



भारतीय वन्यजीव संस्थान
Wildlife Institute of India

STATUS OF SELECT WETLANDS IN THE GANGA RIVER BASIN

POLLUTION THREATS AND
HOTSPOT ASSESSMENT

JULY, 2025

VOLUME II



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“Planning and Management for Aquatic Species Conservation and Maintenance of Ecosystem Services in the Ganga River Basin for a Clean Ganga”

This document is an output of the project Biodiversity Conservation and Ganga Rejuvenation sponsored by the National Mission for Clean Ganga, Ministry of Jal Shakti, Government of India, New Delhi.

Status of select wetlands in the Ganga River Basin: Pollution Threats and Hotspot Assessment
July, 2025

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SUMMARY

Wetlands represent some of Earth's most productive and biodiverse ecosystems, serving as a critical driver of economic activity. These dynamic transition zones between land and water environments foster exceptional biodiversity through their intricate mosaic of habitats and fluctuating water-land interfaces, providing habitat for approximately 50% of threatened and endangered species globally. Beyond their ecological importance, wetlands provide critical ecosystem services, including water treatment and contaminant removal, flood and drought mitigation, erosion control, hydrological regulation, and carbon storage at rates exceeding all other ecosystem types. Unfortunately, the wetland habitats are disappearing rapidly across all types—from inland freshwater systems to coastal and marine areas, water quality and health of wetlands continue to deteriorate on a global scale.



The rate of wetland loss exhibits significant regional variation and continues at an alarming pace in Asia, driven by the large-scale and rapid conversion of both coastal and inland natural wetlands. The degradation is often most severe at the convergence zones where wetlands interface with rapidly expanding urban settlements, intensive agriculture, and growing populations. These pressures contribute to nutrient enrichment, chemical contamination, hydrological alterations, and habitat fragmentation, further compromising wetland function and resilience. This pattern of wetland degradation is especially pronounced in major river systems of India, where concentrated human activities intensify environmental pressures. An effective response to these complex and accelerating threats relies on strong monitoring systems that can track ecological changes and support informed conservation strategies. However, despite the increasing urgency, systematic monitoring, particularly pollution oversight, remains limited.

The Ganga River basin's priority wetlands represent critical biodiversity hotspots and ecosystem service providers, yet face severe threats from inadequate pollution monitoring. Kabartal (Ramsar site, Bihar), East Kolkata Wetlands (Ramsar site, West Bengal), the Sundarban (Ramsar site and UNESCO Biosphere Reserve; West Bengal), Udhwa Lake (Ramsar site; Jharkhand), and Haiderpur (Ramsar site, Uttar Pradesh) are ecologically critical wetlands providing flood buffering, biodiversity support, and livelihood services while serving as significant carbon sinks. Gogabil Lake (Community Reserve, Bihar), though not Ramsar-listed, offers essential floodplain and ecological functions. These priority wetlands are of extraordinary ecological and

socio-economic significance, yet the quality and health of these wetlands is deteriorating due to drainage, pollution, invasive species, unsustainable use, land encroachments, disrupted flow regimes and climate change. Of particular concern is widespread occurrence of chemical pollution from diverse sources that contaminates wetland environments with toxic substances at concentrations that severely harm aquatic biodiversity, degrade water quality, and disrupt essential biogeochemical processes, ultimately compromising critical ecosystem services. Despite their critical ecological functions and the wide range of ecosystem services they provide, these wetlands remain highly vulnerable to agricultural runoff, municipal waste, and industrial discharges. Although ecological assessments and evaluations of ecosystem services are being extensively undertaken, particularly due to their designation as Ramsar sites, a comprehensive pollution monitoring framework remains largely absent. The lack of systematic data on water quality parameters, heavy metals, and emerging pollutants continues to constrain evidence-based conservation planning and effective wetland management.

This synthesis addresses this critical knowledge gap through a comprehensive spatio-temporal assessment of water quality, heavy metals and endocrine-disrupting chemicals (EDCs) across priority wetlands of the Ganga River Basin. The study implemented a systematic monitoring approach across strategically selected sites within six priority wetlands, conducted in February–March 2024, to facilitate a robust ecological assessment. The monitoring network included six sites in Kabartal Wetland, eight in the East Kolkata Wetlands, fifteen across the



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Sundarban Wetland, nine in Udhwa Lake, five in Haiderpur Wetland, and seven in Gogabeel Lake, comprising a total of 50 sampling stations across the target wetlands and monitoring of sixty-seven parameters across these sites. The findings highlight the extent of chemical pollution, the risks posed to species, the key drivers of water quality degradation, and the management framework proposed to address these challenges. These evidence-based insights are intended to inform targeted policy development, support wetland restoration initiatives, and strengthen conservation strategies aimed at safeguarding the ecological integrity and long-term sustainability of these vital ecosystems.

Based on our ecotoxicological monitoring and assessment, these priority wetlands system exhibits severe multi-pollutant contamination, with abiotic compartments (surface waters and sediments) containing EDC concentrations ranging from nanogram to microgram levels across all monitored sites. Across all wetlands, concurrent enrichment of diverse EDCs and heavy metals in both abiotic (water and sediment) and biotic (aquatic organisms) compartments signals the potential for trophic transfer and chronic ecological stress, particularly in long-lived and higher-trophic-level species. The detection of multiple classes of EDCs, including plastic additives, pharmaceuticals, and persistent organics, raises serious ecological concerns due to their synergistic and sub-lethal effects, notably endocrine disruption, reproductive impairment, and developmental anomalies in aquatic biota. Of particular concern is the bioaccumulation of EDCs in edible fish tissue across all monitored sites, posing a potential human health risk through dietary exposure.

Wetland-specific contaminant profiles reveal distinct pollution signatures that are closely linked to land use patterns and anthropogenic activities across the Ganga River basin. Urban and peri-urban wetlands, such as East Kolkata Wetland and Haiderpur Wetland, exhibit heavy contamination from untreated domestic sewage, industrial effluents, and solid waste discharge, reflecting intense infrastructural and population pressures. In contrast, Kabartal, Gogabil, and Udhwa wetlands, located in predominantly rural catchments, show elevated levels of pharmaceutical residues, personal care products, and pesticide contaminants. These pollutants are likely introduced through diffuse agricultural runoff and domestic greywater, which are rarely addressed by conventional monitoring and treatment systems. Despite their non-urban character, these catchments contribute significantly to emerging contaminant loads, highlighting a critical gap in surveillance, regulation, and source attribution for rural landscapes. The Sundarban Wetland, although not urbanized, displays a unique contamination profile driven by transboundary riverine inflows, estuarine industrial activity, and localized human pressures. This complexity underscores the need for integrated watershed-scale pollution control.

