.47 to 17.27 mg/L and 5.77 to 8.02 mg/L, respectively, indicating enriched nutrient input in the monsoon season.

iii. Sediment

Seasonal variation in sediment showed a slight increase in pH from 7.5 to 7.6 during the monsoon, maintaining a mildly alkaline. Specific conductance also rose slightly from 0.241 to

0.258 mS/cm, indicating a modest increase in dissolved ions. A notable decline in calcium carbonate content was observed, dropping from 14% in the pre-monsoon to 5.1% in the monsoon season. The sediment texture shifted significantly, with sand content increasing from 34% to 62.5% and clay decreasing from 24.5% to 22.2%, suggesting enhanced sediment inflow and erosion. Nutrient levels reflected seasonal influences, as available phosphorus increased from 7.6 to 13.8 mg/100g and total phosphorus from 31 to 53 mg/100g. However, available nitrogen showed a slight decline from 14.6 to 12.7 mg/100g. Organic carbon content was higher during the pre-monsoon (0.35%) and decreased during monsoon, possibly due to reduced microbial decomposition or dilution by fresh sediment.

iv. Plankton and Periphyton Density and Diversity

A total 28 phytoplankton species from 5 phyla and 8 classes were recorded in Haidarpur Wetland. Bacillariophyceae (8 species) was the most represented group, followed by Chlorophyceae and Cyanophyceae (7 each), with others like Euglenophyceae (2) and Cosinodiscophyceae, Mediophyceae, Trebouxiophyceae, and Zygnematophyceae (Fig.183). During pre-monsoon, Cyanophyceae dominated (2.7×10^5 cells/L) at Haidarpur-1, followed by Bacillariophyceae (9.6×10^4), indicating favorable conditions such as stable hydrology and nutrient-rich waters. Chlorophyceae, Cosinodiscophyceae, and Trebouxiophyceae showed moderate densities at Haidarpur-4, while Zygnematophyceae were absent. In monsoon, Bacillariophyceae (2.7×10^4 cells/L) and Mediophyceae (2.2×10^4 cells/L) remained abundant, while Zygnematophyceae reappeared (2×10^4 cells/L at Haidarpur-3). Cyanophyceae and Chlorophyceae showed reduced densities, and sensitive groups like Cosinodiscophyceae, Euglenophyceae, and Trebouxiophyceae were absent, indicating the impact of monsoonal disturbances on community composition. Likewise, a total of 12 zooplankton species from 2 phyla and 6 classes were recorded in Haiderpur Wetland, comprising 7 Arthropoda and 5 Rotifera species. Zooplankton abundance ranged from 33 ind/L (minimum at Haiderpur-1 in pre-monsoon) to a maximum at Haiderpur-2 during monsoon. Rotifera dominated pre-monsoon (3 ind/L), while Arthropoda (29 ind/L) dominated during monsoon, followed by Rotifera (15 ind/L). The higher pre-monsoon abundance of Rotifera reflects their adaptability to stable, nutrient-rich conditions, while the monsoonal rise in both groups suggests favourable conditions due to increased nutrient inflow and water mixing. Rotifera contributed the highest overall density, highlighting their role as key primary consumers, while Arthropoda's dominance during monsoon emphasizes their importance in nutrient cycling and energy transfer. These seasonal variations underline the ecological significance of zooplankton and the need for regular monitoring as indicators of wetland health.

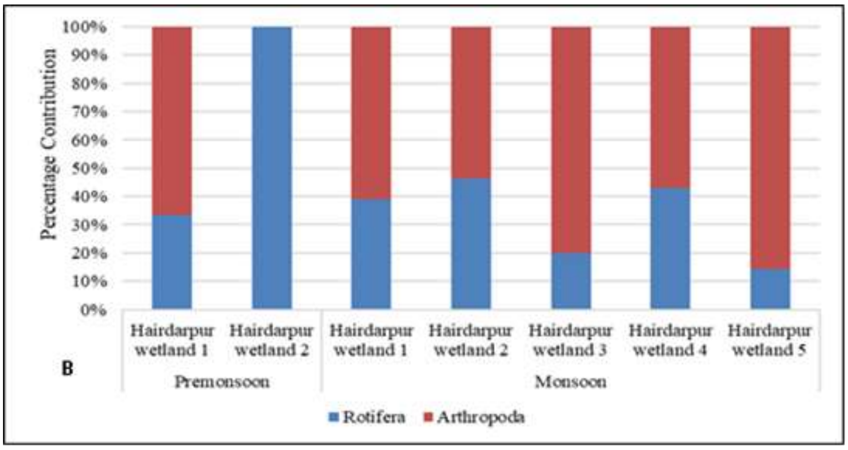


Figure 183: Percentage (%) contribution of A. Phytoplankton and zooplankton groups in Haiderpur Wetland

A total of 61 periphyton species belonging to 5 phyla and 7 classes were recorded in Haiderpur Wetland of Uttar Pradesh (Fig. 184). Bacillariophyceae was the most dominant group (30 species), followed by Chlorophyceae (13), Cyanophyceae (8), Coscinodiscophyceae and Zygnematophyceae (3 each), and Mediophyceae and Euglenophyceae (2 each). Abundance ranged from 2×10^5 to 7×10^6 cells/cm², with the highest at Haidarpur-1 during pre-monsoon and the lowest at Haidarpur-3 in monsoon. During pre-monsoon, Bacillariophyceae (2.8×10^6 cells/cm²) and Cyanophyceae (1.3×10^6 cells/cm²) were most abundant, while groups like Mediophyceae and Zygnematophyceae were absent in monsoon, likely due to their sensitivity to high-flow and turbidity. However, Coscinodiscophyceae and Euglenophyceae persisted across seasons, possibly due to favorable salinity and temperature conditions during monsoon. These findings highlight seasonal shifts in algal community structure influenced by hydrological and environmental changes.

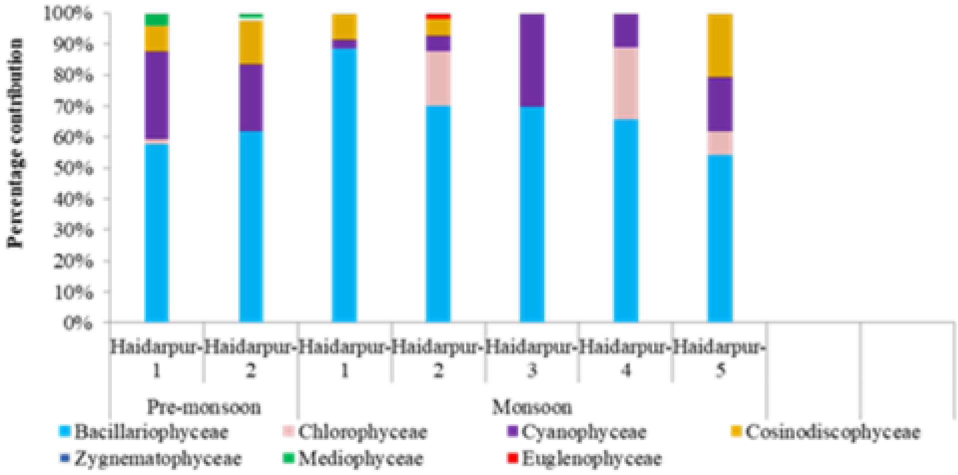


Figure 184: Percentage (%) contribution of periphyton in Haiderpur Wetland

v. Benthic diversity

17 macro-benthic fauna species were recorded from Haiderpur Wetland, Bijnor, belonging to 7 orders and 10 families, including 8 Gastropods, 5 Bivalves, 3 Insects, and 1 Clitellata (Fig.185). Dominant species included *Gyraulus convexiusculus*, *Indoplanorbis exustus*, *Lymnaea acuminata*, and *Bellamya bengalensis* (Gastropods), and *Parreysia favidens*, *Lamellidens marginalis*, *Parreysia shurtleffiana*, *P. caerulea* (Bivalves). The highest macro-benthic abundance was 755 ind/m², with a minimum of 26 ind/m². Gastropods peaked in summer (411 ind/m²) but declined in monsoon (123 ind/m²), while Clitellata dropped from 22 ind/m² in summer to 4 ind/m² in monsoon, reflecting seasonal variation in habitat conditions.

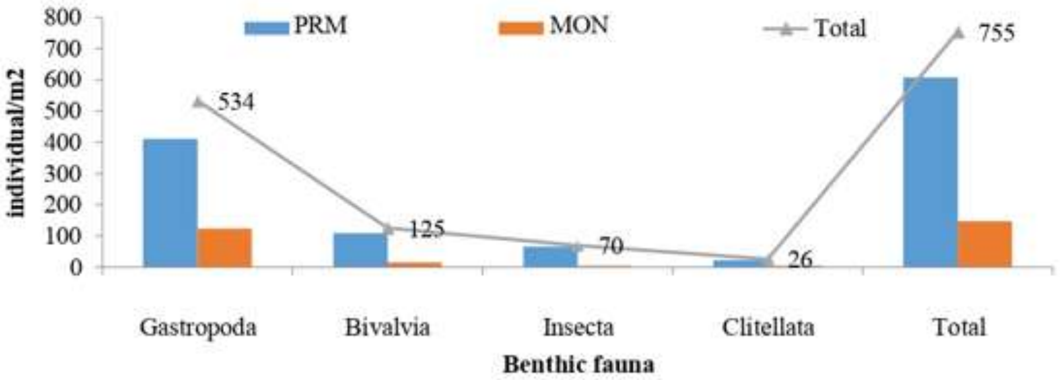


Figure 185: Percentage (%) contribution of benthic fauna in Haiderpur wetland

vi. Pollution status

At Haiderpur wetland, the average chloride concentration showed a slight increase from 9.5 mg/L during the pre-monsoon to 11 mg/L in the monsoon, indicating minimal seasonal variation and generally low contamination levels. The chemical oxygen demand (COD) decreased notably from 32.25 mg/L in the pre-monsoon to 20.64 mg/L during the monsoon season.

vii. Conclusion

Haiderpur Wetland, a Ramsar site within the Hastinapur Wildlife Sanctuary, supports high aquatic biodiversity and robust ecological functions. A total of 74 fish species were recorded, including commercially significant carps and catfish. Zooplankton diversity was also high, with 12 species and notable seasonal shifts in dominance between Rotifera and Arthropoda. Phytoplankton and periphyton communities were diverse, with Bacillariophyceae consistently dominant. The wetland hosted 17 macro-benthic species, including both gastropods and bivalves, reflecting complex benthic habitats. Physico-chemical parameters showed seasonal variations but remained within ecologically stable limits. Nutrient levels, particularly total phosphorus and nitrogen, increased during the monsoon due to runoff. Sediment analysis revealed improved phosphorus enrichment and moderate changes in texture, supporting productivity. Pollution indicators such as chloride and COD remained relatively low, indicating better water quality than Alwara. Overall, Haiderpur demonstrates ecological resilience and high conservation value, requiring ongoing protection and sustainable management.

5.3.1.5. KUNDIPUR WETLAND

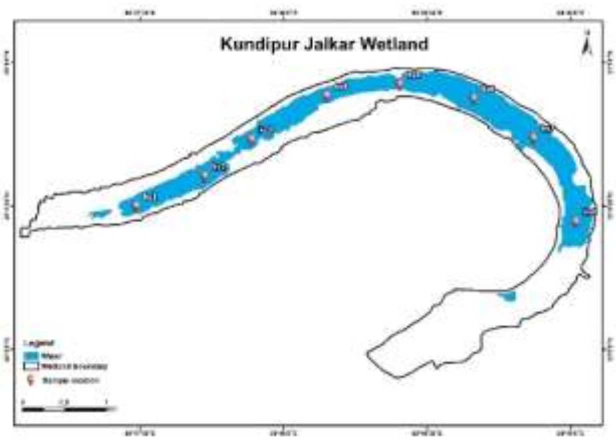


Figure 186: Study area of Kundipur Wetland

Kundipur wetland is situated at Ganrapota, Bongaon, North 24 Parganas and locally known as Kundipur Baor. It was created at the interface of the Ganga-Ichhamati River. After a 1.5-kilometre cut-off from the Ichhamati River, the wetland gradually transformed into a horseshoe lake. Seven villages surround the wetland. A lock gate connects the river and the wetland. The wetland is managed by a cooperative society named "Kundipur Fisherman's Co-operative Society Limited", consisting of 315 members, of whom 105 are active. The sampling was conducted at eight different sites (Fig. 186).

i. Physico-chemical characteristics

During the monsoon period, temperatures in the wetland range from 29.8°C to 31.2°C, reflecting the cooling effect of increased rainfall and cloud cover. The overall maximum recorded depth across the measured periods was 7.6 meters during monsoon, while the minimum was 0.5 meters during pre-monsoon at the same site. The overall maximum recorded pH value was 8.9, while the minimum was 7.72 during the monsoon season. The maximum recorded DO value was 6 mg/L during the pre-monsoon period, while the minimum was 1 mg/L during the monsoon. The maximum recorded specific conductivity value was 414 µS/cm during the pre-monsoon, while the minimum was 280 µS/cm during the monsoon. The maximum recorded turbidity value was 6.1 NTU during the pre-monsoon period, while the minimum was 2.93 NTU during monsoon, indicating very low turbidity levels in the wetland. The maximum recorded total alkalinity was 200 mg/L during the pre-monsoon, while the minimum was 132 mg/L during the monsoon period, indicating slightly higher levels. Total hardness value ranges between 114-174 mg/L, suggesting higher mineral content in the water. The maximum recorded chlorinity value across all seasons is 0.0239 ppt in pre-monsoon. The maximum Total Phosphorus and Total Nitrogen recorded across the survey were 0.2444 mg/L and 0.2375 mg/L during monsoon, while the minimum was 0.0493 mg/L and 0.0155 mg/L at during post-monsoon. The maximum silicate concentration recorded across these observations was 20.08 mg/L during post-monsoon, while the minimum was 3.25 mg/L during the monsoon period.

ii. Sediment

In Kundipur wetland, pH was highest (7.88) in pre-monsoon and slightly declined across seasons, with conductivity dropping in monsoon (217.68 µS/cm) and stabilizing post-monsoon. Silt-clay content remained relatively stable (10-12%), and calcium carbonate ranged from 34.9% in pre-monsoon to 15% in post-monsoon. Phosphate declined from 26.45 mg/100g in pre-monsoon to 22.56 mg/100g in post monsoon, while nitrogen increased from 220 mg/100g in pre-monsoon to 260 mg/100g in post monsoon Organic carbon declined from 6.17% in PRM to 2.19% in MON, then rose to 3.45% in post monsoon.

iii. Pollution status

During pre-monsoon the BOD level ranges between 0.4 to 2.4 mg/ whereas in BOD levels, ranging from 0.8 to 1.06 mg/L. The influx of rainwater and increased water flow dilute organic matter concentrations, leading to lower BOD values. The maximum recorded COD value was 80 mg/ during the post-monsoon period, while the minimum was 4 mg/L during the monsoon. These variations highlight the dynamic nature of the wetland's water quality, which is influenced by seasonal changes and various environmental factors. The maximum recorded Total Solids, Total Dissolved Solids, and Total Suspended Solids levels were 7.988 g/L, 5.7 g/L and 2.288 g/L, respectively, while the minimum levels are 0.136 g/L, 0.104 g/L, and 0.008 g/L, respectively. During the post-monsoon period, TS levels reach their peak, highlighting the impact of runoff and sediment transport.

iv. Heavy metal contamination

Irrespective of the seasons, the metal contamination was dominated by Arsenic, followed by Lead, Chromium and Copper. Copper (Cu) is detected only in pre-Monsoon (0.00129 ± 0.00020 mg/L), suggesting seasonal sources or strong dilution effects in later seasons (Fig.187). The concentrations of all the metals remained within the safety limits established by the USEPA, 2024, except for arsenic (As), which exceeded the permissible limit of 0.01 mg/L.

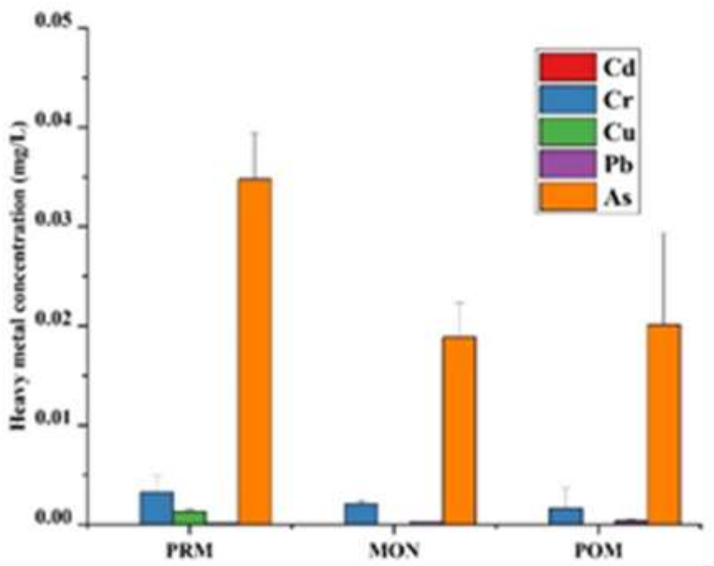


Figure 187: Seasonal variation of metal concentration in water of Kundipur wetland

The trend of metal accumulation in sediment was observed as monsoon > post-monsoon > pre-monsoon (Fig.188). All the metal concentrations remained within the permissible limits except for As, exceeding the safe value of 7.24 µg/g set by the Canadian Interim Sediment Quality Guideline (Marine, 2011). The bioaccumulation of heavy metals in *L. guntea, M. vittatus*, and *N. notopterus* from Kundipur wetland was assessed. *L. guntea* exhibited the highest arsenic concentration (0.018542 ± 0.002900 µg/g), while *M. vittatus* accumulated more cadmium (0.000117 ± 0.000020 µg/g) and chromium (0.002472 ± 0.000370 µg/g).

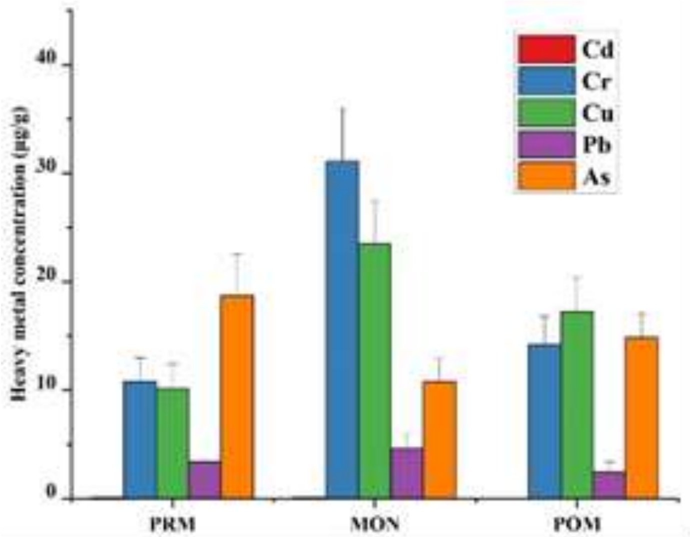


Figure 188: Seasonal variation in metal concentfration in sediment of Kundipur wetland

v. Fish diversity

A total, 16 species belonging to 13 genera, 8 family and 5 order were recorded from Kundipur wetland (Table 17). Among the five orders Cypriniformes contribute 46% of total abundance followed by Siluriformes (Fig.189). SIF species like *Chanda nama* (26%), *Puntius sophore* (14%), *Puntius phutunio* (12%), and *Amblypharyngodon mola* (8%) was found to be dominated species. Riverine minor catfish like *Heteropneustes fossilis* and *Mystus vittatus* were found available during onset of monsoon. Recreational fishery is a powerful income resource in Kundipur wetland. In every part of the wetland, the Cooperative society allows recreational fishery on a ticket and on a terms and conditions basis.