The ecological risk assessment finds that 67% of the six wetland areas are in poor ecological condition, with leading stressors including water quality parameters (Dissolved Oxygen, salinity, and nitrate), Heavy metals (Lead, Cobalt), plastic additives (phthalates and BPA), pesticides (Chlorpyrifos, and DDT metabolites), and personal care products (Triclocarban) indicating that these wetlands function as sinks for industrial, urban, peri-urban, and rural chemical waste.

Based on the ecological risk assessment results derived from lean season sampling data, the management priorities are systematically categorized using evidence-based intervention frameworks that align resource allocation with ecosystem urgency levels, while acknowledging that single-season assessment may represent peak stress conditions requiring validation through multi-seasonal monitoring. Emergency Restoration is designated for East Kolkata Wetlands (86% high risk) requiring immediate comprehensive intervention within 12-18 months to address severe ecosystem degradation observed during lean season conditions, demanding habitat restoration, pollution source control, and intensive year-round monitoring protocols to establish baseline variability. Urgent Intervention applies to Gogabil Community Reserve (71% high risk) necessitating rapid deployment of conservation measures within 18-24 months, including habitat protection and community engagement programs, while recognizing that lean season stress indicators may fluctuate seasonally and require continuous assessment. Major Restoration encompasses Kabartal and Sundarban wetlands (both 67% high risk) requiring substantial restoration investments over 24-36 months, focusing on habitat rehabilitation and water quality improvement, with acknowledgment that seasonal variations in water levels and pollution loads may influence long-term restoration strategies. Targeted Restoration addresses Haiderpur Wetland (60% high risk) through focused management interventions over 18-30 months, emphasizing adaptive management approaches that account for potential seasonal fluctuations in ecosystem stress levels. Protection +

Enhancement governs Udhwa Lake (56% moderate risk) through sustained multi-seasonal monitoring and protective measures over 12-24 months, implementing preventive conservation strategies while establishing comprehensive seasonal baseline data to refine management approaches and ensure optimal resource utilization across diverse hydrological conditions throughout the wetland conservation portfolio.

Furthermore, a tiered and adaptive management framework is proposed to address the varying levels of ecological degradation observed across wetlands. This enhanced framework builds upon existing national wetland management strategies, including the Wetlands (Conservation and Management) Rules and basin-level action plans. Importantly, it responds to critical gaps in current frameworks, particularly the absence of comprehensive pollution monitoring systems necessary for effective and sustainable pollution abatement. The proposed approach adopts a results-based planning structure, featuring clearly defined strategies and actions, objectively verifiable indicators (OVIs), and means of verification (MOVs) to ensure accountability and measurable progress. It also delineates institutional roles and identifies supporting organizations to facilitate coordinated implementation. By aligning intervention priorities with ecological urgency, the framework aims to strengthen wetland resilience, safeguard biodiversity, and ensure the long-term delivery of essential ecosystem services critical to both environmental sustainability and human well-being.

Sunderban



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INTRODUCTION

Wetland ecosystems play a fundamental role in sustaining biodiversity, regulating hydrological cycles, and providing a wide array of ecosystem services essential to human well-being and sustainable development. Healthy wetlands deliver these benefits far more effectively than those subjected to significant human disturbance or degradation. Despite their immense ecological and socio-economic value, ranging from food and water security to climate change mitigation, wetlands are undergoing rapid decline. Since 1970, an estimated 35% of the world's wetlands have been lost, and the remaining wetlands continue to face degradation due to drainage, chemical pollution, invasive species, altered flow regimes, and the intensifying impacts of climate change. This ongoing deterioration has placed a significant proportion of wetland-dependent species at risk, with nearly one-quarter facing extinction. Although wetlands still cover an area larger than Canada globally, the quality and functionality of these ecosystems are diminishing. Since 1970, approximately 35% of global wetlands have been lost, and while some constructed wetlands have been created, their growth remains inadequate to offset these losses.

Among the multiple threats, chemical pollution represents one of the most serious threats to wetland ecosystems. Agricultural runoff, industrial effluents, municipal sewage, and solid wastes introduce a wide range of contaminants including pesticides, heavy metals, nutrients, and endocrine-disrupting chemicals (EDCs) into these sensitive ecosystems. Among the array of toxic groups of pollutants entering wetlands environments, the occurrence of EDCs has emerged as a critical ecological concern due to their persistent, bioaccumulative, mobile, and toxic properties. Over recent decades, there has been growing

recognition of the detrimental effects of these contaminants on a wide range of taxa, including primary producers, zooplankton, insects, amphibians, fish, birds, reptiles, and aquatic mammals. Even so, the monitoring of these toxic contaminants in the Ganga River Basin lacks comprehensive and systematic studies, posing a potential threat to the effectiveness of ongoing conservation efforts for endangered species (Tan et al., 2017).

While wetlands naturally function as contaminant traps, filtering and processing pollutants through



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Gogabil Community Reserve

their complex biogeochemical processes, excessive contamination can overwhelm these natural treatment capacities. These pollutants can compromise water quality, disrupt aquatic food webs, impair reproductive and physiological functions in wildlife, and alter biogeochemical processes critical to ecosystem functioning, including the disruption of carbon sequestration processes that make wetlands vital climate regulators. Given the ecological sensitivity of wetlands and their dual role as both natural water treatment systems and contaminant accumulation sites, the systematic monitoring of chemical pollutants is essential to detect ecological stress, guide management interventions, and inform conservation strategies.

Yet, in India, wetlands remain severely under represented in national and state-level policies addressing chemical pollution. Regulatory frameworks and monitoring efforts tend to prioritize rivers, industrial zones, and urban wastewater systems, often overlooking wetlands as distinct, vulnerable recipients of toxic contaminants. This policy gap leaves wetlands inadequately protected from the threats posed by emerging pollutants, agrochemicals, and industrial effluents, despite their critical role in water purification, biodiversity conservation, and supporting livelihoods. Addressing this oversight is essential for integrating wetland conservation into broader environmental governance and safeguarding their long-term ecological integrity.

The ecotoxicology component of the project "Planning and Management for Aquatic Species Conservation and Maintenance of Ecosystem Services in the Ganga River Basin for a Clean

Ganga" aims to generate a comprehensive understanding of the contamination profiles of emerging pollutants and evaluate their ecological risks to aquatic biodiversity within the GRB.

The key objectives of this component are to:

- i. Investigate the current contamination status and spatial distribution of emerging contaminants in both biotic and abiotic matrices of the GRB including priority wetlands.
- ii. Assess the potential ecotoxicological risks posed by key emerging contaminants to aquatic organisms inhabiting the GRB.

This study was designed to address critical knowledge gaps concerning chemical pollution in ecologically important wetlands of the Ganga River Basin. The specific objectives are to:

1. Assess the water quality status and spatial distribution of key legacy and emerging chemical pollutants, including EDCs, heavy metals, across six priority wetlands: Kabartal, East Kolkata Wetlands, Sundarbans, Udhwa Lake, Haiderpur, and Gogabeel Lake.
2. Identify pollution hotspots and key drivers of water quality degradation within each wetland landscape.
3. Generate evidence-based insights to inform wetland-specific pollution abatement strategies, and interventions aimed at conserving the ecological character and sustainability of these vital wetland systems.



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METHODOLOGY



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STUDY AREA

To evaluate the water quality status and spatial distribution of key legacy and emerging chemical pollutants, including endocrine-disrupting chemicals (EDCs), six priority wetlands within the Ganga River Basin (GRB) were selected, as outlined below. The monitoring network included six sites in Kabartal Wetland, eight in the East Kolkata Wetlands, fifteen across the Sundarban Wetland, nine in Udhwa Lake, five in Haiderpur Wetland, and seven in Gogabil Lake, comprising a total of 50 sampling stations across the target wetlands and monitoring of sixty-seven parameters across these sites (Figure 1; Table 1 and 2).

(I) KABARTAL WETLAND

Kabartal Wetland, also known as Kanwar Jheel, is a freshwater oxbow lake covering 2,620 hectare in Begusarai district, Bihar, formed from the meandering Burhi Gandak river. It was designated as a Ramsar site in 2020, becoming the first Ramsar site in Bihar. The wetland harbors 165 plant species, 394 animal species including over 221 birds, and about 50 fish species, functioning as a key wintering stop on the Central Asian Flyway for 58 migratory waterbirds. Five critically endangered

species inhabit the site, including three vultures – the red-headed vulture (*Sarcogyps calvus*), white-rumped vulture (*Gyps bengalensis*) and Indian vulture (*Gyps indicus*) – and two waterbirds, the sociable lapwing (*Vanellus gregarius*) and Baer's pochard (*Aythya baeri*). The wetland plays a crucial role in flood control in Bihar state where 70% of the land is vulnerable to inundation. It also plays a vital role in supporting local livelihoods of over 15,000 households through fishing, agriculture, and tourism. The major reported threats to the wetland include water management activities such as

drainage, water abstraction, damming and canalization which has resulted in decline in water content within the core wetland area. In addition, agricultural encroachment, poaching and overfishing also poses a serious threat to the integrity of the wetland.

(II) UDHWA LAKE BIRD SANCTUARY

The Udhwa lake bird sanctuary lies in the Rajmahal Sub-Division of Sahebganj district in the state of Jharkhand. It covers an area of 935.5 hectare and comprises two interconnected wetlands, Pataura Lake and Brahma Jamalpur Lake (commonly known as Barhel Lake), which are linked by a channel called the Udhwa Nala to the Ganga River. The wetland supports around 30 species of aquatic plants, over 45 species of fish and 146 species of birds out of which 79 species are resident, 39 are migrant and 28 species are resident migrants. This diverse habitat supports around 14 species are categorized as threatened as per the IUCN Red list which includes the endangered band-tailed fish eagle (*Haliaeetus leucoryphus*) and the vulnerable common pochard (*Aythya ferina*) and lesser adjutant stork (*Leptoptilos javanicus*). The wetland is a crucial stopover point for migratory birds in the Central Asian flyway. Udhwa Lake was designated as an Important Bird and Biodiversity Area (IBA) in 2016 and a Ramsar site in 2025. The wetland plays a vital role in groundwater recharge and flood control, while the surrounding communities rely on it for agriculture and growing eco-tourism activities. However, it faces threats

from illegal fishing, water abstraction, agricultural expansion, and increasing human settlement.

(III) GOGABIL LAKE

Gogabil Lake, situated in Katihar district, Bihar, is an ecologically significant oxbow lake that performs multiple critical ecosystem services. It was declared as the state's first community reserve in 2019 covering an area of 57 hectare. Recognized as an Important Bird Area (IBA) by BirdLife International, it serves as a vital stopover site along the Central Asian Flyway, supporting numerous migratory and resident waterbird species. The lake sustains high fish productivity and acts as a natural fish breeding habitat, forming the basis of traditional community fishing practices and local livelihoods. It plays a pivotal role in water supply, both for irrigation in surrounding agricultural lands and domestic use, while also offering potential for sustainable aquaculture development. Its natural floodwater retention capacity contributes to local flood mitigation, and the lake further aids in groundwater recharge and water purification, improving regional water quality. The lake modulates the local microclimate, supporting climatic stability in the area. Beyond ecological functions, Gogabil holds cultural and recreational value for local communities and is integral to local biodiversity conservation, making it a key site for aquatic ecosystem support and wetland management in northeastern Bihar. The wetland faces threats from encroachment, agricultural runoff, siltation, unsustainable fishing practices, and declining water levels due to hydrological alterations and climate variability.