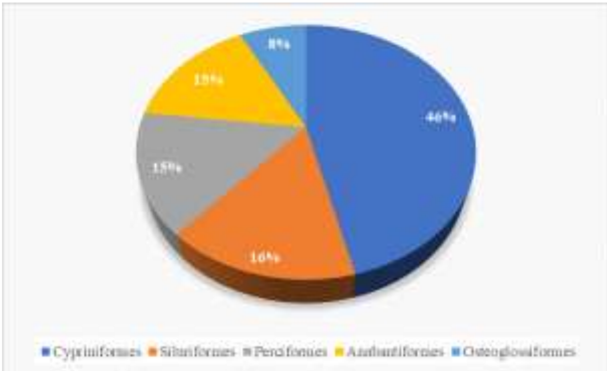


Figure 189: Order (%) wise of fish diversity in Kundipur wetland

Table 17: Fish diversity of Kundipur wetland

Order	Family	Species
Cypriniformes	Cyprinidae	*Labeo rohita*
		Labeo catla
		Cirrhinus mrigala
		Puntius phutunio
		Pethia conchonius
		Puntius sophore
		Cirrhinus reba
		Salmostoma bacaila
	Danionidae	*Amblypharyngodon mola*
Siluriformes	Bagridae	*Mystus vittatus*
	Heteropneustidae	*Heteropneustes fossilis*
Perciformes	Ambassidae	*Chanda nama*
		Parambassis ranga
Anabantiformes	Osphronemidae	*Trichogaster fasciata*
	Channidae	*Channa punctata*
Osteoglossiformes	Notopteridae	*Notopterus notopterus*

vi. Pen Aquaculture as a Sustainable Model for Adaptive Fisheries Management in Kundipur Wetland

A pilot study was conducted to investigate pen aquaculture technology, a low-cost aquaculture system for floodplain wetlands in India, as an alternative livelihood for boosting adaptive ability under changing climatic scenarios in sub-tropical floodplain wetlands (Fig. .190).

Figure 190: Pen culture system in Kundipur Wetland

To make it a climate-smart adaptation system, pens (0.1ha each) were installed in a floodplain wetland. As part of the initiative, the NMCG project distributed various fisheries implements, including CIFRI HDPE pens, FRP boats, ICAR-CIFRI Cage Grow feed, and quality fish seed to support the demonstration of pen culture and CBF techniques. A total of 150 kg of fingerlings of indigenous carps *Labeo rohita* (5102 nos.), *Labeo catla* (4348 nos.) and *Labeo bata* (9259 nos.) were stocked in pen enclosures. After a four-month culture period, the harvested biomass reached 424 kg.

vii. Plankton and Periphyton diversity

During monsoon and post-monsoon, the abundance of Coscinodiscophyceae was dominant, indicating its ecological significance. While Mediophyceae, Noctilucophyceae, Synurophyceae and Ulvophyceae were almost absent at all sites during pre-monsoon, monsoon and post-monsoon. During the pre-monsoon, Rotifers dominated, with the highest count at S8 (12,410 cells/L) followed by S6 (7,256 cells/L) and S7 (6,859 cells/L). On the other hand, Ciliophora dominated at S8 (6,989 cells/L) followed by S7 (5411 cells/L) and S6 (4,117 cells/L) (Fig.191). Among the phytoplankton, Chlorophyceae, Trebouxiophyceae, Zygnematophyceae and Euglenophyceae were dominant at S7 and their numbers are equal (311 cells/L). Xanthophyceae was present only during monsoon and dominated at S4 (8,650 cells/L) followed by S3 (5,210 cells/L). Periphyton abundance at S1 and S7 of Kundipur during post-monsoon was recorded. Among the Bacillariophyceae, *Diatoma, Navicula, Pinnularia, Gomphonema, Flagilaria*, and *Surirella* were exhibited both at S1 and S7. Only *Aulacoseria* of Coscinodiscophyceae was present at S1 only.

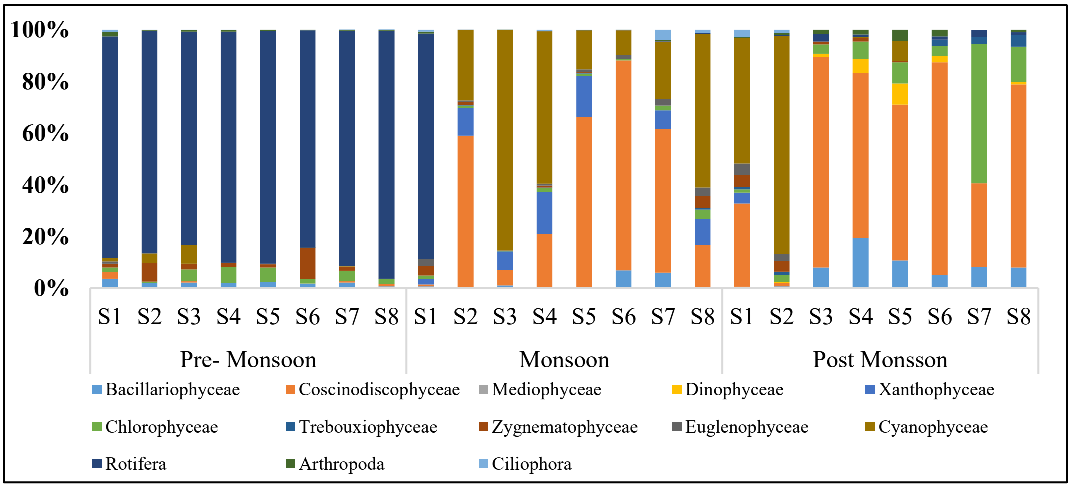


Figure 191: Seasonal variation of phytoplankton (%) abundance in Kundipur Wetland

viii. Benthic diversity of the Kundipur Wetland

A total, 11 macro-benthic fauna species were recorded from Kundipur, belonging to 6 families: Viviparidae (2), Planorbidae (2), Lymnaeidae (2), Ampullariidae (2), Bithyniidae (2), and Thiaridae (1). Lymnaeidae (25%) is the most dominant families followed by Bithyniidae (23%), Viviparidae (24%), Planorbidae (19%), Thiaridae (5%), and Ampullariidae (4%) respectively (Fig.192). The dominant benthic species were as follows: *Gabbia stenothyroides*, *Lymnaea acuminata*, *Pila globosa*, *Idiopoma dissimilis, Gyraulus convexiusculus*, *Indoplanorbis exustus*, and *Melanoides tuberculata*, *Lymnaea luteola*, *and Pila sp. were* recorded in the wetland.

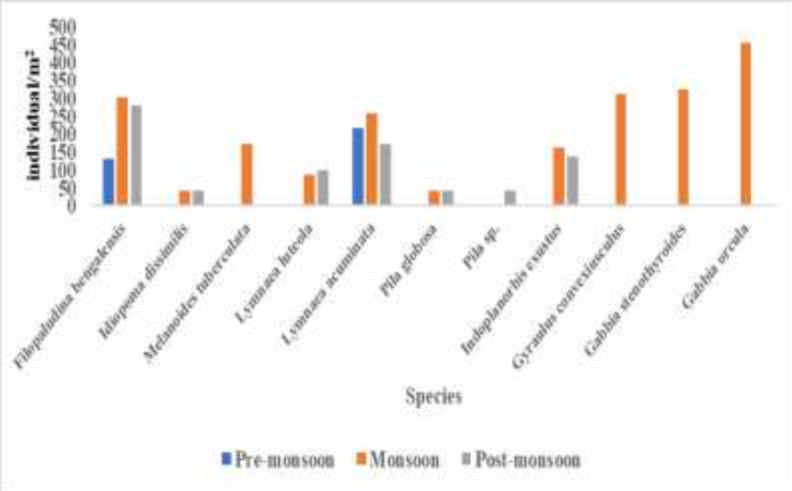


Figure 192: Seasonal variation of the benthic fauna in Kundipur wetland

ix. Analysis of eBPA Concentrations

The BPA levels decline steadily across seasons, from 87.28 ng/L in Pre-Monsoon to 84.62 ng/L in Monsoon, and further to 79.45 ng/L in Post-Monsoon. The gradual decline may be due to dilution or reduced pollutant discharge.

x. Assessment of carbon sequestration potential

The carbon sequestration dynamics in Kundipur wetland revealed significant seasonal fluctuations in both dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC). DOC was highest in the post-monsoon season (3.99 ± 2.50 mg/L), while its lowest value (2.88 ± 0.63 mg/L) was also observed in the same season, likely indicating spatial variability within the site. DIC levels showed a marked seasonal contrast, peaking in the pre-monsoon season (47.20 ± 1.80 mg/L) and dropping sharply during the monsoon (9.29 ± 0.61 mg/L), reflecting the influence of runoff dilution and water column dynamics. Kundipur carbon accumulation, with an estimated 116.97 Mg C/ha stored in the 15.1–30 cm soil layer. Notably, more carbon was stored in the lower layer than in the upper (0-15 cm), suggesting vertical migration or accumulation over time. In contrast, the reference upland site showed a significantly lower carbon stock of 34.57 Mg C/ha in the 0-30 cm profile, highlighting the wetland's superior carbon sink capacity.

xi. Microplastic abundance in the Kundipur wetland

Seasonal analysis of microplastics in the Kundipur Wetland showed distinct variations in both water and sediment samples. During the pre-monsoon season, microplastic abundance was highest, with fragments (11 items/L in water and 16 items/kg in sediment) and fibres (6 items/L in water and 13 items/kg in sediment) being the most prevalent types; foams were also detected in water (1 particle/L) (Fig .193). In the monsoon season, there was a notable decline in microplastic presence across both matrices, with only fibres and fragments detected in water (4 items/L each) and sediment (8 and 4 items/kg, respectively), along with a single film particle in sediment. Post-monsoon samples showed a slight resurgence in water microplastics, especially fibres (9 items/L) and fragments (7 items/L), with traces of films and foams (1 particle/L each), while sediment microplastic levels remained moderate with fibres and fragments at 9 items/kg each. Microbeads were absent in all samples throughout the study period.

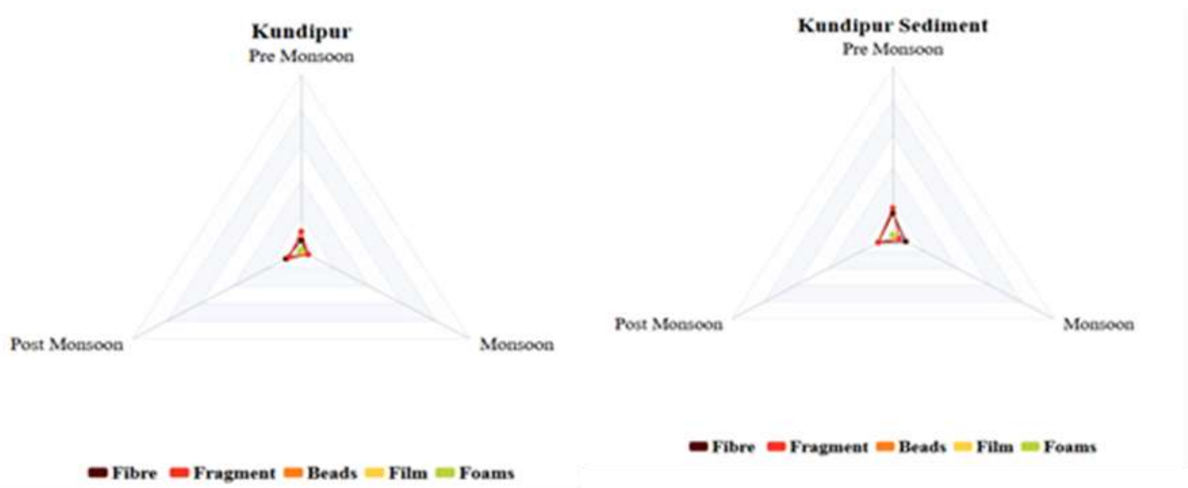


Figure 193: Microplastic abundance in Kundipur wetland

xii. Nutrient profiling of food fishes

The nutrient profiling of *Gudusia chapra* and *Channa punctatus* were carried out from Kundipur wetland. Gross chemical composition identified *Gudusia chapra* as an oil-rich species, while *Channa punctatus* is rich in protein content. Amino acid analysis showed the fish to be rich in essential amino acids such as glutamic acid and lysine, and non-essential aspartic acid. Fatty acid composition revealed myristic (C14:0) and palmitic acids (C16:0) as dominant saturated fatty acids. Oleic acid was the most common MUFA, while docosahexaenoic acid (DHA, C22:6) was the dominant PUFA.

xiii. Conclusion

The Kundipur Wetland is a vital floodplain ecosystem that supports rich biodiversity and serves as a crucial livelihood source for local communities. Its water quality and sediment composition show significant seasonal variations influenced by monsoon dynamics. Despite its ecological richness, the wetland faces challenges from pollution, including arsenic contamination and microplastics. Pen aquaculture and carbon sequestration demonstrate its potential for sustainable resource management and climate resilience. The wetland shows 16 fish species, indicating high ecological value and fisheries potential. Plankton, periphyton, and benthic fauna contribute to its food web complexity. Fish species like *Channa punctatus* and *Gudusia chapra* offer high nutritional benefits. The local fishing community is largely dependent on traditional practices but shows adaptability through integrated livelihoods. Social and infrastructural indicators suggest moderate development with scope for capacity-building. To ensure long-term sustainability, integrated wetland management focusing on conservation, pollution control, and adaptive fisheries is essential.

5.3.1.6. MANIKNAGAR WETLAND

Maniknagar wetland (23.316749°N, 88.32549°E), situated in the Nadia district of West Bengal (Fig.194). The total wetland area covers 11ha, which serves as a biodiversity hotspot, providing a habitat for various species of fish, amphibians, reptiles, and migratory birds, making it an important site for ecological preservation. The wetland also contributes significantly to water purification, filtering out pollutants such as excess nutrients, heavy metals, and sediments, thereby maintaining the quality of water in the surrounding areas. The wetland is managed by the Maniknagar Fishermen Co-operative Society Limited, which consists of 44 members. The sampling was conducted in 8 different sites.

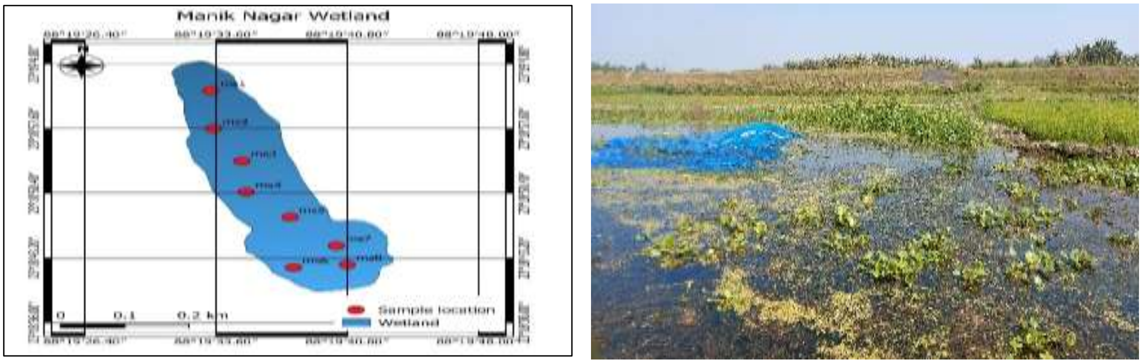


Figure 194: Map of Maniknagar wetland

i. Physico-chemical parameters

The physicochemical characteristics of the Maniknagar wetland across different sites (S1-S5) and seasons (pre-monsoon, monsoon, post-monsoon) exhibit significant spatiotemporal variations, reflecting the dynamic nature of the ecosystem. Water temperature peaked at 33.8°C during the pre-monsoon at S4 and dropped to 23.9°C post-monsoon at S2, with monsoon temperatures slightly lower due to rainfall and cloud cover. Water depth varied seasonally, with the deepest recorded at 5.3 m during monsoon at S3 and the shallowest at 0.38 m pre-monsoon at S4. pH ranged from slightly alkaline (7.72) to highly alkaline (9.1), affected by biological activity and water influx. Dissolved oxygen was highest at 8.4 mg/L (S1, monsoon) and lowest at 2.6 mg/L (S4, post-monsoon), reflecting seasonal changes in water flow and aeration. Specific conductivity was highest pre-monsoon at S3 (463 µS/cm) and lowest during monsoon at S1 (181 µS/cm), showing dilution during rainy periods. Turbidity peaked at 18.7 NTU (S4, pre-monsoon) and was lowest at 9.03 NTU (S5, pre-monsoon), influenced by suspended particles and rainfall. Total alkalinity ranged from 18 mg/L post-monsoon to 136 mg/L pre-monsoon (both at S2), while total hardness varied from 20 mg/L (S1, post-monsoon) to 160 mg/L (S5, pre-monsoon), indicating seasonal changes in mineral content. Chlorinity and salinity followed similar trends, with maximum levels at S5 during pre-monsoon (0.0329 ppt and 0.0596 ppt, respectively) and minimum levels post-monsoon (0.0049 ppt and 0.008844 ppt), highlighting the influence of evaporation and dilution on salt concentration. These variations highlight the intricate relationships between hydrological, climatic, and ecological factors that influence the water quality and overall health of the wetland ecosystem.

ii. Sediment

The sediment pH dropped notably to 5.68 in the post-monsoon period. Conductivity was highest in monsoon (1282.33 µS/cm) and declined to 585.40 µS/cm in post-monsoon. Silt-clay content fluctuated significantly, falling to 7.6% in monsoon and rising to 18.5% in post-monsoon. Calcium carbonate is high in the post-monsoon, reaching 26.36%. Phosphate decreased in monsoon (19.38 mg/100g) but peaked in post-monsoon (26.48 mg/100g). Nitrogen reached its highest in monsoon (450 mg/100g) but dropped to 250 mg/100g in post-monsoon, while organic carbon steadily declined from 3.08% in pre-monsoon to 0.913% in post-monsoon. These seasonal shifts highlight the influence of monsoonal runoff, sediment dynamics, and organic matter processes on the sediment profiles of the wetland.

iii. Pollution status

The Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels in the Maniknagar wetland exhibit clear seasonal variations, indicating fluctuations in organic pollution and water quality. BOD values ranged from a low of 0.8 mg/L pre-monsoon to a high of 2.8 mg/L during the monsoon at S1, reflecting increased microbial activity and organic load during rainfall. Post-monsoon BOD values remained moderate, between 1.2 and 1.6 mg/L. COD levels varied more widely, with the lowest at 4 mg/L pre-monsoon (S1) and the highest at 36 mg/L both pre- and post-monsoon at S2, suggesting significant organic and chemical pollution. These variations underscore the impact of seasonal runoff, water flow, and anthropogenic influences on the wetland's water quality.

iv. Heavy metal contamination

Seasonal variations in metal concentrations in water and sediment samples from the Maniknagar wetland reveal distinct patterns. In water samples, metal concentrations followed the trend As > Cr > Pb > Cu > Cd, with all metals detectable during the pre-monsoon (PRM) season, indicating moderate contamination. During the monsoon (MON), Cadmium and Chromium became non-detectable, while other metals decreased, likely due to dilution from rainfall. In the post-monsoon (POM) season, no metals were detected, suggesting sedimentation or lack of new inputs. All waterborne metal concentrations remained within the safety limits set by USEPA (2024) and BIS (2012). In sediment samples, metal accumulation followed the trend MON > PRM > POM, with the highest levels observed during the monsoon, particularly for Chromium (38.81 µg/g) and Copper (19.60 µg/g), indicating increased contamination from runoff or waste discharge. Lead levels decreased in MON, possibly due to changes in source or transport mechanisms. While most sediment metal concentrations were within permissible limits of the Canadian Interim Sediment Quality Guideline (2011), Cadmium exceeded safe levels (>0.7 µg/g) during both PRM and MON.

v. Fish diversity

A total of 38 fish species belonging to 32 genera, 21 families, and 10 orders were recorded from Maniknagar wetland (Table 18). Season-wise abundance revealed the highest abundance during post monsoon (POM) (n=23), followed by monsoon (MON) (n=21) and pre-monsoon (PRM) (n=16) respectively (Fig.195). The wetland connectivity with the river allows a variety of fish species to migrate in and out of the wetland for breeding migration. The rich post-monsoon abundance indicates the migration of fish species for nourishment and breeding, as the wetlands provide abundant food and shelter.