Sunderban



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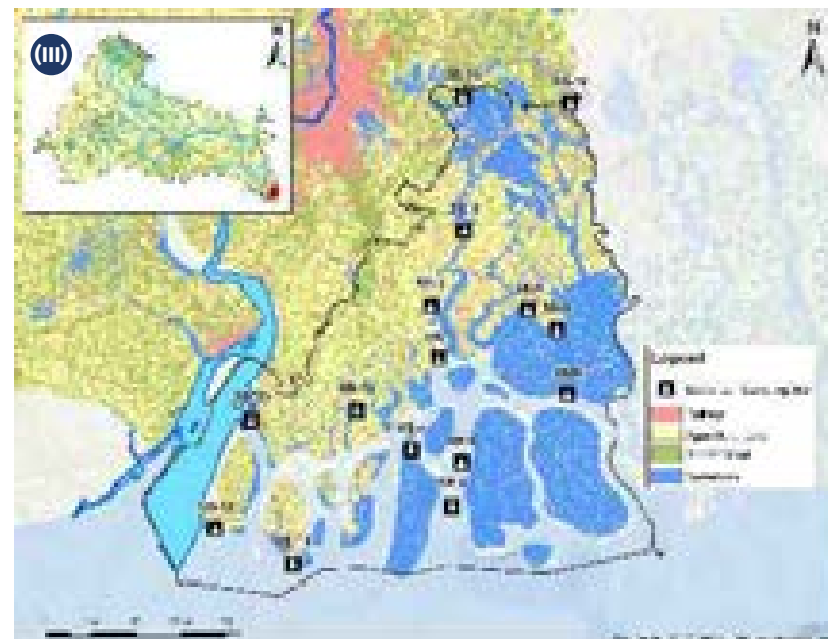
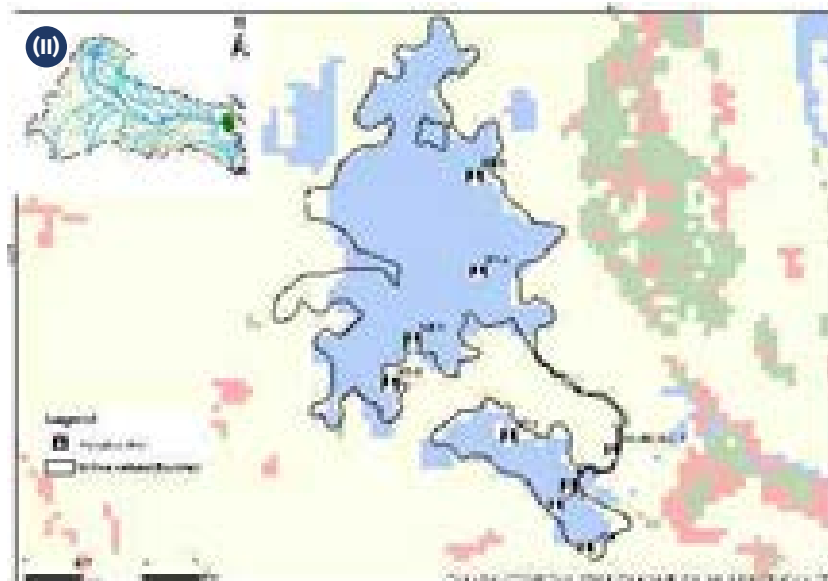
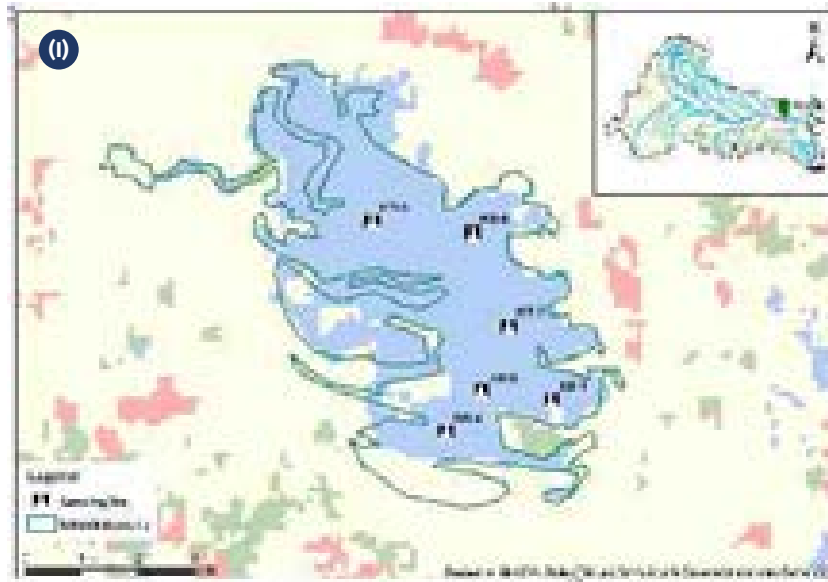
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Haiderpur

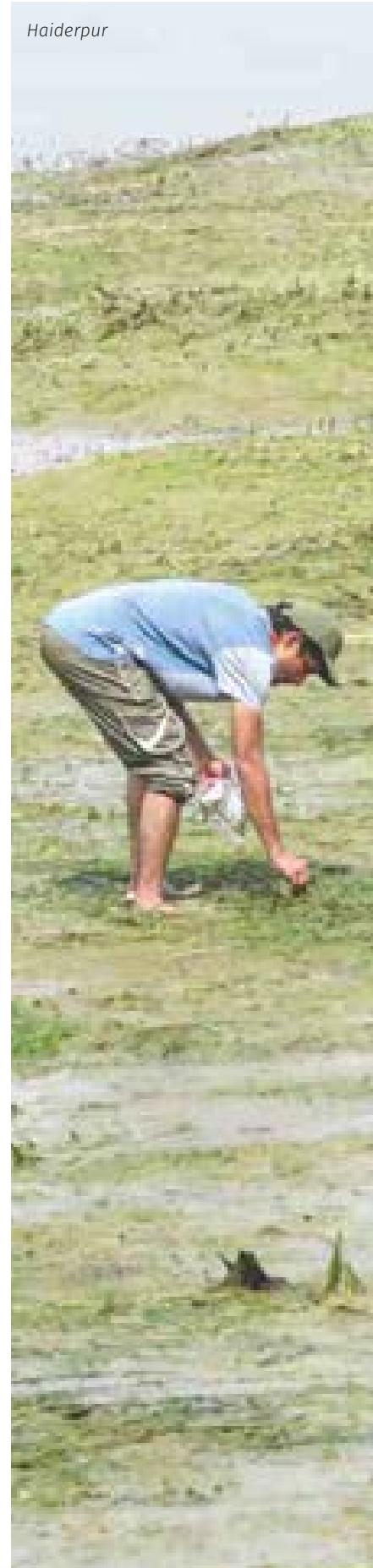




Figure 1: Spatial Distribution of Sampling Sites along the six priority wetlands of GRB for 2024 (February-March 2024)