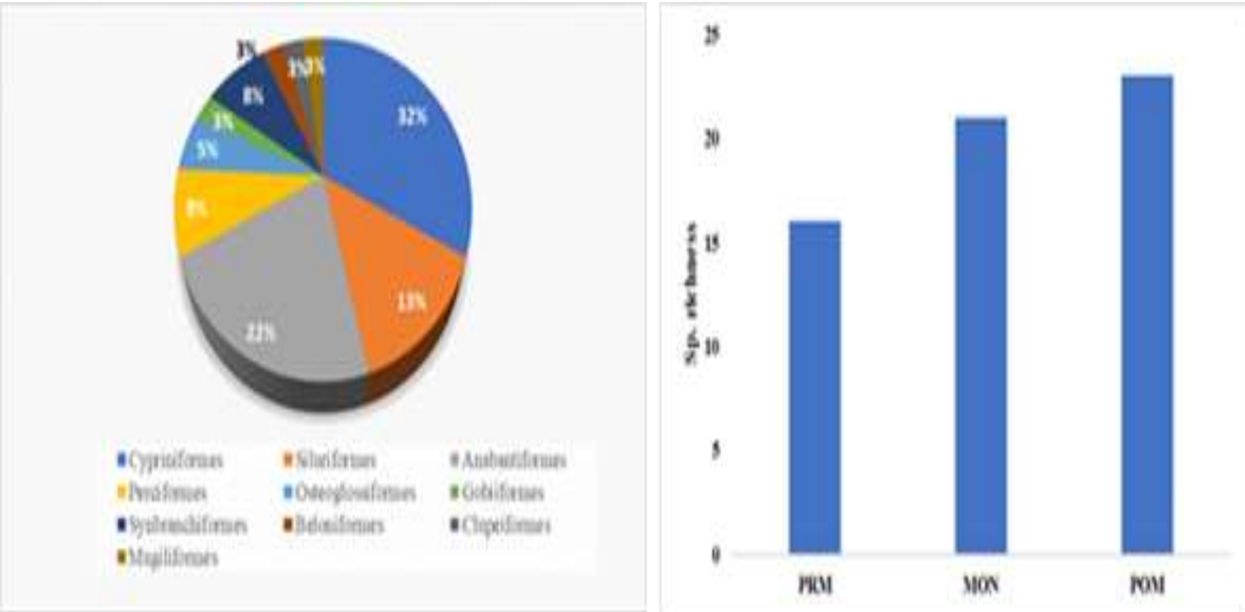


Figure 195: Order (%) wise of fish species in Maniknagar wetland B. Season wise fish abundance in Maniknagar wetland

Table 18: Fish diversity of Maniknagar Wetland

Order	Family	Species
Cypriniformes	Nemacheilidae	*Acanthocobitis botia*
	Danionidae	*Amblypharyngodon mola*
		Salmostoma bacaila
		Salmostoma phulo
	Cyprinidae	*Labeo bata*
		Labeo rohita
		Labeo catla
		Osteobrama cotio
		Cirrhinus reba
		Puntius conchonius
		Puntius sophore
		Systomus sarana
Anabantiformes	Anbantidae	*Anabas testudineus*
	Badidae	*Badis badis*
	Channidae	*Channa gachua*
		Channa marulius
		Channa striatus
	Osphronemidae	*Trichogaster fasciata*
		Trichogaster lalius
	Nandidae	*Nandus nandus*
Siluriformes	Aillidae	*Ailia coila*
	Heteropneustidae	*Heteropneustes fossilis*
	Siluridae	*Wallago attu*
	Clupeidae	*Gudusia chapra*
	Bagridae	*Mystus cavasius*
	Horabagridae	*Pachypterus atehrinoides*
Perciformes	Ambassidae	*Chanda nama*
		Parambassis lala
		Parambassis ranga
Osteoglossiformes	Notopteridae	*Chitala chitala*
		Notopterus notopterus
Gobiiformes	Gobiidae	*Glossogobius giuris*
Synbranchiformes	Mastacembelidae	*Macrognathus pancalus*
		Macrognathus aral
		Mastacembelus armatus
Mugiliformes	Mugilidae	*Rhinomugil corsula*
Beloniformes	Belonidae	*Xenentodon cancila*
Clupeiformes	Clupeidae	*Gudusia chapra*

vi. Plankton and Periphyton diversity

Plankton diversity in the Maniknagar wetland exhibits clear seasonal fluctuations. In Pre-Monsoon, Bacillariophyceae (2,880 cells/L) and Chlorophyceae (2,080 cells/L) dominate phytoplankton, while Rotifera peak at 1,600 individuals/L During Monsoon, phytoplankton, especially Cyanophyceae (19,300 cells/L) and Bacillariophyceae (8,440 cells/L), increase sharply, supporting higher zooplankton like Rotifera at 6,800 individuals/L (Fig.196). In post-monsoon, phytoplankton decline, except Bacillariophyceae rise to 4,000 cells/L, with zooplankton slightly decreasing but stable. The periphyton diversity peaks during the Monsoon season, with Bacillariophyceae and Zygnematophyceae showing the highest phytoplankton densities and Cyanophyceae remaining abundant in Pre and Post-Monsoon periods. Zooplankton, mainly Rotifera, also peak in Monsoon at 4,400 individuals/cm³ in S3. Both phytoplankton and zooplankton decline in post-monsoon, with very low zooplankton in Pre- and Post-Monsoon seasons. This highlights the Monsoon's key role in boosting periphyton and zooplankton populations.

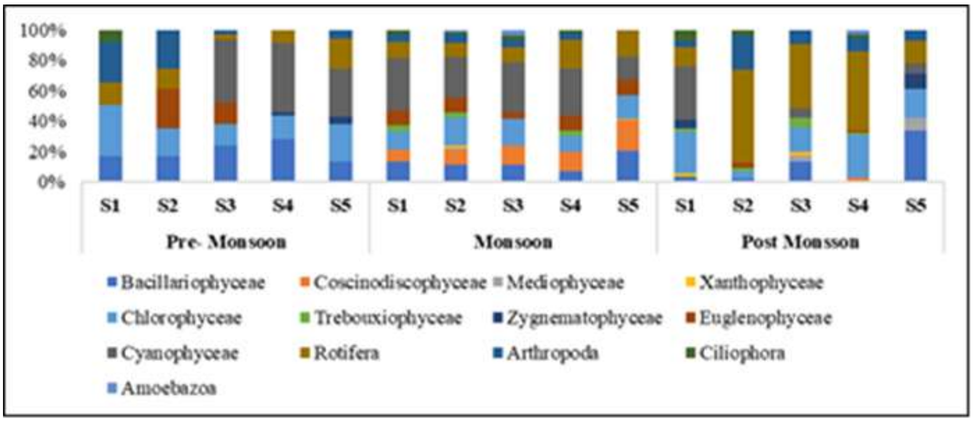


Figure 196: Seasonal percentage variation (%) of plankton in Maniknagar wetland

vii. Benthic Diversity

Eighteen macro-benthic fauna species from 10 families were recorded in Maniknagar wetland, with Viviparidae being the most dominant family (33%) followed by Bithyniidae (25%) and Planorbidae (14%). In the Pre-Monsoon season, *Gabbia orcula* showed the highest abundance (537 individuals/m²). In comparison, *Filopaludina bengalensis* dominated during the Monsoon (303 individuals/m²). Species like *Gabbia orcula* again peaked during post-Monsoon (195 individuals/m²) (Fig.197). Key benthic species included *Gyraulus convexiusculus*, *Mekongia crassa*, *Lymnaea* spp., Chironomid larvae, and *Tubifex tubifex*. (Fig.197). Overall, macro-benthic diversity and abundance were highest in the Pre-Monsoon season, followed by the Post-Monsoon and Monsoon seasons.

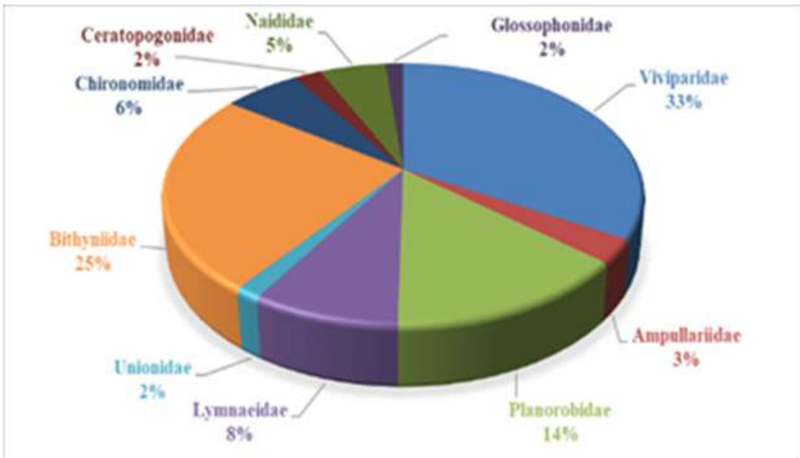


Figure 197: Family-wise (%) distribution of benthic fauna in Maniknagar wetland

In Maniknagar wetland, the carbon dynamics showed that DOC peaked during the monsoon season (5.25 ± 0.15 mg/L), likely due to enhanced organic input from surface runoff, while the lowest DOC levels (2.88 ± 0.63 mg/L) occurred in the post-monsoon period, possibly as a result of microbial degradation or sedimentation. DIC concentrations were highest during the monsoon (25.13 ± 2.33 mg/L) and lowest in the pre-monsoon season (22.12 ± 5.96 mg/L), indicating an overall stable but moderately high inorganic carbon presence throughout the year.

viii. Analysis of eBPA Concentrations

In Maniknagar wetland BPA concentrations are relatively low, ranging from 69.14 ng/L during Monsoon to 74.72 ng/L in Post-Monsoon. The wetland shows minimal seasonal variability, suggesting stable input sources.

ix. Microplastics abundance

The seasonal assessment of microplastics at this wetland site revealed variable concentrations in both water and sediment samples. During the pre-monsoon period, water samples showed moderate levels of fibres (17 items/L) and fragments (18 items/L), with minimal foam presence (1 particle/L), while sediment samples recorded a higher concentration of fragments (26 items/kg) and fibres (18 items/kg), with a single film particle detected. In the monsoon season, a slight decline in microplastic abundance was noted in water, with fibres (11 items/L), fragments (9 items/L), and a rare occurrence of film (1 particle/L); sediment samples showed reduced fibre (14 items/kg) and fragment (19 items/kg) levels, along with continued presence of film (1 particle/kg). Post-monsoon water samples indicated an increase in fibre concentration (21 items/L), moderate fragments (13 items/L), and trace amounts of foam (1 particle/L), while sediment samples displayed a rise in fragments (36 items/kg), with fibres (15 items/kg), and low levels of films and foams (1 particle/kg each) (Fig. 198). Beads were not detected in either water or sediment throughout the study period.

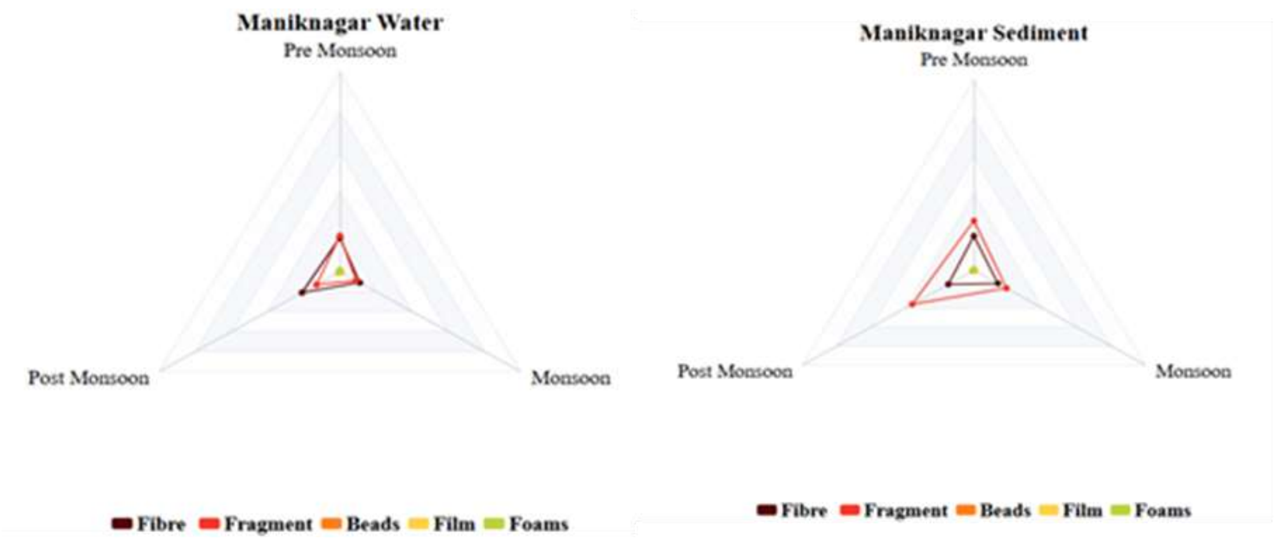


Figure 198: Microplastic abundance in Maniknagar wetland

x. Nutrient profiling of food fishes

The nutrient profiling of nine fish species, *Cirrhinus reba, Systomus sarana, Gudusia chapra, Wallago attu, Notopterus notopterus, Xenentodon cancila, Glossogobius guiris, Macrognathus pancalus*, and *Mastacembelus armatus*, was carried out from Maniknagar wetland, which revealed distinct nutritional qualities across species. Gross chemical composition identified *Cirrhinus reba, Systomus sarana, Wallago attu, Notopterus notopterus, Xenentodon cancila, Glossogobius guiris, Macrognathus pancalus*, and *Mastacembelus armatus* to be protein-rich fishes and *Gudusia chapra*, as an oil-rich fish. Amino acid analysis revealed that most species were rich in essential amino acids, such as lysine and glutamic acid, and non-essential amino acids, including aspartic acid. The fatty acid composition revealed myristic (C14:0) and palmitic acids (C16:0) as dominant saturated fatty acids. Oleic acid was the most common Monounsaturated fatty acids (MUFA), while docosahexaenoic acid (DHA, C22:6) was the dominant polyunsaturated fatty acids (PUFA). Overall, the fish species exhibit valuable nutritional properties, offering rich sources of essential amino acids and beneficial fatty acids, with notable variation based on species-specific metabolism and habitat conditions.

xi. Conclusion

The wetland serves as a crucial ecological and socio-economic resource, supporting rich aquatic biodiversity across 38 fish species. Seasonal variations significantly influence water and sediment quality, with monsoonal runoff impacting nutrient and heavy metal dynamics. Plankton and periphyton diversity peak during monsoon, reflecting enhanced productivity. Benthic fauna is most abundant in pre-monsoon, indicating seasonally favourable conditions. Nutritional profiling highlights the presence of both protein- and oil-rich fish, enhancing the wetland food value. The local fishing community, largely from Scheduled Castes, faces socio-economic constraints including low literacy and income levels, prompting a partial shift to agriculture. To ensure long-term viability, the wetland requires the implementation of adaptive fisheries, culture-based practices, and targeted government support. An integrated approach that combines conservation with livelihood enhancement is essential for preserving the ecological integrity and socio-economic importance of Maniknagar Wetland.

6. COMPONENT: V

Community Sensitization on Biodivesity Conservation, including River Dolphin, along with Fish Biodiversity including Hilsa for Improving the Livelihood of Fishers

6.1. OBJECTIVE I: CREATING PUBLIC AND FISHERS PARTICIPATION IN DOLPHIN AND FISH DIVERSITY CONSERVATION WITH SPECIAL REFERENCE TO HILSA

6.1.1. Importance of Ganga Awareness Programme

The Ganga, also known as the Ganges, is one of the most iconic rivers in the world, revered not only for its ecological significance but also for its profound spiritual and cultural importance in India. Originating from the Himalayas and flowing through the heart of the Indian subcontinent, the Ganga plays a crucial role in the lives of millions of people. It is essential to raise awareness about the river's significance to ensure its preservation and protection, as the river faces numerous environmental challenges today. Raising awareness about the need for sustainable water management practices, reducing pollution, and implementing effective waste treatment systems is vital to ensure the Ganga continues to serve its people and environment. Raising awareness about sustainable development practices, eco-friendly industries, and the need for proper waste disposal can help mitigate this damage and ensure that the Ganga remains a source of prosperity.

6.1.2. The Role of Awareness in Ganga Conservation

Increasing awareness about the importance of the Ganga is crucial for its preservation. Public education campaigns, government initiatives, and community involvement are essential to reduce pollution and protect the river's ecosystems. Programs to educate people on the dangers of polluting the river, alternatives to plastic, and waste management are necessary to instill a sense of responsibility toward protecting the river.

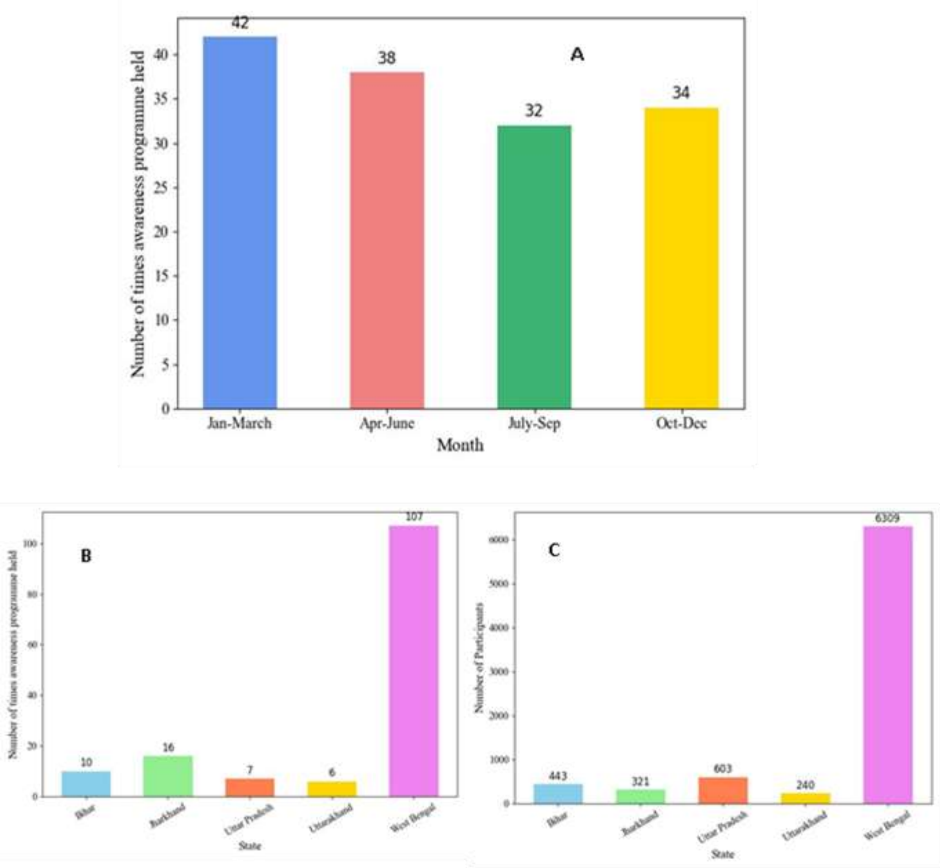


Figure 199: (A-C). A. Quarter-wise mass awareness B. State-wise number of awareness C. State wise number of participants

Additionally, promoting eco-tourism and involving local communities in conservation efforts can help spread the message of sustainability. ICAR-Central Inland Fisheries Research Institute, Barrackpore under National Mission for Clean Ganga, Ministry of Jal Shakti (Phase III), Government of India held 144 awareness programmes on dolphin and fish biodiversity conservation involving sensitization of 7,916 fisher folks and local communities across different rivers of West Bengal were sensitized. The details are mentioned below in Table 19. The quarterwise awareness was held maximum during October-December (63%) (Fig. 199). The number of participants in the awareness was recorded maximum at West Bengal (80%) and minimum at Uttarakhand (3%) (Fig. 200-206).

Table 19: List of awareness programs conducted in various sites under Phase III during 2024

Sl no.	Site	River stretch/tributary	Date	No. of participants
1.	Haldia Ferry Ghat, Haldia, WB	River Haldi	16.01.2024	35
2.	Narghat, Purba Medinipur, WB		17.01.2024	40
3.	Kalighat, Kolkata, WB	River Adi Ganga	16.01.2024	15
4.	Taki, North 24 Parganas, , WB	River Ichamati	22.01.2024	10
5.	Islampur, Murshidabad, WB	River Jalangi	28.01.2024	9
6.	Tehattaghat, Nadia, WB		29.01.2024	16
7.	Farakka, TaltolaGhat, WB	River Ganga	02.02.2024	74
8.	Nabadwip, Prabhupada Ghat, WB		16.02.2024	27
9.	Barrackpore, Monirampore Ghat, WB		22.02.2024	31
10.	Krishnanagar, WB			11
11.	Ashisnagar, Durgapur Barrage, WB			13
12.	Nimtola, Farakka,WB			24
13.	Birnagar, Farakka, WB		24.02.2024	13
14.	Bot tola, Farakka, WB		26.02.2024	11
15.	Sikarpur, Farakka, WB			11
16.	Ayodhya,GuptarGhat, Uttar Pradesh	River Saryu	13.03.2024	46
17.	Bhagalpur, Bihar	River Ganga	13.03.2024	45
18.	Buxar, Ahilya Ghat, Bihar		15.03.2024	48
19.	Patna, Gandhi Ghat, Bihar		14.03.2024	38
20.	Khagaria, Bihar		19.03.2024	8
21.	Supaul, Bihar		21.03.2024	9
22.	Naugachia, Bihar		22.03.2024	16
23.	Rajnagar,Malda,W.B		01.03.2024	10
24.	Rajnagar-2,Malda,W.B		01.03.2024	9
25.	Gajipur,Malda,W.B		01.03.2024	12
26.	Rajmahal,Jharkhand		06.03.2024	21
27.	Khejurighat,W.B		09.03.2024	17
28.	Khejuri ghat-1,W.B		09.03.2024	15
29.	Khejuri ghat-2,W.B		09.03.2024	14
30.	Baliara, Fraserganj, W.B	River Ganga	12.03.2024	31
31.	Diamond Harbour, W.B		14.03.2024	41
32.	Godakhali, W.B		15.03.2024	22
33.	Neemsahar,Farakka,W.B		16.03.2024	11
34.	Sikarpur,Jharkhand		16.03.2024	17
35.	Radhanagar,Jharkhand		16.03.2024	14
36.	Jahanabad Basanta Ghat, Jharkhand	River Gandak	20.03.2024	7
37.	Dak Bangla Ghat, Jharkhand		21.03.2024	8
38.	Dumaria Ghat, Jharkhand	River Kosi	22.03.2024	9
39.	Murahia fishing Village, Jharkhand		23.03.2024	19
40.	Shreeghar, Jharkhand		21.03.2024	12
41.	Shreeghar-2, Jharkhand		21.03.2024	10
42.	Shreeghar 8 no, Jharkhand		21.03.2024	15
43.	Rajnagar Ghat-2,Malda,WB		06.04.2024	19
44.	Bin Nagar,Malda,WB		06.04.2024	15
45.	Rajnagar Ghat 1,Malda,WB		10.04.2024	36
46.	Hilsa ranching station, Farakka, WB		10.04.2024	32

47.	Sikarpur,Malda,WB		16.04.2024	12
48.	Bin nagar,Malda,WB		20.04.2024	15
49.	Khejuria Ghat,Malda,WB		20.04.2024	16
50.	Lalutola Ghat,Malda,WB		27.10.2024	10
51.	Bin nagar,Malda,WB		27.10.2024	13
52.	Boat Ghat, Yamuna River, UP		27.10.2024	15
53.	Kada Dham, Kausambi, UP		07.05.2024	100
54.	Sirsa, Prayagraj, UP		09.05.2024	50
55.	Mirzapur, UP		11.05.2024	250
56.	Rajnagar Ghat ,Malda,WB		15.05.2024	50
57.	PaglaGhat ,Malda,WB		02.05.2024	18
58.	Panchanandapur,Malda,WB		02.05.2024	11
59.	Deerforest ,Farakka,		02.05.2024	21
60.	Neemsahar ,Farakka,WB		09.05.2024	35
61.	Rajnagar ghat ,Malda,WB		09.05.2024	16
62.	Rajnagar ghat-2 ,Malda,WB		18.05.2024	14
63.	Hilsa ranching station ,Farakka,WB		18.05.2024	10
64.	Begamganjfutanibazer,Jharkhand		23.05.2024	40
65.	Radhanagar,Jharkhand		29.05.2024	15
66.	Balagarh, WB		29.05.2024	16
67.	Barrackpore, WB		31.05.2024	120
68.	Rajnagar Ghat,Malda,WB		05.06.2024	18
69.	Khejuria Ghat,Malda,WB		05.06.2024	9
70.	Kalna, WB		05.06.2024	12
71.	Tribeni, WB		06.06.2024	32
72.	Mayapur, WB		07.06.2024	25
73.	Lalbag, WB		08.06.2024	25
74.	Berhampore, WB		12.06.2024	40
75.	Bally, WB		13.06.2024	30
76.	Deerfoest, Farakka,WB		14.06.2024	63
77.	Nimtola, Farakka,WB		15.06.2024	09
78.	Nimsahar, Farakka,WB		15.06.2024	18
79.	Nimsahar -2, Farakka,WB	River Ganga	24.06.2024	16
80.	Nimsahar -2, Farakka,WB		24.06.2024	15
81.	Farakka, Hilsa Ranching Station, WB		05.07.2024	60
82.	Rajmahal, Jharkhand		05.07.2024	44
83.	Kamarganj, Sultanganj, Bihar		12.07.2024	62
84.	Radhnagar, Malda, WB		12.07.2024	16
85.	Radhnagar-1, Malda, WB		12.07.2024	8
86.	Khejuria Ghat, Malda,WB		12.07.2024	13
87.	Khejuria Ghat-2, Malda, WB		12.07.2024	10
88.	Binnagar Ghat, Malda, WB		12.07.2024	23
89.	Hukum Chapra Ghat, Ballia, Uttar Pradesh		19.07.2024	54
90.	Raja Ghat, Patna, Bihar		20.07.2024	56
91.	Sojhi Ghat, Munger, Bihar		21.07.2024	73
92.	Kulideyar Ghat, Murshidabad, WB		26.07.2024	11
93.	Hossenpore Ghat, Murshidabad, WB		26.07.2024	35
94.	Khejuria Ghat, Malda, WB		06.08.2024	10
95.	Khejuria Ghat-2, Malda, WB		06.08.2024	11
96.	Nimtala, Farakka,WB		12.08.2024	13
97.	Nimshahar, Farakka, WB		12.08.2024	13

98.	Adi Krishnanagar Ghat, Ganga Sagar, WB		14.08.2024	43
99.	Hilsa ranching station, Farakka, WB		15.08.2024	18
100.	Nimshahar, Farakka, WB		27.08.2024	14
101.	Khejuria Ghat, Malda, WB		31.08.2024	12
102.	Khejuria Ghat-2, Malda, WB		31.08.2024	10
103.	Hilsa conservation workshop, ICAR-CIFRI, Barrackpore		05.09.2024	84
104.	Goran Bose II, South 24 Pgns, WB	River Matla	07.09.2024	8
105.	Goran Bose I, South 24 Pgns, WB		08.09.2024	11
106.	Islampur, Nadia, West Bengal	River Jalangi	08.09.2024	05
107.	Nimshahar,Farakka, WB	River Ganga	11.09.2024	12
108.	Deerforest, Farakka, WB		11.09.2024	13
109.	Taltola Ghat ,Farakka, WB		14.09.2024	13
110.	Fraserganj , South 24 Pgns, WB		24.09.2024	32
111.	Diamond Harbour, South 24 Pgns, WB		25.09.2024	26
112.	Godakhali, South 24 Pgns,WB		26.09.2024	15
113.	Tehri, Uttarakhand		02.10.2024	30
114.	Mirjapur, Farakka, WB		04.10.2024	12
115.	Dolphin Awareness * (Prayagraj, Bihar and West Bengal)		05.10.2024	264
116.	Taltola ghat, Farakka,WB		04.10.2024	13
117.	Khejuriya ghat, Malda,WB		14.10.2024	13
118.	Nimsaher, Farakka, WB		31.10.2024	12
119.	Sikarpur, Jharkhand, WB		31.10.2024	18
120.	Haridwar, Uttarakhand		04.11.2024	55
121.	Alakananda (Badrinath), Uttarakhand		06.11.2024	52
122.	Koteshwar Tehri, Uttarakhand		07.11.2024	16
123.	Koti colony, Uttarakhand		07.11.2024	31
124.	Garhwal University, Uttarakhand		07.11.2024	56
125.	Farakka, WB		07.11.2024	24
126.	Pipra, Jharkhand		07.11.2024	30
127.	Hilsa Station, Farakka, WB		14.11.2024	45
128.	ICAR-CIFRI, Barrackpore, WB		19.11.2024	40
129.	Diamond Harbour, WB		23.11.2024	110
130.	Rajnagar, Malda, WB		29.11.2024	10
131.	Nayagram, Malda, WB		29.11.2024	12
132.	Shridhar, Jharkhand		06.12.2024	28
133.	Nimtola, Jharkhand		06.12.2024	32
134.	ICAR-CIFRI, Barrackpore		09.12.2024	30
135.	Hilsa ranching station ,Farakka, WB		14.12.2024	43
136.	Nayagram, Malda, WB		14.12.2024	22
137.	ICAR-CIFRI, Barrackpore, WB		23.12.2024	30
138.	Army Public School, Barrackpore, WB		23.12.2024	213
139.	Kultoli Mela, Sunderban,WB		26.12.2024	3512
140.	ICAR-CIFRI, Barrackpore,WB		26.12.2024	32
141.	Rajnagar, Malda, WB		29.12.2024	12
142.	Tribeni, Hooghly, WB		29.12.2024	68
143.	Kalna, East Burdwan, WB		29.12.2024	57
144.	Nabadwip, Nadia, WB		30.12.2024	41
		Total sensitized populace		**7916**

Figure 200: Mass awareness on dolphin and fish biodiversity including Hilsa in different tributaries of river Ganga (Jan-March, 2024)

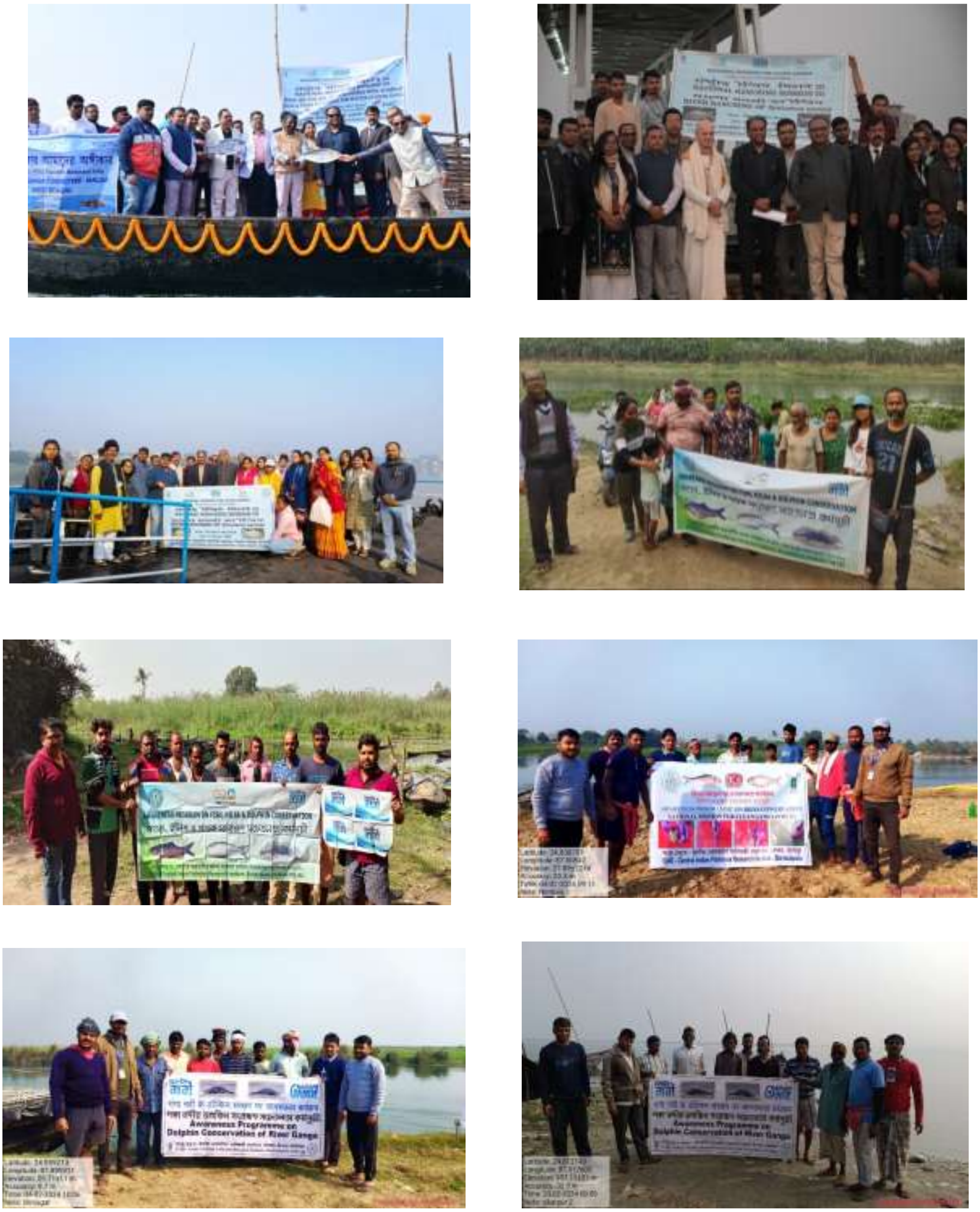


Figure 201: Mass awareness on dolphin and fish biodiversity including Hilsa in different tributaries of river Ganga (Jan-March, 2024)

Figure 202: Mass awareness of dolphin and fish biodiversity, including Hilsa in different sites of river Ganga

Figure 203: Mass awareness was performed in different tributaries of River Ganga during September 2024


महाशीर जनजागरूकता कार्यक्रम

Figure 204: Awareness in different sites of River Ganga

Figure 205: Glimpses of the NMCG CIFRI project (Phase III) launching workshop on 10.02.2024 at Farakka

Figure 206: Awareness in Dolphin conservation in different sites of River Ganga

6.2. OBJECTIVE II: ESTABLISHING THE ECONOMIC STATUS AND CONTRIBUTION OF THE LOCAL FISHERS UNDER 'ARTHA GANGA' CONCEPT OF THE RIVER GANGA

The Arth Ganga concept, introduced under the Namami Gange Programme by the Government of India, aims to shift from a project-based approach to a people-centric and sustainable development model for the Ganga River Basin. This initiative focuses on linking the ecological health of the Ganga with economic prosperity by actively involving local communities in sustainable livelihood activities and promoting a circular economy. Fisheries play a central role in this vision by offering sustainable livelihoods, supporting biodiversity conservation, and maintaining the ecological balance of the river ecosystem.

ICAR-CIFRI has been instrumental in implementing this concept through various initiatives under the National Mission for Clean Ganga (NMCG). These efforts include annual river ranching programs to replenish fish stocks, awareness campaigns on issues such as overfishing and dolphin conservation, and capacity-building workshops that train fishers in sustainable and climate-resilient fishing practices.

Additionally, ICAR-CIFRI has supported fishers through skill development initiatives aimed at introducing techniques for higher income generation. The promotion of sustainable aquaculture practices, such as cage and pen culture in floodplain wetlands, has helped diversify livelihood options and enhance economic resilience. To understand the socio-economic status of fishers dependent on river Ganga, ICAR-CIFRI conducted a comprehensive study across 2,378 km of the Ganga River, covering 379 fishing villages in 47 districts across Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal. Using a multi-stage stratified random sampling method, data were collected from 684 fishers through direct observations, household surveys, focus group discussions, and secondary data analysis.

6.2.1. Socio-Economic Profile of Fishers Dependent on the River Ganga

6.2.1.1. Social Profile of Fishers

In the upper stretch of the Ganga, a notable 43% of the fishers fall into the young age bracket (up to 35 years), illustrating a predominance of younger individuals engaged in fishing activities in this region. Moving to the middle stretch, the proportion of young fishers slightly decreases to 39%, while in the lower stretch, the demographic shifts considerably, with 52% of the fishers being classified as middle-aged. The educational background of fishers along the river also shows variation: 43% of fishers in the upper stretch possess primary education, whereas in the middle stretch, widespread illiteracy prevails, with the majority lacking even basic education. In contrast, 49% of fishers in the lower stretch have attained primary education. Regarding fishing experience, 38% of respondents in the upper stretch have up to 10 years of experience, while in the middle and lower stretches, 32% and 34% of fishers, respectively, have 11–20 years of experience. The survey further reveals that 88% of respondents identify fishing as their primary livelihood, while others engage in wage labor (6.64%), agricultural farming (3.05%), livestock rearing (1.8%), and miscellaneous occupations such as shopkeeping, welding, boat driving, and small trading (1.08%). Across all regions, most fishers prefer a multigear and multispecies approach, combining various types of gears rather than relying on a single gear type, to maximize catch efficiency and adapt to the diverse aquatic environments along the river.

6.2.1.2. Livelihood Diversification

To assess livelihood diversification across the river's stretches, the Simpson Index was employed. The findings indicate greater diversification in the upper stretch, where the index stands at 0.46. This is attributed to the comparatively lower fish catch in this area, which likely encourages households to engage in a variety of income-generating activities. In contrast, the lower stretch exhibits less livelihood diversity, a trend that corresponds with higher fish catches in the region. This pattern suggests that the abundance of fishery resources in the lower stretch leads to a higher dependence on fishing as the primary source of income, thereby reducing the motivation to diversify livelihood activities.

6.2.1.3. Catch and Income of Fishers

The Catch per Unit Effort (CPUE) data presented in this study provide valuable insights into the productivity and fishery dynamics of the Ganga River system. Among the states, West Bengal reported the highest mean CPUE at 7.82 kg per fisher per day, followed by Uttar Pradesh at 5.18 kg, Jharkhand at 3.61 kg, Uttarakhand at 3.21 kg, and Bihar at 3.15 kg per fisher per day. This data highlights significant regional variation in fishing efficiency along the river, reflecting differences in fish abundance, gear usage, and fishing practices across states. In the upper stretch of the Ganga, the average monthly income of fishers is ₹5,950, in the middle stretch ₹8,430, and the lower stretch ₹11,273. When compared to a previous study (2017), these figures show an increase of 36.94% in the upper stretch, 43.7% in the middle stretch, and 54.8% in the lower stretch (Fig.207). The variation in income levels corresponds with differences in fish availability, catch efficiency, and market access across the stretches. The highest income is observed in the lower stretch, where fishers benefit from better resource availability and higher-value species. These changes indicate an overall improvement in the economic condition of fishers along the river.

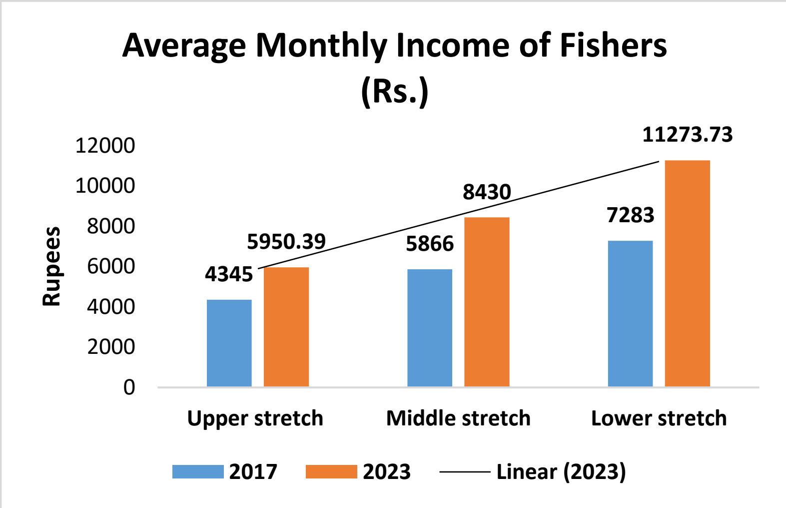


Figure 207: Monthly income of fishers in 2023-24

6.2.3. Socio-Economic Profile of Fishers in different tributaries of River Ganga

A mixed-method approach was adopted to assess the socio-economic status of riverine fishers, integrating both qualitative and quantitative tools. The survey covered fishing villages across stretches of the river. Primary data were collected through household surveys with semi-structured interviews, focus group discussions (FGDs) with key stakeholders, and direct observations at fishing sites and landing centres.

6.2.3.1. Haldi River

Figure 208: Harvesting of fish

The fishing community surveyed (n=100) is entirely male, with 82% of respondents aged between 30 to 59 years. Educational attainment is low; 39% never attended school, and only 12% completed secondary education, with none having pursued higher studies. Families are almost evenly split between nuclear (52%) and joint (48%) structures, and most households (63%) consist of less than 5 members, often relying on multiple income sources. All respondents identify as Hindu, with 73% belonging to the Other Backward Classes (OBC) and 27% to the Scheduled Castes (SC). Housing conditions reflect modest living standards, with 44% living in semi-pakka, 37% in pakka, and 19% in kutcha houses. Fishing is the primary occupation, supplemented by additional activities like agriculture (35%), horticulture (33%), livestock rearing (17%), and labour work (15%). Experience in fishing is substantial, as 47% have more than 20 years, 31% have 10–20 years, and 22% have 3–10 years of experience, indicating a deep-rooted dependence on this traditional livelihood. Fishing gear mainly includes gill nets, cast, dip, or drag nets (43%), and the average daily fish catch is 11–20 kg (Fig.208). The monthly income of the fisher's ranges from ₹1,000–20,000, with 57% earning between ₹8,001–14,000.