- (I) Kabartal Wetland
- (II) Udhwa Wetland
- (III) Sundarban Wetland
- (IV) East Kolkata Wetland
- (V) Haiderpur Wetland
- (VI) Gogabil Wetland River

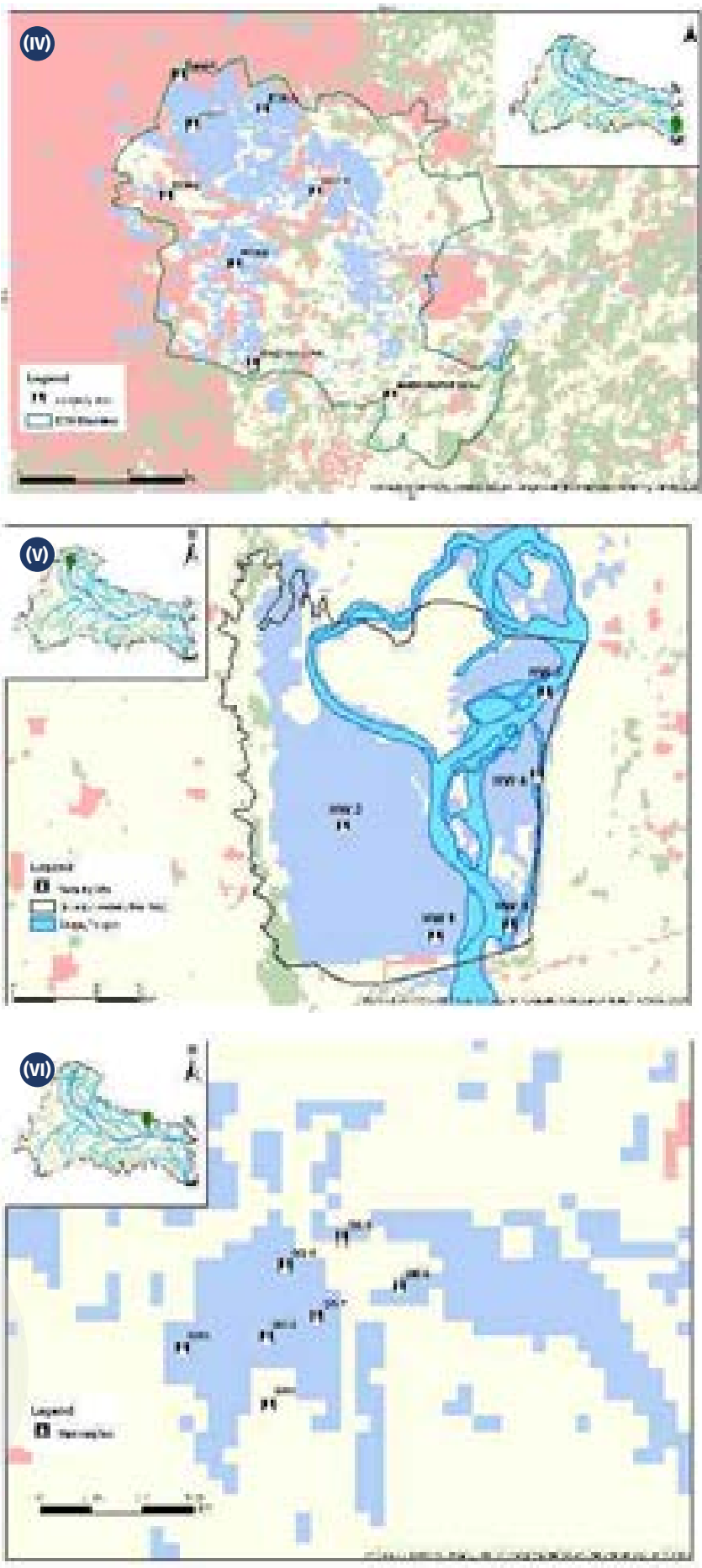


Table 1: Sampling Sites across the six priority wetlands for 2024 (Feb-March 2024)

Priority Wetland	Administrative Region		Site ID	Latitude	Longitude
	State	District			
Kabartal Wetland	Bihar	Begusarai	KB-1	25.59781	86.16128
			KB-2	25.60767	86.15698
			KB-3	25.59926	86.15336
			KB-4	25.59589	86.15093
			KB-5	25.63067	86.13172
			KB-6	25.62824	86.14971
Gogabil Community Reserve	Bihar	Katihar	GB1	25.37051	87.69432
			GB 2	25.37444	87.69434
			GB3	25.37396	87.68851
			GB 4	25.37854	87.69581
			GB 5	25.37996	87.69979
			GB 6	25.37699	87.70365
			GB 7	25.37547	87.69784
Udhwa Wetland	Jharkhand	Sahebganj	UP 1	24.97160	87.82496
			UP 2	24.96948	87.82328
			UP 3	24.96462	87.82671
			UP 4	24.97739	87.81792
			UB 1	24.98858	87.80681
			UB 2	24.98379	87.80383
			UB 3	24.99594	87.81509
			UB 4	25.00654	87.81513
			UDHWA NALA	24.97705	87.84134
Sundarban Wetland	West Bengal	South 24 Parganas	SB-1	22.01646	88.61677
			SB-2	22.13359	88.59788
			SB-3	22.30359	88.67968
			SB-4	21.81143	88.55158
			SB-5	21.68591	88.64955
			SB-6	21.78239	88.67221
			SB-7	22.12585	88.83439
			SB-8	22.08155	88.90377
			SB-9	21.93630	88.92808
			SB-10	21.90161	88.41765
			SB-11	21.55456	88.26386
			SB-12	21.63273	88.07630
			SB-13	21.87982	88.16393
			SB-14	22.58762	88.93626
			SB-15	22.60309	88.67594

Priority Wetland	Administrative Region		Site ID	Latitude	Longitude
	State	District			
East Kolkata Wetland		Kolkata	Canal-1	22.56359	88.41562
			ECW-1	22.58444	88.41687
			ECW-2	22.55023	88.41079
			ECW-3	22.56761	88.45475
			ECW-4	22.51684	88.42133
			ECW-5	22.53079	88.47230
			Tolly Nallah	22.46714	88.41314
			Narayanpur Khal	22.43528	88.47844
Haiderpur Wetland	Uttar Pradesh	Bijnor and Muzaffarnagar	HW 1	29.37621	78.02648
			HW 2	29.39611	78.01129
			HW 3	29.38128	78.05049
			HW 4	29.41537	78.05498
			HW 5	29.43457	78.05623