6.2.3.2. Alakananda River

The fishing community surveyed (n=57) is entirely male, with 78% of respondents aged between 30 and 59 years and 22.22% representing the youth age group of 15–29 years (Fig.209). No participants were below 15 or above 60. Educational attainment is low, with 33.33% never attending school, and only 11.11% completed secondary education, with the rest having primary (16.67%) or middle school (38.89%) levels of schooling. Most families (88.89%) consist of fewer than 10 members, indicating a prevalence of large households that may depend on shared income sources. All respondents identify as Hindu, with 55.56% belonging to the General category, 33.33% to the Scheduled Castes (SC), and 11.11% to the Other Backwards Classes (OBC). Housing conditions reflect mixed standards, with 38.89% living in semi-pakka, 38.89% in pakka, and 22.22% in kutcha houses. Agriculture is the primary occupation (57.78%), supported by fishing (22.22%), labor work (12%), and other jobs (8%).

Experience in fishing is modest, with 88.89% having 3–10 years of experience and only 11.11% having 10–20 years, suggesting a relatively recent shift into fishing as a livelihood activity. Monthly income of the fishers ranges from ₹1,000–20,000, with 38.89% earning ₹10,000–15,000, 33.33% earning up to ₹10,000, and 27.78% earning above ₹15,000. Weekly fish consumption is moderate, with 78.57% consuming 1–3 kg and 14.29% consuming 4–6 kg, indicating regular but limited fish intake within households.

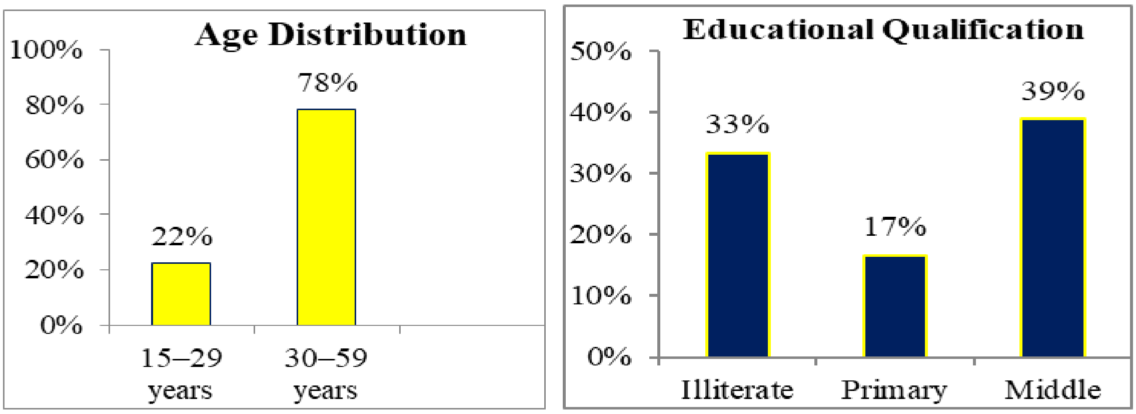


Figure 209: Age and Education Distribution of fishers

6.2.3.3. Bhilangna River

The fishing community surveyed (n=100) is entirely male, with 71% of respondents aged between 30 and 59 years and 28% representing the youth age group of 15–29 years. Educational attainment is low, with 42% never attending school, and 28% each completed primary and middle school levels, with none having pursued higher education. Families are predominantly joint (57%), with 42% being nuclear, often relying on collective incomes to sustain livelihoods. The community includes both Hindus and Muslims, indicating religious diversity, and most respondents belong to the Scheduled Castes. Housing conditions reflect modest standards, with 85% living in semi-pakka and 14% in kutcha houses. Fishing remains the primary occupation, supported by traditional gear such as cast nets, dragnets, and gill nets, revealing continued dependence on manual fishing methods and natural water bodies altered by development interventions. The monthly income of the fishers ranges from ₹1,000–10,000, with 62% earning between ₹4,000 and ₹ 6,000, indicating subsistence-level livelihoods.

6.2.3.4. Nayar River

The fishing community surveyed (n=100) is entirely male, with 47% of respondents aged between 30 and 59 years, 34% youth (15–29 years), and 19% elderly (60 years and above). Educational attainment is low, with 51% never attending school, 33% completing primary education, 11% completing middle school, and only 5% completing secondary education. Families are predominantly nuclear (69%), and most households (64%) consist of less than 5 members. All respondents identify as Hindu, with a caste distribution of 39% General, 29% Other Backward Classes (OBC), 25% Scheduled Castes (SC), and 7% Scheduled Tribes (ST). Housing reflects modest standards, with 63% living in pakka, 17% in semi-pakka, and 20% in kutcha houses. Access to drinking water varies, and most households' own televisions, smartphones, and motorbikes. Fishing is the primary occupation (21%), supplemented by agriculture (43%), wage labor (24%), and livestock rearing (12%). Most fishers have 10–20 years of experience (61%), indicating considerable familiarity with fishing practices despite diversified livelihoods. Daily fish catch varies, with 48% catching 1–10 kg, 36% 11–15 kg, and 16% 16–20 kg. Monthly income ranges widely but is modest overall, with 73% earning between ₹1,000 and ₹8,000 and an average income of ₹5,700.

6.2.3.5. Saryu River

Figure 210: Fishers Engaged in sorting of fish

The fishing community surveyed (n=100) is entirely male, with 63% of respondents aged between 30 and 59 years, 22% youth (15–29 years), and 15% elderly (60 years and above). Educational attainment is low, 39% are illiterate, 32% completed primary education, and 29% middle school; none pursued higher education. Families are predominantly joint (71%), with 74% of households having less than 10 members (Fig. 210). Housing conditions are mixed, with 45% living in pakka, 35% in semi-pakka, and 19% in kutcha houses. All households have access to electricity. The community is mainly composed of Other Backward Classes (OBC, 71%), followed by the General category (19%) and Scheduled Castes (SC, 10%). All respondents identify as Hindu. Fishing is the primary occupation, supplemented by agriculture (61%) and livestock or other work (19%). Most fishers (52%) have over 20 years of fishing experience, reflecting deep-rooted engagement with the livelihood. Daily catch ranges from 1–10 kg (55%), 11–15 kg (26%), to 16–20 kg (19%). The average monthly income is ₹9,200, with the majority (45%) earning between ₹1,000 and ₹8,000. Although long-term experience and joint family structures provide socio-economic resilience, low education levels and environmental degradation highlight the need for sustainable fishing strategies and skill development programs.

6.2.3.6. Yamuna River

The fishing community surveyed (n=88) is primarily composed of individuals in their working years, 86.36% are aged 30–59, while 13.64% are youth (15–29 years). Education levels remain low: 50% have completed only primary schooling, 31.82% are illiterate, and 18.18% have reached middle school. Scheduled Castes make up 36.36% of the population, with Other Backward Classes (OBC) and General category each representing 31.82%. Most respondents are Hindus (86.36%), while 13.64% follow Islam. Housing conditions reflect modest living standards: 63.64% reside in semi-pakka structures, 31.82% in pakka houses, and 4.55% in kutcha homes. Fishing forms the backbone of the community's livelihood, particularly among marginalized groups. Monthly income varies: 72.73% earn ₹10,000–15,000, 22.73% earn ₹15,000–20,000, while 4.55% earn ₹5,000–10,000. Despite their reliance on natural resources, environmental degradation and weak governance challenge livelihood stability. Adoption of modern fishing practices and improved access to markets are essential for community revitalization.

6.2.3.7. Ramganga River

The fishing community surveyed (n=100) primarily composed of middle-aged fishers (70%), with 30% being younger individuals. Educational attainment is low: 30% are illiterate, 60% have completed primary education, and only 10% have reached middle school. The family structures include 57.14% joint families and 42.86% nuclear families. Caste-wise, 50% belong to the General category, 40% to OBC, and 10% to Scheduled Tribes (Fig. 211). Housing conditions are

Figure 211: Data collection of Ramganga fishers

modest; 80% live in semi-pakka homes, 10% in pakka, and 10% in kutcha houses. Traditional fishing gear, like cast, drag, and gill nets, is commonly used. Monthly income varies: 70% earn ₹5,000–₹10,000, 10% earn below ₹5,000, and 20% earn ₹10,000–₹15,000. Seasonal fish availability and outdated fishing techniques affect income. Enhancing financial support mechanisms and introducing modern gear are crucial for improving resilience and livelihoods.

6.2.3.8. Jalangi River

The fishing community surveyed (n=100) was primarily composed of fishers ranging from 21–77 years, with 40% aged 30–59. Education levels are low: 38% are illiterate, 34% have primary education, and only 2% have reached higher education, with illiteracy higher among those over 50. Nuclear families dominate (70%), and 53% of households have less than 10 members. Housing is mainly semi-pakka (85%), followed by kutcha (10%) and pakka (5%). All are Hindus, primarily from the Scheduled Castes, mainly Halder and Biswas. Drinking water sources include borewells (46%), Panchayat taps (27%), municipal pipelines (19%), and ponds (8%). All households have electricity, and most own smartphones, TVs, and motorbikes, though cars are rare. Fishing is the main livelihood (60%), with others engaged in labor (13%), jute/masonry work (10%), livestock rearing (9%), and farming (8%). The average fishing experience is 24 years. Most (71%) earn ₹1,000–8,000/month; 16% earn ₹8,001–14,000, and 13% earn ₹14,001–20,000. The average monthly income was estimated to be ₹5,488.

6.2.3.9. Adi Ganga River

The fishing community surveyed (n= 80) primarily composed fishers ranging fishers (76%) along the Adi Ganga are middle-aged (30–59), with 16% aged 15–29. Education levels are poor, 38% are illiterate and another 38% have only primary education, with no one reporting schooling beyond the primary level. Scheduled Castes form the majority (54%), followed by OBCs (23%) and the General category (8%). Most fishers are Hindus (77%), while Muslims make up a small minority (8%). Fishing remains the primary occupation for 46%, followed by agriculture (38%) and wage labor (31%). In terms of experience, 38% have 10–20 years, 31% have 3–10 years, and only 15% have over 20 years of experience. Income distribution shows 31% earning ₹10,000–15,000 monthly, another 31% earning more than ₹15,000, and 23% earning below ₹10,000. Despite their dependence on fishing, financial limitations hinder investments in modern gear and improved living conditions. The ecological degradation of Adi Ganga, marked by pollution, biodiversity loss, and declining fish catch, poses a critical threat to livelihoods, necessitating immediate interventions in pollution control, waste management, and sustainable fishery practices for long-term viability.

6.2.3.10. Damodar River

Figure 212: Data collection of Damodar fishers

The fishing community surveyed (n= 72) in this region are middle-aged (77.78%), with education levels remaining low, 38.89% are illiterate, 44.44% have only primary education, and 16.67% have reached middle school (Fig. 212). The vast majority (94.44%) are married and reside in joint families (83.33%), indicating strong adherence to traditional family systems. While fishing remains the primary occupation, many supplements their income through labor (61.11%) and agriculture (38.89%). Fishing experience varies, with most (38.89%) having 21–30 years in the profession, reflecting a seasoned workforce. In terms of income, the majority (83.33%) earn between ₹10,000–15,000 per month, with a smaller segment (16.67%) earning ₹15,000–20,000. Notably, no one earns below ₹10,000 or above ₹20,000. These trends point to economic stability at modest levels, emphasizing the need for targeted strategies that enhance income, improve access to resources, and strengthen livelihood resilience.

6.2.3.11. Rupnarayan River

The fishing community surveyed (n= 100) primarily comprised fishers of middle-aged (79%), with fewer youth (11%) and elderly (6%). Fishing is male-dominated (94%), while women primarily engage in marketing activities. Education levels are low, with 45% illiterate and 41% having only primary education; just 14% have secondary or higher schooling, limiting opportunities for skill development and adoption of modern fishing techniques. The community mainly consists of Scheduled Castes (83%), followed by OBC (16%) and General caste (1%). Large families with 6–9 members are common (82%), and housing conditions reflect economic constraints; 52% live in semi-pucca, 39% in kutcha, and only 9% in pucca houses. Most fishers (75%) catch between 1–5 kg daily, earning ₹8,000–10,000 per month, showing high dependence on fishing but with limited income. Challenges like pollution, declining fish stocks, low literacy, and weak institutional support threaten their livelihoods, making literacy programs, sustainable fishing practices, and better access to government schemes critical for enhancing resilience.

6.2.3.12. Churni River

The fishing community surveyed (n= 84) primarily comprised fishers of middle-aged (76.19%), with only 14.29% categorized as youth. Educational attainment is low, with 31.82% being illiterate, 50% having only primary education, and 18.18% reaching middle school. The community is predominantly composed of Scheduled Castes (66.67%), followed by General (19.05%) and OBC (14%) categories. Hindus make up the vast majority (95.24%), with a small Muslim minority (4.76%). Housing conditions reflect moderate economic standing, 42.86% live in semi-pakka houses, 38.10% in pakka, and 19.05% in kutcha structures, showing vulnerability to environmental and infrastructural stress. In terms of income, 71.43% earn ₹5,000–10,000 per month, while 14.29% earn less than ₹5,000, and another 14.29% fall in the ₹10,000–15,000 range; notably, none earn above ₹15,000.

6.2.3.13. Ichamati River

The fishing community surveyed (n= 100) primarily comprised fishers of middle-aged (66%), with fishing dominated by males (84%) while women primarily engaged in shrimp seed collection. Education levels remain low, with 31% illiterate and 45% having only primary education; just 12% reach secondary or higher education, particularly among women. Scheduled Castes form the majority (88%), with 12% from OBC communities. Housing conditions are mixed, with 42% living in semi-pucca and 41% in kutcha houses, while only 17% have pucca homes. Families tend to be large, as 56% have less than 9 members and 33% have more than 9 members. Daily catch volumes vary: 58% collect 1–10 kg, 28% catch 11–15 kg, and 14% catch 16–20 kg. Monthly incomes are modest, with 62% earning ₹8,001–14,000 and only 5% earning above ₹14,000. The fishers face multiple challenges, including climate impacts, inadequate infrastructure, limited access to schemes, and health risks.

6.2.3.14. Matla River

In the river Malta region, the surveyed fishing community (n = 120) primarily comprised individuals aged 30–59 years (76%). Men (76%) were mainly engaged in fishing and farming, while women (24%) focused on household duties, seed collection, and crab harvesting. Education levels are low, with most having only primary schooling and high illiteracy, especially among women. The community comprises 58% Scheduled Castes, 36% OBC, and 3% General/ST, with nuclear families slightly more common (55%) and generally large family sizes, 18% have more than nine members. Housing is mixed, with 42% living in semi-pakka, 41% in pakka, and 15% in kutcha homes, and all households have access. Fishing is the main livelihood, supplemented by livestock rearing (50%), farming (30%), and other work. Fishing experience varies: 55% have 3–10 years, 26% have 10–20 years, and 20% have over 20 years. Daily catches vary, with 48% catching 11–15 kg and 21% catching 1–10 kg. Monthly incomes range widely, with 52% earning ₹8,001–14,000 and 33% earning ₹1,000–8,000 (Fig. 213).

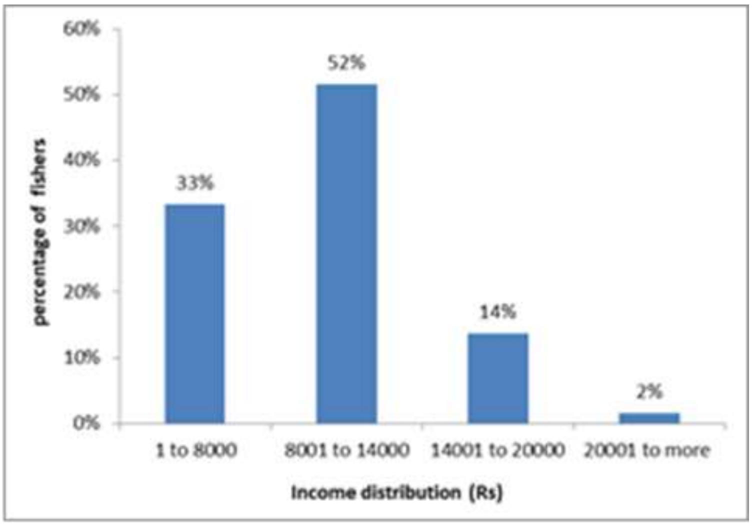


Figure 213: Monthly income of fishers of River Matla

6.2.3.15. Gandak River

In the river Gandak region, the surveyed fishing community (n = 100) primarily comprised individuals aged 30–59 years (72%), and all are male. Education levels are low, with 56% illiterate, 28% having primary education, and only 2% reaching secondary school; no one has higher education. Joint families dominate (68%), mostly with 6–9 members (67%). Housing is predominantly semi-pakka (64%), followed by pakka (27%) and kutcha (9%). All households have electricity, and media access through phones and TVs is common. The majority belong to the OBC caste (88%) and are Hindu. Water access is mainly through private borewells and public supply. Fishing is the primary occupation, supplemented by agriculture (47%), fruit/vegetable farming (25%), and livestock rearing (18%). Most fishers (52%) have over 20 years of experience. Daily catches are low, with 84% catching 1–10 kg, and monthly incomes are modest, 57% earn ₹1,000–8,000, 25% earn ₹8,001–14,000, and only 18% earn above ₹14,000.

6.2.3.16. Kosi River

In the river Kosi region, the surveyed fishing community (n = 164) primarily comprised individuals aged 30–59 years (62.58%) with a significant youth presence (28.83%), and all are male (Fig. 214). Education levels are low, with 50.61% illiterate, 29.88% having only primary education, and very few attaining secondary or higher schooling. Housing conditions vary, with 46.34% living in kutcha houses, 42.07% in pakka, and 11.59% in semi-pakka homes. Fishing experience is moderate, with 54.27% having 11–30 years of experience and 27.44% having up to 10 years of experience. Income levels show that most fishers (60.37%) earn between ₹10,000–15,000 monthly, 20.12% earn ₹15,000–20,000, and only 13.41% exceed ₹20,000, indicating limited opportunities for higher earnings (Fig. 215). Overfishing, illegal gear use, and pesticide contamination have severely depleted fish stocks.

Figure 214: Interaction with Kosi Fishers

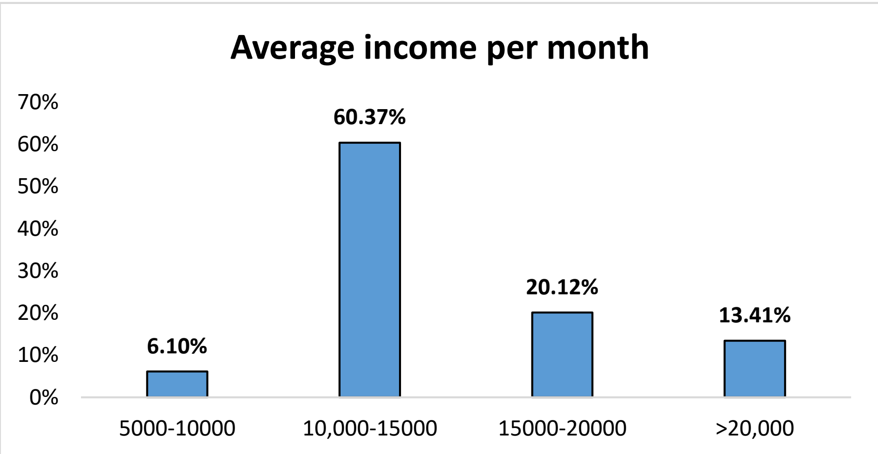


Figure 215: Income distribution of fishers of river Kosi

6.2.4. Socio-Economic Profile of Fishers Dependent on the river Ganga

6.2.4.1. Akaipur Wetland

Fishing in Akaipur Beel is mainly done by middle-aged men (69.23%), with low participation from youth and the elderly (15.38% each). The sector is heavily male-dominated (96.15% men). Education levels are low, with most fishers having only primary (46.15%) or no education (30.77%). Housing is split between Pakka and Semi-pakka structures (38.46% each), while 23.08% live in Kaccha houses. The monthly incomes ranged uniformly between ₹5,000-₹10,000, indicating limited economic diversity (Fig. 216). Challenges include poaching, weed infestation, siltation, water depletion, and ecological threats. Low incomes, inadequate training, and conflicts further strain livelihoods. Addressing these requires focused efforts in education, infrastructure, and wetland conservation.