(IV) EAST KOLKATA WETLANDS

The East Kolkata Wetlands, spanning approximately 12,500 hectares on the eastern periphery of Kolkata, West Bengal, represent a globally unique and multifunctional wetland system. Designated as a Ramsar Site in 2002, this ecosystem is one of the world's largest sewage-fed aquaculture systems, ingeniously developed and managed by local communities. The wetlands serve as a natural urban wastewater treatment facility, processing nearly one-third of Kolkata's sewage, and reusing the treated water for pisciculture, vegetable farming, and rice cultivation. This innovative waste-to-resource approach enables the production of around 150 tons of fresh vegetables daily and 10,500 tons of table fish annually, directly supporting the livelihoods of over 50,000 people. In addition to their economic significance, the wetlands provide crucial ecosystem services including solid waste management, flood control, climate regulation, water purification, and groundwater recharge. Ecologically, the wetlands support rich biodiversity, serve as a habitat for waterfowl, and maintain nutrient cycling processes. They also preserve traditional aquaculture practices, contribute to the cultural landscape, and serve as a valuable site for education and research. However, the system is increasingly at risk due to the growing volume and changing composition of municipal sewage and unauthorized industrial discharges into the wastewater channels. The

introduction of toxic substances into canal sludge poses a serious threat to the edible quality of fish and vegetables, raising concerns about food safety and public health. Additionally, such contamination can disrupt aquatic ecological processes, degrade water quality, and reduce the wetlands' waste assimilation capacity, threatening the long-term sustainability of this globally significant urban wetland system.

(V) SUNDARBAN WETLAND

The Sundarbans—a UNESCO World Heritage Site and India's largest Ramsar Wetland—anchors a biodiverse estuarine landscape, sheltering over 528 vascular plants species, 250 fish species, 300 avian species, 59 reptiles, and 42 mammals, including endangered Royal Bengal Tigers (*Panthera tigris*), Irrawaddy (*Orcaella brevirostris*) and, Gangetic (*Platanista gangetica*) dolphins and finless porpoises (*Neophocaena phocaenoides*).

As Earth's largest contiguous transboundary mangrove forest, it sustains millions across coastal West Bengal in India through critical ecosystem services, including cyclone buffering, timber provision, and fisheries underpinning regional food security (Iqbal, 2020). It further supports ecological balance via oxygen generation and waste recycling while bolstering climate resilience through carbon sequestration (Dasgupta et al., 2018). The Sundarban mangrove ecosystem serves as a critical blue carbon sink, with organic-rich soils storing up





to 1,023 Mg C ha⁻¹ — surpassing many terrestrial forests and positioning it as a key asset for climate mitigation (Donato et al., 2011; Alongi, 2012). However, rising contamination of water, sediment, and fish threatens these functions. Pollutants such as heavy metals, pesticides, plastic additives and microplastics impair mangrove root physiology and soil microbial communities, destabilizing carbon-rich peat layers critical for sequestration (Guzzella et al., 2004; Zuloaga et al., 2012; Bhupander & Debapriya, 2012; Sarkar, 2016; Khuman et al., 2019; Mandal et al., 2019; Zanardi-Lamardo et al., 2019; Chakraborty et al., 2020; Basu et al., 2021; Gupta et al., 2024; Bhattacharyya et al., 2018). Concurrently, bioaccumulation in fish disrupts aquatic biodiversity, including commercially vital eroding food security. This dual degradation of flora and fauna undermines to sustain ecological balance, and amplifies vulnerability to climate change risks to long-term climate resilience (Chowdhury et al., 2019; Rahman et al., 2021). This dual degradation of flora and fauna undermines the Sundarbans' capacity to sustain ecological balance and amplifies its vulnerability to climate change, posing significant risks to long-term climate resilience.

(VI) HAIDERPUR WETLAND

Haiderpur wetland is a human-made wetland, formed in 1984 by the construction of the Madhya Ganga Barrage on the Gangetic floodplain. It is located within the boundaries of Hastinapur Wildlife Sanctuary covering an area of 6908 hectare. It was designated as a Ramsar site in 2021. The wetland supports 32 species of plants, over 300 species of birds of which 102 species are waterbirds, more than 40 species of fishes and at least 10 species of mammals. This habitat supports around 15 globally threatened species, such as the critically endangered gharial (*Gavialis gangeticus*) and the endangered hog deer (*Axis porcinus*), black-bellied tern (*Sterna acuticauda*), steppe eagle (*Aquila nipalensis*), Indian skimmer (*Rynchops albicollis*) and gold mahseer (*Tor putitora*). The site regularly supports more than 1% of the global population of greylag goose (*Anser anser*) and bar-headed goose (*Anser indicus*). The wetland supports local livelihood through fisheries and water chestnut cultivation and contributes to the maintenance of hydrological regimes and hazard reduction. The site also serves as a destination for tourism, recreation, and educational activities. Major threats to the site include encroachment by farmers, illegal fishing, water diversion, and invasive weeds.

Sampling Strategy

Sampling campaigns were undertaken during the Pre-Monsoon (February–June) periods of 2022 and

2024. This report presents water quality conditions and chemical contamination levels based on recent sampling data collected in 2024 to provide the current status.

The physical and chemical properties of the surface water were assessed online using a ProDSS Multi parameter Digital Water Quality Meter (YSI, USA). Surface water, sediment, and fish samples were collected from designated sampling sites along the selected wetlands in accordance with standard sampling protocols and established guidelines. Briefly, surface water and sediment samples were collected from a total of 50 sampling sites across six priority wetlands. At each site, 4–5 grab samples were collected, at an average depth of 0–15 cm below surface water, bulked together to form a composite sample. The samples were collected in pre-cleaned amber glass bottles/PP bottles (water) and aluminium zip-locks (sediment), labelled, and preserved. They were stored in an ice box (4°C) for shipping and processed within 48–72 hours. Biological samples a total of 649 freshly-caught fishes of 58 species (Pre-Monsoon 2024) were obtained from the local fisherman as part of their routine fishing activities. The total length and weight of each individual were recorded on-site. The species were identified on-site, packed in a sealed bag, and kept in an ice-box for transportation to the laboratory, where they were stored in a deep freezer at -50 °C until further processing.