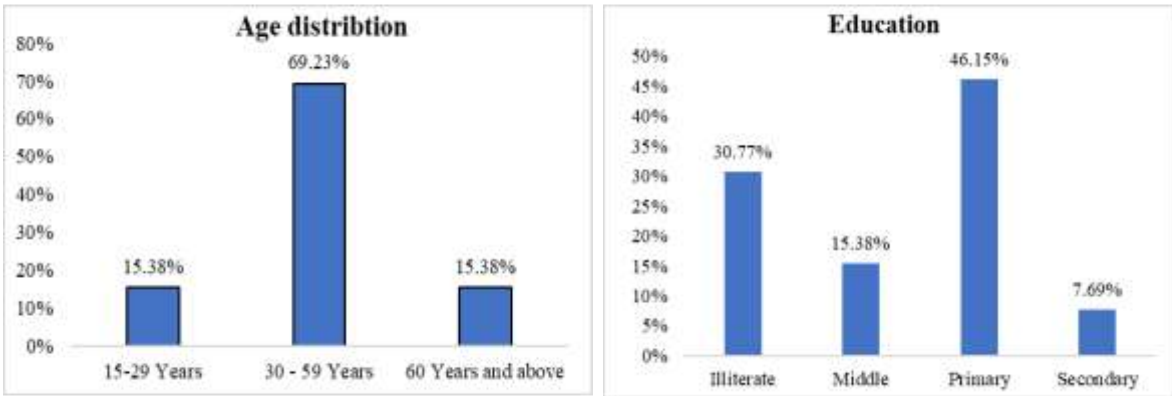


Figure 216: Age distribution and educational profile of fishers

6.2.4.2. Bijpur Wetland

The fishing community around the Bijpur wetland is primarily composed of middle-aged males, with 76% aged 30-59, and a male majority (76%) in the workforce (Fig.217). Education levels remain low, with 55% having only primary education and 21% being illiterate, indicating limited access to education or early entry into fishing (Fig. 217). Family structures are shifting, with 55% living in nuclear families and 45% in joint families. Marginalized groups dominate the community, including Scheduled Castes (58%) and Other Backward Classes (36%), while religious affiliation is mostly Hindu (76%), followed by Muslim (15%) and Christian (9%). Housing conditions reflect moderate stability, with 42% living in semi-pakka houses, 41% in pakka houses, and 15% in katcha houses. Many fishers engage in secondary occupations like livestock rearing (50%), farming (30%), and agriculture (15%), with 5% in other work. Experience levels vary, with 55% having 3–10 years in fishing, 26% with 10–20 years, and

20% with over 20 years. Income remains modest; 52% earn ₹8,001–₹14,000 monthly, 33% earn less than ₹8,000, 14% between ₹14,001–₹20,000, and only 2% exceed ₹20,000 (Fig. 217). The Bijpur wetland is under threat from habitat encroachment, plastic pollution, and overfishing, leading to ecosystem degradation and reduced fish stocks. Sustainable land use, waste management, responsible fishing, and community awareness are vital for preserving the wetland and ensuring long-term livelihoods.

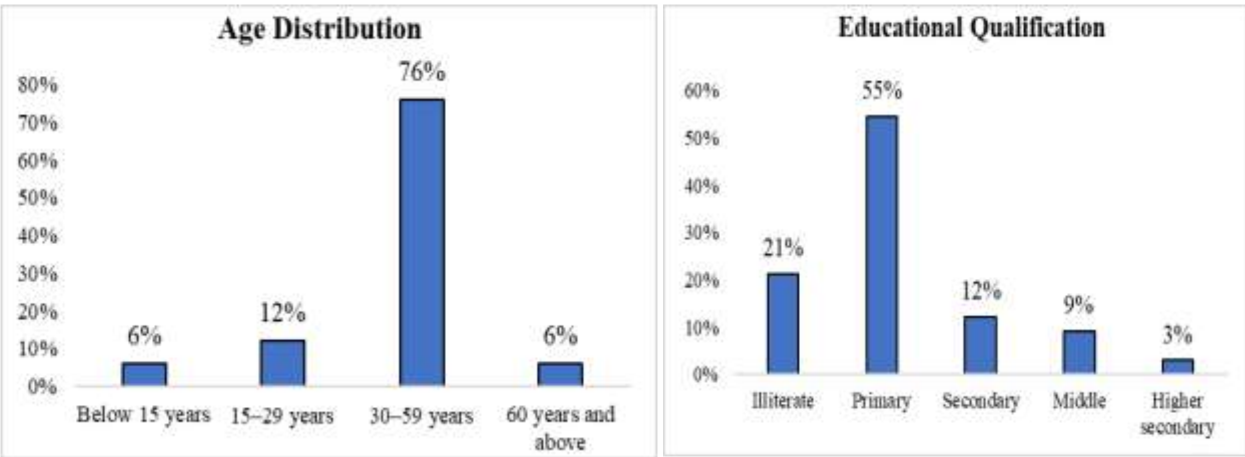


Figure 217: Age distribution and educational profile of fishers

6.2.4.3. Kundipur wetland

Fishers in the Kundipur wetland are predominantly middle-aged (63%) and all male, with secondary livelihoods supplementing fishing. Literacy levels are fair, with most having completed middle (41%) or primary (34%) education. Families are mostly nuclear (61%) and small (63% with 1–5 members), and all belong to the Scheduled Castes and follow Hinduism. Housing is mainly pakka (47%) or semi-pakka (38%), with universal access to electricity (Fig 218). Fishing is often combined with agriculture (34%), labor (27%), or livestock rearing (17%), though 22% rely solely on fishing. Most have 10–20 years of experience. Water is accessed via borewells, municipal lines, and Panchayat taps, while most households' own TVs, smartphones, and motorbikes. Fishing methods vary, with catch sizes ranging from 1–20 kg and monthly incomes between ₹1,000–₹20,000 (Fig 218). The wetland faces threats from encroachment, pollution, and overfishing, making sustainable practices and conservation efforts essential for the community's future.

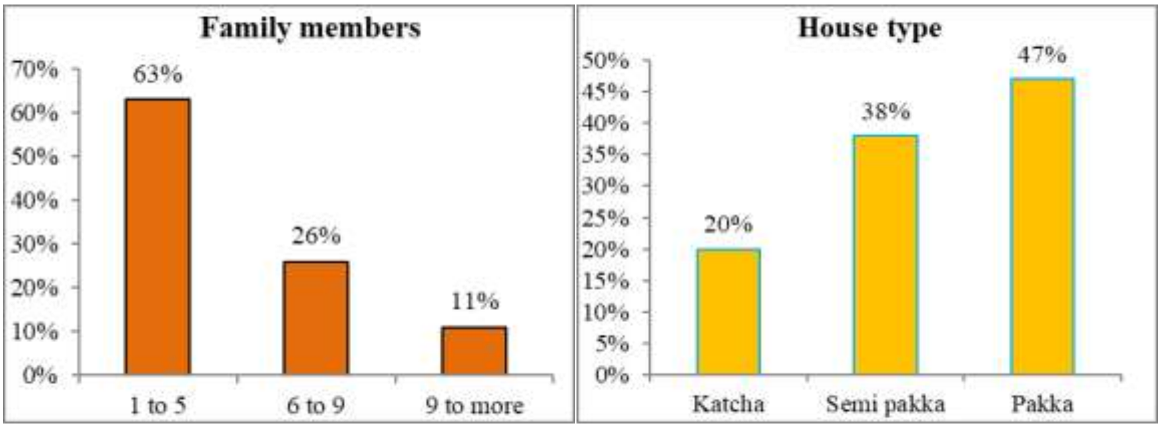


Figure 218: Family size and House type of fishers of Kundipur wetland, West Bengal

6.2.4.4. Maniknagar wetland

The fishing community of Maniknagar Wetland is predominantly composed of middle-aged males (86%), with minimal representation from younger (6%) and older (10%) age groups. Education levels are low, with 45% illiterate and only 8% having completed higher secondary education (Fig.219). Most families are large, with 64% having 6–9 members, and the majority (95%) belong to Scheduled Castes. Housing is mostly semi-pucca (52%), followed by kutcha (31%) and pucca (17%) structures. Fishers use cast nets, dragnets, and gill nets, with most catching 2–5 kg of fish daily and earning ₹4,000–₹6,000 per month. Challenges include macrophyte infestation, low fish density, and poor soil conditions, which have led to declining catches and a shift toward agricultural labor. The Maniknagar Fisheries Co-operative Society is seeking government and technical support to promote sustainable, culture-based fisheries and improve livelihoods.

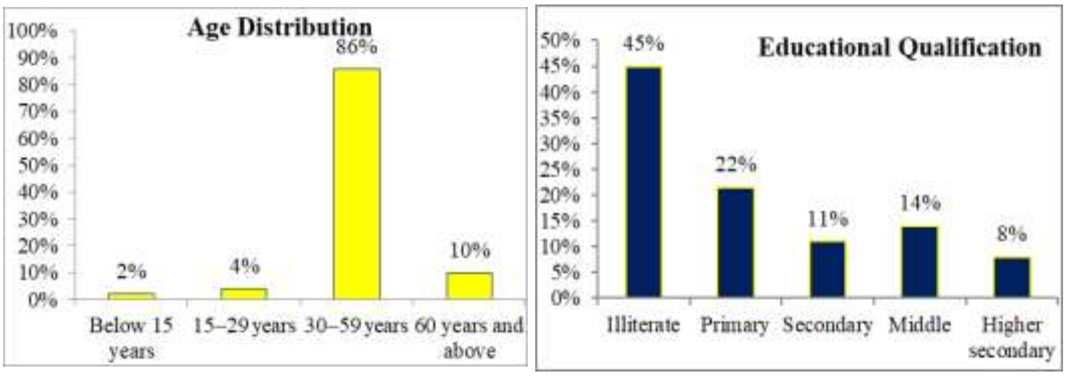


Figure 219: Age distribution and educational profile of fishers of Manikanagar wetland

7. Publications

7.1. Research papers

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2. Kundu, S., Biswas, A., Ray, A., Roy, S., Gupta, S. D., Ramteke, M. H., Kumar, V., & Das, B. K. (2024). Bisphenol A contamination in Hilsa shad and assessment of potential health hazard: A pioneering investigation in the national river Ganga, India. Journal of hazardous materials, 461, 132532. https://doi.org/10.1016/j.jhazmat.2023.132532
3. Kundu, S., Ray, A., Gupta, S. D., Biswas, A., Roy, S., Tiwari, N. K., Santhana Kumar, V., & Das, B. K. (2024). Environmental bisphenol A disrupts methylation of steroidogenic genes in the ovary of Paradise threadfin *Polynemus paradiseus* via abnormal DNA methylation: Implications for human exposure and health risk assessment. Chemosphere, 351, 141236. https://doi.org/10.1016/j.chemosphere.2024.141236
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8. Das, B. K., Kumari, K., Ganguly, S., Talukder, A. K., Ray, A., Dutta, S., & Baisakhi, B. (2024). Unlocking the nutritional potential: amino acid profile of eight Indian food fishes and their role in meeting recommended dietary allowances. Frontiers in Sustainable Food Systems, 8, 1432034. https://doi.org/10.3389/fsufs.2024.1432034
9. Chakraborty, H., Das, B. K., Chakraborty, N., Sahoo, A. K., & Maity, J. (2024). Distribution patterns of antioxidants in the organs of anadromous fish *Tenualosa ilisha* (Hamilton, 1822)—a profiling in different age groups for future application in anti-aging. Frontiers in Marine Science, 11, 1452775. https://doi.org/10.3389/fmars.2024.1452775
10. Chakraborty, H., Chakraborty, H. J., Das, B. K., & Maity, J. (2024). Age-specific changes in the serum proteome of female anadromous, Hilsa *Tenualosa ilisha*: a comparative analysis across developmental stages. Frontiers in Immunology, 15, 1448627. https://doi.org/10.3389/fimmu.2024.1448627
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12. Kundu, S., Das, B. K., & Gupta, S. D. (2024). Hormonal Symphony: The Dynamic Duo of IGF and EGF in Gonadotropin-Induced Fish Ovarian Development and Egg Maturation. Animal Reproduction Science, 107663. https://doi.org/10.1016/j.anireprosci.2024.107663.
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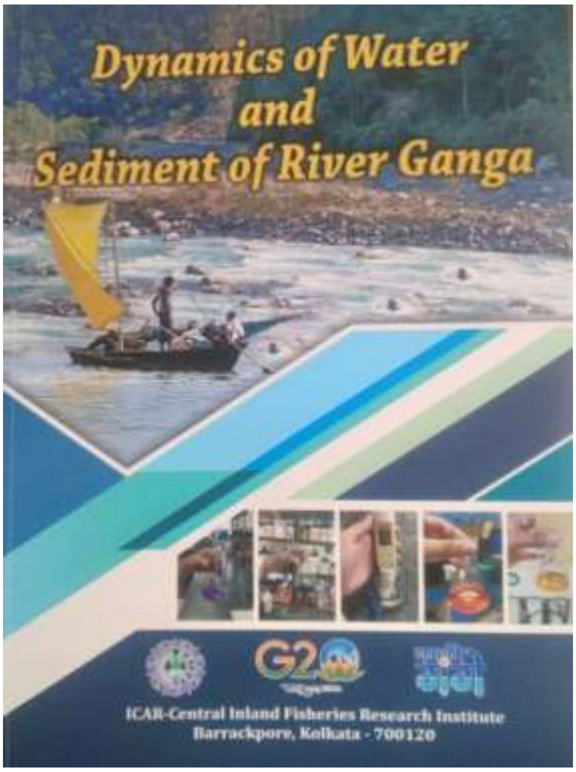
7.2. Books published

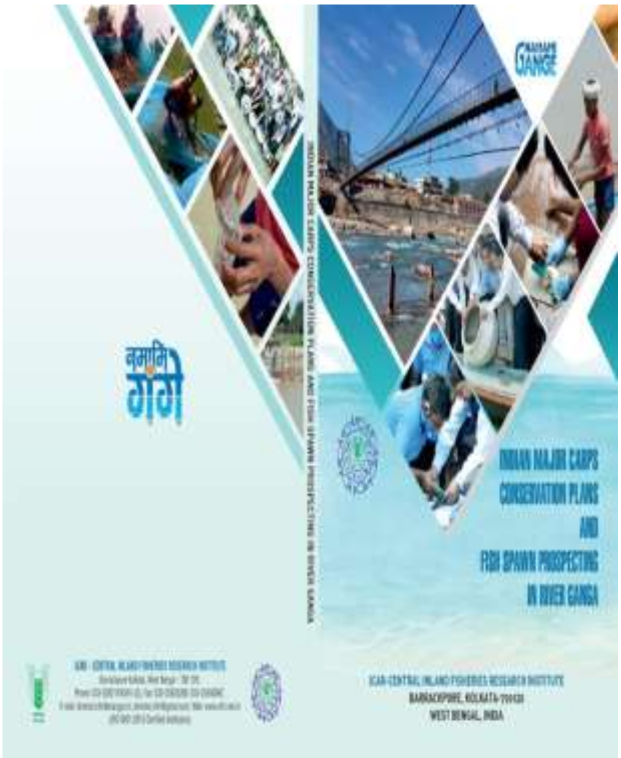
1. Das, B. K., Tiwari, N. K., Das, A. K. Dynamics of Water and Sediment of River Ganga, (2024) ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata and National Mission for Clean Ganga, New Delhi. 240p. ISBN: 81-85482-50-0.
2. Das B.K., Swain, H.S., Ramteke, M.H., Das Gupta, S., Tiwari, N.K., Kumar, V. Upadhyay, A., Prasad, S (2024). Indian Major Carps Conservation Plans and Fish Spawn Prospecting in River Ganga, ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata and National Mission for Clean Ganga, New Delhi. 102p. ISBN: 81-85482-60-8.
3. Das B.K., Bhakta, D., Ramteke, H., Swain, H.S., Das Gupta, S. (2024) River Ranching Guidelines, ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata and National Mission for Clean Ganga, New Delhi. 102p. ISBN: 81-85482-60-8.
4. Das, B. K., Thengal, G., Johnson, C. (2024). Fish Catch and Fisheries Socio-economic of river Ganga. ICAR- Central Inland Fisheries Research Institute, Barrackpore. ISBN: 81-85482-70-5.

7.3. Photo album/Pamphlet

1. River Ranching-A Glimpse (2024) ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata and National Mission for Clean Ganga, New Delhi. 95p. ISBN: 81-85482-51-9.
2. ICAR-CIFRI, under the NMCG phase III project, has came out with a pamphlet on the societal and economic status of the fishers alongside the River Ganga Basin from 2022-23. The pamphlet provides a brief description of the demographic profile of the fishers residing along the banks of River Ganga from the upper stretch (Haridwar) to the lower estuarine section (Fraserganj).



Dynamics of Water and Sediment of River Ganga



IMC conservation plans and fish spawn prospecting in river Ganga

River Ranching Guidelines

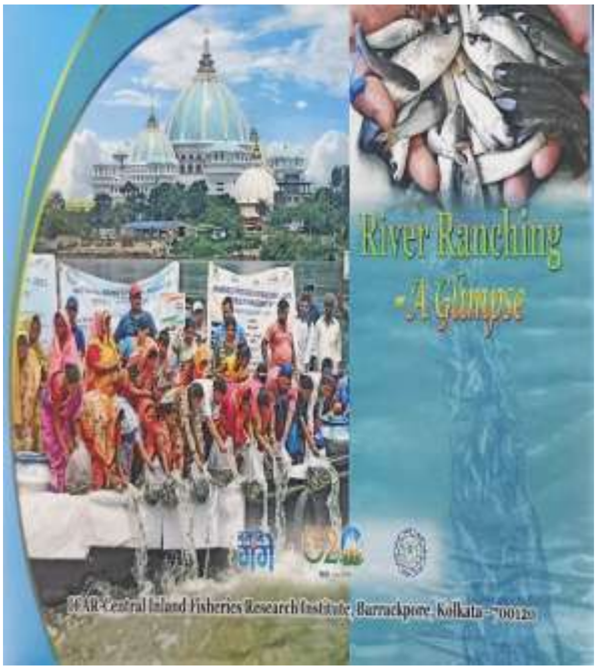
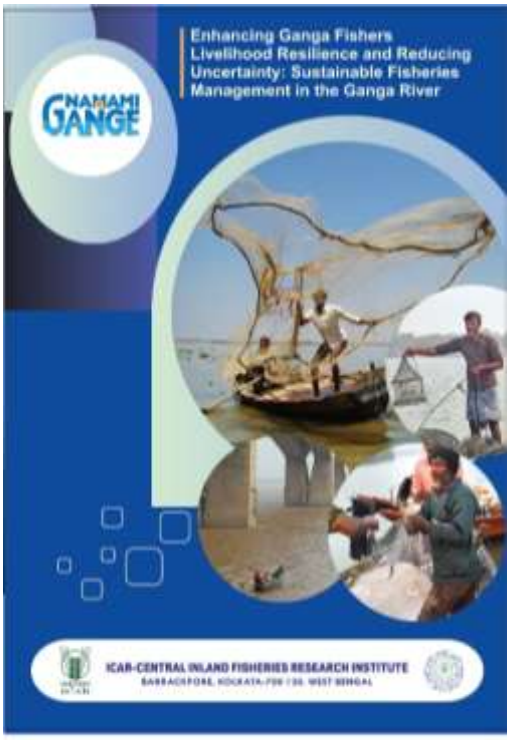
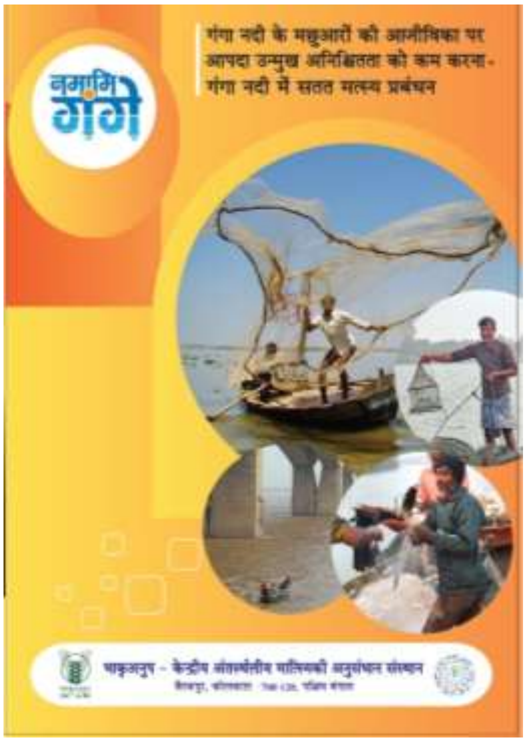


Photo album on River Ranching





7.4. Conference papers

1. Das Gupta S. *, Ray A., Kundu S., Ramteke M.H. and Das B.K. Observation on the fecundity and Gonado-Somatic Index in captively reared Gangetic wild broodstock of Indian Major Carps. Pp.177, Das, B. K., Chanu, T. N., Sajina A. M., Bhakta, D., Gogoi, P., Karnatak,Meena, D. K., Roy, A., Kumari, S. Sahoo, A. K., Sarkar, D. J., Jha, D. N., Das, A. Kand Rajesh, K. M. (Eds.). 2024. Book of Abstracts. 13th IFAF, Satellite Symposia on 'Fish genetic resource and conservation','Riverine fisheries: Habitat mapping and environmental health', 'Sustainable fisheries and aquaculture in Northeast India' and 'Natural Farming'. ICAR-CIFRI, Barrackpore, Kolkata-700120, India. pp 861. ISBN 81-85482-62-4.
2. Ghosh S., Kundu S. Das B.K. Bioinformatics-based genome-wideidentification of heat shock proteins in *Labeo rohita.* Pp.249, Das, B. K., Chanu, T. N., Sajina A. M., Bhakta, D., Gogoi, P., Karnatak,Meena, D. K., Roy, A., Kumari, S. Sahoo, A. K., Sarkar, D. J., Jha, D. N., Das, A. Kand Rajesh, K. M. (Eds.). 2024. Book of Abstracts. 13th IFAF, Satellite Symposia on 'Fish genetic resource and conservation',' Riverine fisheries: Habitat mapping and environmental health''Sustainable fisheries and aquaculture in Northeast India' and

'Natural Farming'. ICAR-CIFRI, Barrackpore, Kolkata-700120, India. pp 861. ISBN 81-85482-62-4.

3. Chakraborty H.*, Das, B.K, Sahoo A.K., Sadhukhan R., Maity J.. A study on proximate analysis of anadromousHilsa *Tenualosa ilisha* (Hamilton, 1822) with relevance to different size groups and sex. Pp.304, Das, B. K., Chanu, T. N., Sajina A. M., Bhakta, D., Gogoi, P., Karnatak,Meena, D. K., Roy, A., Kumari, S. Sahoo, A. K., Sarkar, D. J., Jha, D. N., Das, A. Kand Rajesh, K. M. (Eds.). 2024. Book of Abstracts. 13th IFAF, Satellite Symposia on 'Fish genetic resource and conservation','Riverine fisheries: Habitat mapping and environmental health', 'Sustainable fisheries and aquaculture in Northeast India' and 'Natural Farming'. ICAR-CIFRI, Barrackpore, Kolkata-700120, India. pp 861. ISBN 81-85482-62-4.
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1. Bartaman (Bengali), 25.01.2024, Biodiversity assessment by CIFRI in river Jalangi
2. Sanbad Pratidin News (Bengali), Farakka 10.02.2024, NMCG Phase III Launching workshop
3. Press Information Bureau, 12.02.2024, NMCG Phase III Launching workshop
4. Samaja (Odia), 12.02.2024, Fish Conservation in river Ganga & steps taken by ICAR-CIFRI
5. Kalinga Chronicle, 12.02.2024, Fish Conservation in river Ganga & steps taken by ICAR-CIFRI
6. Sanyam Bharat, 08.03.2024, Release of 1lakh of fish seed in Praygraj
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8. Shree 7 News, 08.03.2024, Release of 1lakh of fish seed in Praygraj
9. NirbhayPalghar, 08.03.2024, Release of 1lakh of fish seed in Praygraj
10. Sahaj Satta, 14.03.2024, Release of 1lakh of fish seed in Ayodhya
11. Prahari Bharat, 14.03.2024, Release of 1lakh of fish seed in Ayodhya
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47. Prabhat Khabar (Hindi), 13.07.2024, River ranching at Sultanganj
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66. Published in Kalinga Chronicle on 31 December, 2024, Topic: Ranching of native sarana by ICAR-CIFRI.
67. Published in Ekdin (Bengali) on 31 December, 2024, Topic: Ranching of native sarana by ICAR-CIFRI.

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1. Facebook News on River Ranching in Bally, at ICAR-CIFRI page, 17 June, 2024
2. Instagram News on River Ranching in Bally, in ICAR-CIFRI page, 17 June, 2024 https://www.instagram.com/p/C8OxR0vSJHd/?igsh=MWF6djB6MGdjc3hiNw==
3. Facebook News on River Ranching in Bally, in ICAR-CIFRI page, 17 June, 2024 https://www.facebook.com/share/p/Uo63ADgvgrTZvhC4/?mibextid=qi2Omg
4. Instagram News 'Title: River ranching by the Secretary Dr. A. Likhi at Barrackpore,(https://www.instagram.com/p/DAkWjcRtjs9/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==)

5. Published in Bengali YouTube Channel_Public on 23 December, 2024 (Topic: CIFRI NMCG Exhibition pavillion in Sunderban) https://youtu.be/xH5cuwp_V8w?si=nTGkq5jygLBLuxz3
6. Published in Bengali YouTube Channel_Gramin Krishi Samachar on 25 December, 2024 (Topic: CIFRI NMCG Exhibition pavillion in Sunderban) https://public.app/video/sp_ytf2glaxdj6n6?utm_medium=android&utm_source=share

8.3. Eletronic Media

1. Krishi darshan (DD Bangla: 01.01.2024) : Topic : TV. Report on Sunderban Kristi Mela o Loko Kristi Utsav Kultali 2023 (https://youtube.com/watch?v=n1SfoYe-TYI)
2. ES News Bangla (25.01.2024) : Topic : TV. Report on CIFRI initiative in survey and conservation of small indeigenous fishes (https://www.facebook.com/share/v/jbyX9q9nDxa9DyuJ/?mibextid=SphRi8)
3. In Shot News (25.01.2024): CIFRI survey in Ichamati River (https://link.public.app/w2vqf?utm_medium=android&utm_source=share)
4. Big News (25.01.2024): CIFRI survey under NMCG (https://www.facebook.com/share/v/643Zfb1Qj3ZetfLt/?mibextid=jmPrMh)
5. DD News Bangla, Farakka 10.02.2024, NMCG Phase III Launching workshop (https://www.facebook.com/share/v/jEZxN3S3xaV4xN5p/?mibextid=qi2Omg
6. Akaashvani Kolkata Farakka 10.02.2024, NMCG Phase III Launching workshop (https://www.facebook.com/share/v/yxQ5FGEvok5TEuzg/?mibextid=qi2Omg)
7. E News Daily Bulletin, Farakka 10.02.2024, NMCG Phase III Launching workshop (https://fb.watch/q6_n69bQE3/?mibextid=2JQ9oc)
8. NTV News Daily Bulletin, Farakka 10.02.2024, NMCG Phase III Launching workshop (https://fb.watch/q6_rtkV7y4/?mibextid=2JQ9oc)
9. Aajkal News (Bengali), Farakka 10.02.2024, NMCG Phase III Launching (https://www.aajkaal.in/story/8141/the_number_of_fish_in_the_clean_waters_of_the_ganges_is_increasing_said_the_director_general_of_the_national_clean_ganga_mission)
10. City Bulletein News (14.03.2024)- Ranching in river Saryu, Ayodhya (https://www.youtube.com/watch?v=K8GsL3-ixto&t=1s)
11. Saket News (14.03.2024)- Ranching in river Saryu, Ayodhya (https://youtu.be/jZGhpv6BSp0?si=7ShLVNE4Pu17JDgI)
12. News on River Ranching in Berhampore, at Madhyabanga News, 13 June 2024 https://madhyabanga.news/fishing-seedlings-released-berhampore/(YouTube https://www.youtube.com/watch?v=iNUZdzO76M0)

13. News on River Ranching in Berhampore, at NBTV News, 13 June 2024 (Facebook link:https://www.facebook.com/61558685018614/videos/830758785774412/?rdid=lBGXEblawQmOgkpV)
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15. -News on River ranching at Farakka (Doordarshan Bangla) on 5 July, 2024 (https://www.facebook.com/watch/?v=1011217620562970)
16. E-News on River ranching at Farakka (Daily Bulletin Bangla) on 5 July, 2024 (https://www.facebook.com/share/v/odC3r1BmFYB1uHVS/?mibextid=xfxF2i)
17. E-News on River ranching at Farakka (Akashvani Kolkata Bangla) on 5 July, 2024(https://www.facebook.com/share/v/766QZ7XhhKPjGcP8/?mibextid=qi2Omg)
18. E-News on River ranching at Farakka (NTV News Bangla) on 5 July, 2024 (https://www.facebook.com/share/v/2MgyEeYjDsZ3YxZM/?mibextid=xfxF2i)
19. E-News on River ranching at Farakka (Tara News Bangla) on 5 July, 2024 (https://www.facebook.com/share/v/pGWUe1tAnMP5WVvC/?mibextid=xfxF2i)
20. News on River ranching at Patna (Live media News Hindi) on 20 July, 2024 (https://youtube.com/post/Ugkx4-yD5L3h AmN7G4GRLuQoJN4Msrho_uw?feature=shared)
21. E-News on River ranching at Munger (Prayag Khabar Hindi) on 21 July, 2024 (https://youtu.be/CeH-ts9KUlU?si=OFtrheFGK6PLZ1-y)
22. E-News on River ranching at Munger (Munger live Hindi) on 21 July, 2024 (https://youtu.be/o5Zl5fPQ_f0?si=1awmcyA--P_Yglb4)
23. E-News on River ranching at Munger (Prabhat Khabar Hindi) on 21 July, 2024 (https://epaper.prabhatkhabar.com/bhagalpur/munger/2024-07-22/3)
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25. Published in Daily Hunt (English) 'Title: Community and Conservation Unite: ICAR-CIFRI's Awareness Program at Ganga Sagar' (https://dhunt.in/WNFAp) dated: 28.09.2024.
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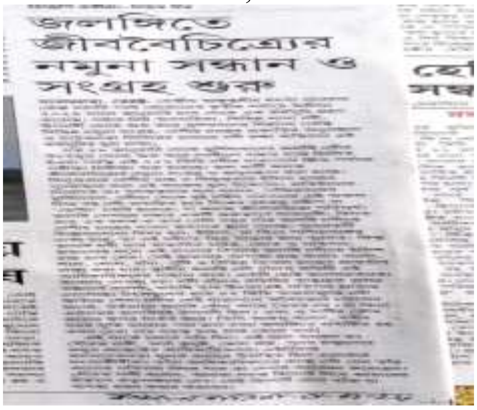

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Prahri Bharat, 14.03.2024

www.jagran.com

सरयू नदी में छोड़े एक लाख मछली के बीज

सरयू, अयोध्या: नदियों में विलुप्त हो रही महत्वपूर्ण मत्स्य प्रजातियों के संरक्षण एवं संवर्धन के लिए भारतीय कृषि अनुसंधान परिषद के संस्थान केंद्रीय अन्तर्स्थलीय मात्स्यिकी अनुसंधान संस्थान (सिफरी), प्रयागराज की ओर से गुप्तारघाट पर सरयू नदी में एक लाख मछलियों के बीज छोड़े गए। राष्ट्रीय स्वच्छ गंगा मिशन के अंतर्गत आयोजित इस कार्यक्रम में भारतीय प्रमुख प्रजातियों कतला, रोहू, मृगल के बीजों को छोड़ा गया। इस अवसर पर संस्थान के केन्द्राध्यक्ष डा. डीपेन झा ने कार्यक्रम के बारे में जानकारी दी। सिफरी के निदेशक डा. बीके दास ने उपस्थित लोगों को नमामि गंगे परियोजना के बारे में विस्तृत जानकारी दी। कार्यक्रम के मुख्य अतिथि सांसद लल्लू सिंह ने अपने संबोधन में सरयू नदी को स्वच्छ रखने एवं जैव विविधता को बचाने का आह्वान किया।

Dainik Jagran, 14.03.2024

सरयू नदी में सिफरी द्वारा एक लाख मछली छोड़ा गया

Awadh Gatha, 14.03.2024

River Ranching: An Essential for the Conservation of Fish Fauna in the Ganga River

Kalinga chronicle News, 14.03.2024

City Bulletin News, Ayodhya, 14.03.2024

Saket News, Ayodhya, 14.03.2024

Ranchingof Hilsa fertilised eggs and Spawn for restoration at Jharkhand upstream of the Farakka Barrage in the River Ganga

Kalinga chronicle News, 20.03.2024

Hilsa Seed Ranching Program at Gaziapar ICAR -CIFRI's Sustainability Concern

Kolkata,(KCN):On March 12, 2024, ICAR-Central Inland Fisheries Research Institute undertook a Hilsa seed ranching program at Gaziapara, located on Malda-Jharkhand border. This initiative is a part of CIFRI's continuous efforts to ... conservation principles and local livelihood support.

Hilsa, known for its unique taste and nutritional value, has seen dwindling numbers in recent years, prompting the need for interventions such as the one undertaken by ... contributing to restoration of the nat... balance and biodiver... of the river ecosystem.

The CIFRI's Hilsa s... ranching program i... testament to institute's commitm... to research-ba... interventions for ...

Kalinga chronicle News, 20.03.2024

ICAR CIFRI organizes artificial breeding of prized Hilsa in river Ganga under NamamiGange programme

Kalinga chronicle News, 20.03.2024

Awareness Programmeon Fish and Dolphin Conservation

KOLKATA,(KCN):On March 13, 2024, the ICAR-CIFRI team organized an awareness programme under the NMCG project, focusing on fish and dolphin conservation along the Ganges River basin(Seoraphuli Ghat). A total of 50 army doctors, along with the brigadier from the base hospital(Barrackpore cantonment) actively participated, showcasing a commitment to environmental conservation. The programme aimed to educate local communities about the ecological significance of these aquatic species, promote conservation practices and encourage public involvement in preservation efforts. Through educational sessions, participants were informed about the threats faced by fish and dolphin populations, emphasizing the importance of conservation measures. The initiative successfully heightened awareness among local communities, leading to a notable shift in attitudes towards environmental stewardship. Increased adoption of sustainable practices among fishermen and heightened community engagement in conservation activities underscored the programme impact. Moreover, the involvement of army personnel fostered stronger collaboration between government agencies, the military, and local communities, laying a foundation for continued efforts to safeguard the Ganga River ecosystem. Overall, the programme effectively mobilized stakeholders and raised awareness about preserving fish and dolphin species in the Ganges River basin.

Kalinga Chronicle, 11.04.2024

Endangered Ecosystem of River Churni, ICAR-CIFRI Steps Forward

Kalinga Chronicle, 18.04.2024

চূর্ণী নদী ব্যাপকভাবে পরিবেশগত সংকটের সম্মুখীন

বিপন্ন বাস্তুতন্ত্রের পুনরুদ্ধারে সিফরির প্রয়াস

Duronto Barta, 24.04.2024

SHREE 7NEWS

सच का आइना

नमामि गंगे परियोजना के अंतर्गत सिफरी प्रयागराज के द्वारा यमुना नदी में मत्स्य बीज छोड़ा गया

Shree 7 news (Hindi), 08.05.2024

Sanyam Bharat (English), 08.05.2024

Sanyam Bharat (Hindi), 08.05.2024

Voice of Prayagraj (Hindi), 08.05.2024

Chetna Vichaar Bharat (Hindi), 10.05.2024

Tereth Raj Times (Hindi), 10.05.2024

Voice of Prayagraj (Hindi), 10.05.2024

Varanasi News www.shree7news.in

विलुप्त हो रहे मत्स्य प्रजातियों के संरक्षण एवम् संवर्धन को ध्यान में रखते हुए गंगा नदी में मछलियों को छोड़ा गया

SHREE 7NEWS वाराणसी। 10-05-2024

Shree 7News (Hindi), 10.05.2024

गंगा नदी में मछलियों की विलुप्त प्रजातियों को छोड़ा

Chaya Aaj (Hindi), 10.05.2024

गंगा-यमुना में सात फीसदी बढ़ गईं देसी मछलियों की संख्या

Danik Jagran (Hindi), 12.05.2024

मत्स्य संरक्षण के लिए गंगा नदी में छोड़ा गया मछलियों को

परफेक्ट मिशन (सतीश चंद्र)

प्रयागराज। गंगा के मत्स्य विविधता को पुनर्स्थापित एवं संवर्धित करने के लिए सिरसा, प्रयागराज के पास गंगा नदी में पंद्रह हजार मछलियों के छोटे बच्चों को छोड़ा गया। यह कार्यक्रम भारत सरकार के नमामि गंगे परियोजना के अंतर्गत भा.कृ.अनु.प.-केंद्रीय अन्तर्स्थलीय मात्स्यिकी अनुसंधान संस्थान (सिफरी) द्वारा आयोजित किया गया। इस अवसर पर भारतीय प्रमुख कार्प- कतला, रोहू, मृगल मछलियों के बड़े अंगुलिकाओं को छोड़ा गया।

राष्ट्रीय स्वच्छ गंगा मिशन (एन एम सी जी) के अन्तर्गत यह कार्यक्रम सिरसा, प्रयागराज के श्रीराम प्रताप इंटर कॉलेज पर आयोजित किया गया व कार्यक्रम में संस्थान के केन्द्राध्यक्ष डा० डी एन झा ने उपस्थित लोगों का स्वागत किया और नमामि गंगे परियोजना के बारे में विस्तृत जानकारी दी व इसके अन्तर्गत गंगा एवं इसकी सहायक नदियों में कम हो रहे महत्वपूर्ण मत्स्य प्रजातियों के बीज का रैंचिंग होना रहा है साथ ही लोगों को गंगा के जैव विविधता और स्वच्छता के बारे में जागरूक करना है। कार्यक्रम में मुख्य अतिथि के रूप में डॉ.शिव प्रकाश पाठक, प्रधानाचार्य, श्रीराम प्रताप इंटर कॉलेज, सिरसा उपस्थित थे। अपने सम्बोधन में उन्होंने गंगा की आवश्यकता और हमारे कर्तव्य पर सभा को बताया। विशिष्ट अतिथि राजेश शर्मा, संयोजक गंगा विचार मंच, राष्ट्रीय स्वच्छ गंगा मिशन ने भाग लिया और गंगा के स्वच्छता के लिए किए जाने वाले कार्य एवं सावधानियों को बताया। इस अवसर पर श्री बृज बली सिंह शिक्षक प्रतिनिधि के रूप में सभा में अपनी बातों को रखा और सभी ने गंगा के प्रति जागरूक होने के साथ ही गंगा को स्वच्छ रखने का संकल्प व्यक्त किया।

कार्यक्रम में गंगा विचार मंच, श्रीराम प्रताप इंटर कॉलेज आदि के साथ साथ आस-पास गांव के मत्स्य पालक, मत्स्य व्यवसायी तथा गंगा तट पर रहने वाले स्थानीय लोगों ने भाग लिया। कार्यक्रम के अन्त में संस्थान के वैज्ञानिक डा० वेंकटेश ठाकुर ने धन्यवाद ज्ञापन करते हुए कहा हम इस परियोजना के उद्देश्यों को पाने में सफलता प्राप्त करेंगे। कार्यक्रम में संस्थान के वैज्ञानिक डॉ विकास कुमार, जितेंद्र कुमार, शोधार्थी डॉ रईस भट्ट, डॉ संदीप मिश्रा, डॉ पारुल, आशीष कुमार, सुश्री अर्पिता पटेल, रामभजन वर्मा तथा जितेंद्र कुमार, रामसजीवन, रवि कुमार, शिवम उमेश सिंह, रमा शंकर यादव, राजनारायण आदि ने भाग लिया।

Perfect Mission (Hindi), 12.05.2024

रिवर रैंचिंग के तहत गंगा नदी में छोड़ी गईं 25 हजार मत्स्य अंगुलिकाएं

अखंड भारत संदेश

प्रयागराज, रविवार 12.05.2024 | 02

मत्स्य संरक्षण के लिए सिरसा गंगा नदी में छात्रों ने छोड़ी मछलियां

नमामि गंगे के तहत केंद्रीय अंतरस्थलीय मत्स्यकी अनुसंधान द्वारा जैव विविधता और गंगा को स्वच्छ रखने हेतु की गई अनोखी पहल

Danik Jagran (Hindi), 16.05.2024

Akhand Bharat Sandesh (Hindi), 12.05.2024

দ্বারকেশ্বর নদীতে মাছের বৈচিত্র্যের মূল্যায়ন ও পুনরুজ্জীবনে সিফরির উদ্যোগ

Sanyam Bharat (Hindi), 12.05.2024

Duranta Barta (Bengali), 29.05.2024

Ranching of IMC fingerlings for conservation at Balagarh, West Bengal

Kolkata,(KCN): ICAR-Central Inland Fisheries Research Institute (CIFRI), Barrackpore, performed a River Ranching Program-2024 at Balagarh, West Bengal, as part of the "Namami Gange" programme, with the goal of protecting and revitalising the Ganga River. Along with local fishermen and other members of the ICAR-CIFRI NMCG project team, 3.06 lakh IMC fingerlings were released into the Ganga River at P.C. Pal Ghat, Balagarh. In the event, 50 fishermen from local co-operative society and local women from fisher families had participated the ranching programme. Scientists from ICAR-CIFRI gave an overview of the goals of the Namami Gange initiative and emphasised its recent accomplishments. Speaking with local fisherman, they emphasised the significance of preserving the Ganges river system's health in order to protect the variety of native fish species.