Table 2: Target chemicals monitored

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

Sample treatment and instrument analysis

The sample analysis was done as per the established and validated in-house methods for different contaminant class in diverse matrices (Sah et al, 2024a; Sah et al, 2024b). The extracts were identified and quantified by Ultra-High

Performance Liquid Chromatography-Tandem Mass Spectrometry (UHPLC-MS/MS), Gas Chromatography-Tandem Mass Spectrometry (GC-MS-MS), and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The analytical data quality was guaranteed through the implementation of laboratory quality assurance and quality control methods, including the use of in-house standard operating procedures, calibration with standards, analysis of reagent blanks, recovery of Standard Reference materials (SRM) and analysis of replicates. The target chemicals monitored in this study are presented in Table 2.

Data Analysis

This report presents water quality conditions and chemical contamination levels based on recent sampling data collected in 2024 to provide the current status, with results presented both site-wise and zone-wise for comprehensive assessment. The water quality assessment employed statistical consolidation of seasonal monitoring data into annual representative values using weighted averaging techniques with 95% confidence intervals to establish statistically robust baseline conditions for policy reference. Maximum observed concentrations were utilized for ecological risk assessment and hotspot identification, as peak contamination events pose the greatest threat to ecosystem health and regulatory compliance, regardless of average conditions. Spatial analysis and GIS mapping integrated these risk-based assessments to identify priority intervention areas requiring immediate policy attention in these selected Wetlands.



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RESULTS AND DISCUSSION

STATUS OF WATER QUALITY PARAMETERS IN SIX PRIORITY WETLANDS

This section discusses the water quality of six priority wetlands as recorded during the surveys in 2024 (February-March). The main pollution parameters that have to be considered for surface water quality management, in general, include water temperature, pH, dissolved solids, dissolved oxygen, nitrates, conductivity, total dissolved solids, and salinity etc. All of the above parameters have been evaluated on-site by using hand-held digital kit ProDSS and YSI. The overall status of water quality in the six priority wetlands is presented in Table 3 and Table 4. Based on water quality monitoring using 2024 data from sampling period February-March.

In the present study, the water quality classification employs a protective threshold approach where any parameter exceedance triggers investigation, with severity rankings guiding intervention priorities while maintaining strict standards for ecosystem protection. Classifications are based on severity of exceedance (factor by which threshold is exceeded) and number of violations. The "weakest link" guideline ensures that the worst-performing parameter determines site classification, maintaining strict standards for ecosystem protection while providing actionable severity rankings for policy decisions.

The results indicate that 67% of the wetlands (4 out of 6) had predominantly poor water quality conditions ($\geq 50\%$ poor stations). Only Udhwa Wetland showed relatively better performance with 60% good monitoring sites. East Kolkata Wetlands demonstrated severe contamination with 89% of stations having poor water quality and only 11% classified as good. Sundarban Wetland showed concerning conditions with 71% of stations having poor water quality and 29% classified as good. Udhwa Wetland displayed mixed results, with 60% of stations showing good water quality and 40% classified as poor. Kabartal Wetland had equal distribution with 50% of stations showing good water quality and 50% classified as poor.

A detailed assessment of each monitored water quality parameter is presented in the following section (Table 3 and Table 4), providing wetland-wise analysis to support targeted management and policy interventions.



Haiderpur

1. pH

pH is the negative logarithm of the hydrogen ion (H^+) concentration of a solution and is a measure of whether the liquid/solid is alkaline or acid. In fresh water bodies, hydrogen ions are governed by the equilibrium between carbonate ions, carbon dioxide and bicarbonate. pH affects many biological and chemical activities in the water bodies e.g., different organisms flourish within different pH ranges. However, most of the aquatic animals prefer a pH range of 6.5 to 8.5. A pH outside this range could reduce the biodiversity in the water systems as it may stress the physiological systems of many organisms and can reduce their reproduction potential. Additionally, a low pH can result in high mobility and bioavailability of toxic contaminants for uptake by different aquatic plants and animals (U.S. Environmental Protection Agency, n.d.-a; U.S. Environmental Protection Agency, n.d.-b). This can result in circumstances that are highly toxic to aquatic life, particularly to vulnerable or sensitive species. In the present study, a wide fluctuations in the pH values were observed in six priority wetlands:



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Table 3: Water Quality Status of the Six Priority Wetlands of GRB Based on Pre-Monsoon (February-March)

Category	Kabartal Wetland	Udhwa Wetland	Gogabil Wetland	Haiderpur Wetland	East Kolkata Wetland	Sundarban Wetland
DO (mg/L)	2.33 - 9.87 (5.10 $\pm$ 1.21)	5.88 - 13.93 (8.85 $\pm$ 1.19)	5.01 - 14.38 (10.22 $\pm$ 1.35)	1.33 - 11.52 (6.33 $\pm$ 1.72)	1.36 - 11.11 (3.42 $\pm$ 1.20)	0.73 - 7.54 (5.71 $\pm$ 0.42)
TDS (mg/L)	188 - 261 (224 $\pm$ 12)	94 - 201 (118 $\pm$ 10)	124 - 171 (137 $\pm$ 6.31)	146 - 336 (206 $\pm$ 34)	595 - 1486 (814 $\pm$ 109)	1446 - 29770 (18310 $\pm$ 2199)
Salinity (ppt)	0.14 - 0.20 (0.17 $\pm$ 0.01)	0.07 - 0.15 (0.09 $\pm$ 0.01)	0.09 - 0.12 (0.10 $\pm$ 0.00)	0.11 - 0.25 (0.15 $\pm$ 0.03)	0.45 - 1.17 (0.62 $\pm$ 0.09)	1.14 - 29.68 (17.46 $\pm$ 2.24)
Cond (μ S/cm)	272 - 392 (328 $\pm$ 20.65)	135 - 310 (178 $\pm$ 16.86)	185 - 247 (204 $\pm$ 8.88)	215 - 510 (302 $\pm$ 53)	926 - 2286 (1251 $\pm$ 166)	2276 - 46794 (28546 $\pm$ 3373)
pH	7.23 - 8.20 (7.65 $\pm$ 0.15)	6.93 - 10.39 (8.53 $\pm$ 0.49)	7.46 - 10.54 (9.28 $\pm$ 0.46)	7.51 - 8.39 (7.96 $\pm$ 0.14)	6.84 - 8.20 (7.61 $\pm$ 0.16)	7.51 - 8.20 (7.96 $\pm$ 0.05)
Nitrate (mg/L)	4.69 - 7.86 (5.78 $\pm$ 0.52)	0.01 - 4.20 (0.91 $\pm$ 0.57)	0.81 - 5.64 (2.25 $\pm$ 0.60)	0.75 - 2.30 (1.28 $\pm$ 0.27)	0.71 - 2.72 (1.21 $\pm$ 0.24)	1.28 - 63.27 (20.05 $\pm$ 5.66)