Extensive work and noteworthy accomplishments from NMCG Phases I and II had been highlighted. These included surveying fish diversity, assessing the stocks of economically significant species such as Hilsa, producing seeds from wild germplasm of particular fish kinds, and putting ranching programmes into action in river segments that have run dry. The successful execution of this effort may strengthen the Ganga river system's long-term viability.

THE KALINGA CHRONICLE

Popular people's Daily of Odisha

Women fishers supports River Ranching under NamamiGange Program at Balagarh, West Bengal

Kalinga Chronicle (English), 31.05.2024

Kalinga Chronicle (English), 01.06.2024

With eye on sky, scientists start releasing fishlings in the Hooghly for future harvest

ABOUT 6L FINGERLINGS RELEASED IN 2 DAYS

Times of India (English), 01.06.2024

India's first photo newspaper

FOTO FACT NEWS

Foto Fact News (English), 11.06.2024

Ranching Hat-trick at Kalna by ICAR-CIFRI, with 5.33 IMC Fingerlings

Anwar Hussain • 15hr

ICAR-Central Inland Fisheries Research Institute (CIFRI), Barrackpore under its flagship NamamiGange project continues the National Ranching Program III to conserve and restore the biodiversity of River Ganga at Kalna, East Bardhaman, on June 2024. Restocking the river's declining fish populations is the primary goal of river ranching. Over 100 lakh Indian Major Carp fish fingerlings have been raised by ICAR-CIFRI to date, at various locations throughout four states in the nation.

In an effort to protect and revive the Ganga River, ICAR-CIFRI implemented a ranching programme in Kalna.

Daily Hunt (English), 12.06.2024

Restoring Riverine Ecosystem: ICAR-CIFRI Ranched 3 lakh Fingerlings at Mayapur

Kolkata,(KCN): ICAR-Central Inland Fisheries Research Institute, Barrackpore under its flagship NamamiGange project continues the National Ranching Program III at Mayapur, Nadia, West Bengal towards conservation and restoration of River Ganga. The main objective of the river ranching is to replenish the depleted fish stocks of the river. Till today, ICAR-CIFRI has ranched more than 110 lakhs of fish fingerlings of Indian Major Carps in several sites across the four states of the country. In Mayapur, ICAR-CIFRI implemented a ranching programme aimed at protecting and revitalising the Ganga river. 25 local men and women fishers as well as scientists and other members of the ICAR-CIFRI project team carried out the event. In an effort to replenish the riverine stock, 3.23 lakh additional fingerlings of Indian Major Carps were released into the Ganga River at Swarupganj Ghat, Mayapur. The goals of the NamamiGange initiative were described by scientists from ICAR-CIFRI. They highlighted some of its most recent achievements and made the local fishermen aware of the importance of preserving the Ganges river system's health in order to protect the variety of indigenous fish species. Results from NMCG Phases I and II were emphasised, as were the noteworthy accomplishments. Studies on fish diversity, assessments of populations of economically significant species (such as Hilsa), the development of seeds from wild germplasm of certain fish species, and the mega ranching activities in the designated river length were among them. The Ganga river system may become more viable in the long run if this ranching event is successful.

Kalinga Chronicle (English), 12.06.2024


একদিন

রিভার রেঞ্চিং প্রোগ্রাম বলাগড়ে

Ekdin (Bengali), 13.06.2024


Bangla Jago Tv / বিজ্ঞান ও পরিবেশ / river ranching program to conserve river ecosystems

River Ranching Program

River Ranching Program:নদীর বাস্তুতন্ত্র সংরক্ষণে রিভার রেঞ্চিং প্রোগ্রাম, আইসিএআর-সিফরির উদ্যোগ

নদী রেঞ্চিং হল একটি আধুনিক পদ্ধতি যা মিষ্টি জলের মাছের প্রজনন ও সংরক্ষণে ব্যবহৃত হয়।

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Bangla Jago TV (Bengali), 13.06.2024


Fishing Seedlings Released: ভাগীরথীতে ছাড়া হল তিন লক্ষের বেশি দেশি মাছের চারা

Madhyabanga News(Bengali) 13.06.2024


গঙ্গায় ছাড়া হল মৃগেল, রুই, কাতলা

মানবেন্দ্র চক্রবর্তী

Uttarer Saradin (Bengali), 15.06.2024

High News (Bengali), 13.06.2024


National Ranching Program associated with Belur Math Ramkrishna Mission: A Milestone made by ICAR-CIFRI

Kalinga Chronicle (English), 17 .06. 2024


আনন্দবাজার পত্রিকা

গঙ্গায় ছাড়া হল তিন লক্ষ মাছ

Ananda Bazar Patrika (Bengali), 06.07.2024

River ranching at Farakka (Doordarshan Bangla), 05.07.2024

Akashvani Kolkata (Bengali), 06.07.2024

NTV News Bangla, 06.07.2024


आयोजन

गंगा नदी में छोड़ी गईं तीन लाख मछलियां

जैव विविधता

Prabhat Khabar (Hindi), 13.07.2024


कमरगंज गंगा घाट में छोड़े गए मछलियों के तीन लाख बच्चे

Jagran (Hindi), 13.07.2024

पटना के राजा घाट में छोड़े गए 2.5 लाख मछलियां

Hindustan Ka Prateek (Hindi), 21.07.2024

Doordarshan Uttar Pradesh, 20.07.2024

गंगा में छोड़े गये प्रमुख कार्प के तीन लाख बीज

रामगढ़। क्षेत्र के हुकूम छपरा घाट पर गंगा नदी में शुक्रवार को सिफरी द्वारा तीन लाख प्रमुख कार्प के बीज को छोड़ा गया। इस अवसर पर मत्स्य अधिकारी बिपिन बिहारी ओझा, सिफरी के निदेशक डॉ. बी.के. दास द्वारा कतला, रोहू तथा मृगल मछलियों के बीज को गंगा नदी में छोड़ा। इस दौरान उन्होंने गंगा नदी में मछली और रैंचिंग के महत्व को बताया। बता दें कि गंगा नदी में विलुप्त हो रहे मत्स्य प्रजातियों के संरक्षण एवम संवर्धन को ध्यान में रखते हुए, भारतीय कृषि अनुसंधान परिषद -केन्द्रीय अंतरस्थलीय मात्स्यिकी अनुसंधान संस्थान (सिफरी) के द्वारा हुकूम छपरा घाट पर गंगा नदी में तीन लाख महत्वपूर्ण मछलियों के बीज छोड़े गये। कार्यक्रम में आस-पास गांव के मत्स्य पालक, मत्स्य व्यवसायी तथा गंगा तट पर रहने वाले स्थानीय लोगों ने भाग लिया। इस अवसर पर डॉ गणेश चंद्र, वैज्ञानिक, अशोक कुमार, डा. वीआर ठाकुर, हल्दी थानाध्यक्ष, अर्जुन साह, डॉ धर्म नाथ झा आदि मौजूद रहे।

Ballia News, 20.07.2024

Live Media News, 21.07.2024

Prayag Khabar (Hindi), 21.07.2024

मुंगेर गंगा नदी में छोड़ा मछली का 2.50 लाख जीरा

Prabhat Khabar (Hindi), 21.07.2024


मुंगेर 22-07-2024

गंगा में तीन तरह की मछलियों के जीरे गिराए गए

तीन लाख जीरा गिराए, डीएम ने मछुआरों से कहा, अभी तीन दिन गंगा नदी में मछली नहीं पकड़ें

Dainik Bhasakar (Hindi), 22.07.2024


अपना मुंगेर

गंगा नदी को प्रदूषण मुक्त बनाने का संकल्प

मार्च से मिलेगी पीएनजी की सुविधा

Hindustan (Hindi), 22.07.2024

मुंगेर गंगा नदी में छोड़ा मछली का 2.50 लाख जीरा

E-News on River ranching at Munger (Prabhat Khabar Hindi) on 22.07.2024


E-News on River ranching at Munger (Munger TV Hindi) on 21.07.2024


নমামি গঙ্গে ও সিফরির মেলবন্ধন

ইলিশ সংরক্ষণ ও পুনরুদ্ধার বিষয়ক সচেতনতা শিবির

Ajkaal (Bengali), 06.09.2024

Daily Hunt (Bengali), 28.09.2024

The Hilsa Struggle: Fishermen Battling Challenges for Survival

BIC News (Bengali), 05.09.2024

Kalinga Chronicle (English), 23.10.2024

গঙ্গায় মাছের চারা

বলাগড়: মৎস্যজীবীদের সঙ্গে নিয়ে বৃহস্পতিবার বলাগড় ফেরিঘাট এলাকায় কেন্দ্রীয় অভ্যন্তরীণ মৎস্য গবেষণা সংস্থার ব্যারাকপুর শাখার তরফে মাছের চারা ছাড়া হল গঙ্গায়। পাশাপাশি মৎস্যজীবীদের জীবন-জীবিকা নিয়ে কর্মশালাও হয়। তাতে গঙ্গা পরিষ্কার-পরিচ্ছন্ন রাখার বিষয়ে জোর দেওয়া হয়। সংস্থার ওই শাখার প্রধান বসন্তকুমার দাস জানান, এ দিন ১০ হাজার রুই, কাতলা ও মৃগেল মাছের চারা ছাড়া হয়েছে। এই নিয়ে চার বছরে পাঁচটি পর্বে গঙ্গায় মোট ১২ লক্ষ ১০ হাজার মাছের চারা ছাড়া হয়েছে। কর্মশালায় ছিলেন নদী বিশেষজ্ঞেরা, জীব বৈচিত্র্য বিশেষজ্ঞ সন্দীপ বেহেরা, বিজ্ঞানী অরুণ পণ্ডিত প্রমুখ।

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नदी में छोड़ी गयीं विलुप्त हो रहीं मछलियां

हुगली. सेंट्रल इनलैंड फिशरीज रिसर्च इंस्टीट्यूट (सीफआरआइ), बैरकपुर के प्रयास से भागीरथी-हुगली नदी में गुरुवार को 10,000 मछलियां छोड़ी गयीं. यह कार्यक्रम बालागढ़ के श्रीपुर फेरीघाट पर हुआ. 'नमामि गंगे' परियोजना के राष्ट्रीय रैंचिंग मिशन-3 के तहत रोहू, कतला, मृगेल, लेटा, सउरी, पोठिया सहित अन्य प्रजातियों के मछलियां छोड़ी गयीं. ये मछलियां कभी गंगा नदी में अधिक मात्रा में पायी जाती थीं, लेकिन प्रदूषण के कारण ये प्रजातियां लगभग विलुप्त हो चुकी हैं. सीफआरआइ, बैरकपुर के निदेशक बसंत कुमार दास की देखरेख में आयोजित कार्यक्रम में नदी पर अनुसंधान कर रहे देश-विदेश के प्रतिष्ठित व्यक्ति उपस्थित थे. इस दौरान डॉ संदीप बेहेरा, वैज्ञानिक अरुण पंडित, प्रोफेसर डॉ संतोष थापी, डॉ साकेत पांडेय सहित सीफआरआई के अधिकारी व कर्मचारी उपस्थित थे.

Anandabazar (Bengali), 25.10.2024

Pravat Khabar (Hindi), 25.10.2024

Hooghly News (Bengali), 24.10.2024

Hooghly TV (Bengali), 25.10.2024

গঙ্গার বুকে জীবনের আশা

গঙ্গা উৎসবে বিরল মাছের পোনা ছাড়লেন মন্ত্রী সি আর পাটিল

Anandabazar Patrika (06.11.2024)

গঙ্গায় মহসীর মাছের সংরক্ষণে উদ্যোগী সিফরি

নিজস্ব প্রতিনিধি, বিধাননগর: গঙ্গায় মহসীর মাছের সংরক্ষণের জন্য বিশেষ উদ্যোগ নিল আইসিএআর-সেন্ট্রাল ইনল্যান্ড ফিশারিজ রিসার্চ ইনস্টিটিউট (সিফরি)। সম্প্রতি, এ নিয়ে উত্তরাখণ্ডের টেহরিতে এই মাছের গণসচেতনতার জন্য একটি অনুষ্ঠানেরও আয়োজন করা হয়েছিল। সেখানে উপস্থিত ছিলেন সিফরির ডিরেক্টর বসন্তকুমার দাস। সচেতনতার পাশাপাশি, মৎস্যজীবীদের হাতে জালও বিতরণ করা হয়। ন্যাশনাল মিশন ফর ক্লিন গঙ্গা প্রকল্পে এই উদ্যোগ নেওয়া হয়েছে। সিফরির পক্ষ থেকে এলাকার মানুষকে জানানো হয়, মহসীর মাছ ওই অঞ্চলের মিষ্টিজলের বাস্তুতন্ত্রের পক্ষে একটি গুরুত্বপূর্ণ প্রজাতি। তাই এই মাছকে রক্ষা করতে হবে।

Bartaman (06.11.2024)

Awareness Drive on Hilsa Conservation at Diamond Harbour: ICAR-CIFRI's Latest Effort

Kolkata,(KCN): ICAR-Central Inland Fisheries Research Institute (ICAR-CIFRI), Barrackpore, in collaboration with the KankuraMasat Social Welfare Society, had organised a sensitisation programme at Diamond Harbour, South 24 Pargana, to promote Hilsa conservation under the National Mission for Clean Ganga (NMCG). The event, attended by over 110 fishers, aimed at raising awareness about sustainable fishing practices to conserve Hilsa fisheries and highlighting the ecological importance of Hilsa.Dr. B.K. Das, Director of ICAR-CIFRI and Principal Investigator of the NMCG project stressed the ecological and socio-cultural significance of Hilsa in his address. He urged the fishing community to avoid catching juvenile Hilsa and to refrain from using zero-mesh nets, which significantly threaten the species' sustainability. During an interactive session, Dr. Das listened to the concerns of the fishers regarding fishing regulations and challenges. He emphasised that conserving Hilsa is not only critical for maintaining the health of river ecosystems but for preserving the cultural heritage and livelihoods of fishing communities dependent on the species. Mr. Pratangshu Bose, President, Kankura Masat Social Welfare Society, underscored the importance of community involvement in conservation efforts. He highlighted that collective action, enhanced awareness, and adherence to sustainable fishing practices are essential for maintaining Hilsa populations. A technical session was organized by the staff of the NMCG in which all aspects of hilsa conservation were discussed. The fishers were advised not to catch "KHOKA fish", maintain the ban period on Hilsa catching and not to use nets below mesh size 110 mm. They also informed us about the work done in Farakka at Hilsa Ranching Station, like live adult hilsa ranching, artificial breeding of hilsa, and releasing fertilized hilsa eggs in the upstream of the Farakka barrage. The NMCG team also informed them about the salient achievements like 1,50,284 adult Hilsa ranching and more than 31.65 lakhs fertilized Hilsa eggs released at Jharkhand, Murshidabad region at the upstream of Farakka barrage in river Ganga. In the interactive session, the farmers also complained about zero mesh size net used by some local fishers, resulting in the depletion of Juvenile Hilsa stock in the region in this region. The program was concluded with a vote of thanks fromDr. Santhana Kumar V., Co-PI, Scientist, ICAR-CIFRI. The event, a key initiative under the NMCG, reaffirmed the commitment of stakeholders to adopt sustainable practices and safeguard Hilsa for future generations. It is a significant step towards integrating conservation goals with the livelihoods of the fishing community.

Kalinga Chronicle (25.11.2024)

The Kalinga Chronicle

Mahseer Conservation in Tehri: ICAR-CIFRI Promotes under NMCG Initiative

Kalinga Chronicle (8.11.2024)

YouTube Channel_Public (23.12.2024)　　YouTube_Gramin Krishi Samachar 25.12.24

Akashvani_Facebook page (24.12.2024)

2.61 lakhs IMC Ranchingby ICAR-CIFRI:Celebrationof International Day for Biological Diversity

Kalinga Chronicle (30.12.2024)

Reviving Ganga's Glory: ICAR-CIFRI's Year-End Conservation Drive

Kolkata,(KCN): In a significant step towards the conservation of indigenous aquatic life, ICAR-Central Inland Fisheries Research Institute (CIFRI) has ranched 1.52 lakh Sarana (Systomus sarana) fish into the holy River Ganga at Mayapur, West Bengal. The event, which took place on December 30, 2024, also saw the ranching of 1 lakh Indian Major Carps (IMC) as part of ongoing efforts to restore the river's biodiversity. The initiative aims to rejuvenate the Ganga's aquatic ecosystem, focusing on preserving and promoting the population of native species like Sarana, which has been endangered due to environmental degradation, habitat loss, and overfishing. The Sarana fish, known for its importance in the river's ecosystem, plays a vital role in maintaining ecological balance.

The event was marked by the presence of Dr. B.K. Das, Director, ICAR-CIFRI, who is also the Principal Investigator for the National Mission for Clean Ganga (NMCG) Project. Dr. Das emphasized the importance of restoring indigenous fish species to ensure the long-term sustainability of the Ganga's biodiversity. In addition to the fish ranching, the event also included awareness program aimed at educating the common people about the significance of dolphin conservation and the importance of preserving the Ganga's riverine diversity. Dolphins, which are a key indicator of the river's ecological health, were highlighted as part of the broader efforts to safeguard all riverine species.

ICAR-CIFRI's initiatives are aligned with the national efforts to clean and conserve the Ganga under the NMCG project. This release is part of a broader strategy that combines conservation, research, and public engagement to restore the river's ecosystem, which is vital for millions of people and diverse wildlife. The presence of local communities underscored the collective effort needed to preserve the Ganga's biodiversity. The event in Mayapur represents a hopeful step forward in the ongoing battle to restore the river's health and protect its rich aquatic life for future generations.

গঙ্গায় ২.৬১ লাখ মাছ রেঞ্চিং আইসিএআর-সিফরি'র

Kalinga Chronicle (31.12.2024)　　Ekdin (31.12.2024)

9. Quarterly targets & achievements

Sl No.	Description of component wise activities	Target (Q1-Q4) 2024	Achievements
1.	Captive breeding of commercially important indigenous fish species and ranching programme through livelihood enhancement and conservation in the 'Artha Ganga' concept	40.0 lakhs (ranching) 3.0 crore (IMC spawn)	54.44 lakhs of ranching 76.0 lakhs of IMC spawn produced
2.	Establishment of Hilsa stock in middle stretch through ranching of Hilsa seed bred through captive breeding and wild adults	30,000 (adult Hilsa) 3.0 lakh (spawn)	28.69 thousand ranching of wild Hilsa adults 5.6 lakhs fertilized eggs & 0.3 lakh spawn of Hilsa released
3.	Seed production, restoration & stock assessment of selected mahseer species in the upper stretch of river Ganga	5000 Mahseer fingerling ranching 50 Mahseer brooders Stock assessment of 2 fish species	6500 Mahseer fingerling released 73 Mahseer brooders developed Stock assessment of 2 hill stream fishes (*T.putitora* & *S.richardsonii*) is completed
4.	Stock assessment of important fishes in selected tributaries and wetlands of the Ganga river basin for their conservation and management	NA	Survey of 16 tributaries and 4 wetlands completed for fisheries & ecological data
5.	Community sensitization on dolphin and fish biodiversity, including Hilsa, for improving the livelihood of fishers	5 Nos. 9000 fishers	144 nos. 7916 fishers
6.	Nutrient profiling of 2 indigenous fish species from river Ganga, and associated wetlands will be carried out	6	Nutrient profiling of 30 indigenous fish species from river Ganga were generated.
7.	Mass media communications such as News papers including regional, youtu bes, infographics etc.	15	102

10. ACKNOWLEDGEMENT

ICAR-Central Inland Fisheries Research Institute (CIFRI) acknowledge the Ministry of Jal Sakti, Government of India for providing financial support and an extensive platform for research and development along the River Ganga through this project *National Mission for Clean Ganga* (No: Sanctioned under National Mission on Clean Ganga, vide F. NO. Ad-35012/1/2023-NMC-NMCG) under *Namami Gange Programme*. Special thanks to General Manager, Farakka Thermal Power Station NTPC Ltd., Farakka for the continuous support provided to the team NMCG, ICAR-CIFRI. The work would not have been completed without the active cooperation of fishers and all the other stakeholders of river Ganga and the concerned tributaries, hence, ICAR-CIFRI highly acknowledges their support in the implementation of the project work successfully.

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