Table 4: Assessment of Water Quality Condition in the Six Priority Wetlands of GRB Based on Pre-Monsoon (February-March)

Category	Water Quality Condition (%) in 6 Priority Wetlands of GRB					
	Kabartal Wetland	Udhwa Wetland	Gogabil Wetland	Haiderpur Wetland	East Kolkata Wetland	Sundarban Wetland
Good	50%	60%	-	-	11%	29%
Poor	50%	40%	100%	100%	89%	71%

Haiderpur Wetland

The pH values in Haiderpur wetland ranged from 7.51 - 8.39 (with mean and standard error noted as 7.96 ± 0.14) with all locations falling within the alkaline range. Comparing the observed results with aquatic life standards (Aquatic Life Criteria: 6.5-8.5) the wetland exhibited no threshold exceedance, indicating adequate pH levels for sustaining aquatic life.

Gogabil Wetland

In the present study, pH values in Gogabil Wetland ranged from 7.46 to 10.54 (mean 9.28 ± 0.46). Comparison with established aquatic life criteria (6.5-8.5) revealed 71% exceedance across sampling sites. The observed alkaline conditions are attributed to agricultural runoff containing urea-based fertilizers and lime amendments, which introduce ammonia and carbonate compounds that elevate pH levels beyond optimal ranges for aquatic biota. These elevated pH conditions may induce physiological stress in sensitive aquatic species, potentially compromising ecosystem integrity and biodiversity within the wetland system.

Udhwa Lake Bird Sanctuary

pH levels in Udhwa Lake Bird Sanctuary ranged from 6.93 to 10.39 (mean 8.53 ± 0.49). Comparison with established aquatic life criteria (6.5-8.5) indicated that 44% of sampling sites exceeded recommended pH thresholds. Elevated pH values are attributed to multiple sources including solid waste leachate infiltration and agricultural runoff containing alkaline compounds such as urea and lime-based fertilizers. Additionally, dense aquatic vegetation contributes to pH elevation through photosynthesis-mediated CO_2 depletion, which reduces carbonic acid concentrations and increases water alkalinity (Gupta, 2021). These alkaline conditions may induce physiological stress in pH-sensitive aquatic species, potentially compromising ecological stability within the sanctuary ecosystem

Kabartal Wetland

In the present study, pH in Kabartal ranged from 7.23 - 8.20 (7.65 ± 0.15). The recorded values adhered to aquatic life criteria (6.5-8.5 mg/L) indicating adequate pH levels for aquatic organisms, but with slightly alkaline levels.

East Kolkata Wetland

The East Kolkata Wetlands (EKW), a man made wetland located on the eastern peripheries of Kolkata, West Bengal form a part of the huge inter-distributary water networks of Gangetic delta. During the present ecotoxicological assessment, pH values in EKW ranged from 6.84 to 8.20 (7.61 ± 0.16). All measured pH levels remained within established aquatic life criteria (6.5-8.5), demonstrating complete compliance with recommended thresholds and indicating optimal pH conditions conducive to maintaining balanced aquatic ecosystem function.

Sunderban Wetland

The Sunderbans represents the world's largest mangrove delta ecosystem, situated at the confluence of the Ganga, Brahmaputra, and Meghna rivers. This system is characterized by brackish waters influenced by tidal saline intrusion and freshwater discharge, creating dynamic salinity gradients and nutrient regimes. In the present study, pH values in Sunderban wetlands ranged from 7.51 to 8.20 (7.96 ± 0.05). Comparison with established aquatic life criteria (6.5-8.5) demonstrated complete compliance across all sampling locations, with no threshold exceedances observed, indicating optimal pH conditions for sustaining aquatic biota within this complex estuarine environment.



Symbol (physical parameter)	pH
Method(s) used for analysis	Digital calibrated water quality probe meter with pH sensitive probe. Calibrated at 3 point calibration range at 4.0 (acidic), 7.0 (neutral) and 10.0 (basic)
Occurrence/Origin	Industrial discharges, agricultural runoff, Mining runoff, organic matter decomposition, natural weathering, industrial discharges, agricultural runoff, photosynthesis.
Aquatic Life Criteria	6.5-8.5 is preferable

2. DISSOLVED OXYGEN (DO)

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

water and also at higher altitudes water holds relatively less oxygen (U.S. Environmental Protection Agency, n.d.-a; U.S. Environmental Protection Agency, n.d.-b). For freshwater ecosystems, dissolved oxygen concentrations should maintain levels >5 mg/L for optimal aquatic health. According to EPA coastal water quality criteria (SW-I), estuarine and coastal waters require a minimum dissolved oxygen concentration of ≥ 5.0 mg/L, with an absolute minimum threshold of ≥ 3.5 mg/L under any conditions. For inland brackish waters designated for fisheries use (Class D), the minimum dissolved oxygen requirement is ≥ 4.0 mg/L (USEPA, 1986 Water Quality Criteria for Marine and Estuarine Waters).

Symbol (physical parameter)	DO
Units Used	mg/L O ₂
Method(s) used for analysis	Digital calibrated water quality probe meter with DO sensitive probe
Occurrence/Origin	Agricultural runoffs, industrial and sewage discharge
Aquatic Life Criteria	>5 mg/L is preferable

Dissolved oxygen (DO) concentrations were measured in six identified priority wetlands during the current study, with the findings summarized as follows:

Haiderpur Wetland

In the present study, dissolved oxygen concentrations ranged from 1.33 to 11.52 mg/L (mean 6.33 ± 1.72 mg/L) during the pre-monsoon season. Comparison with established aquatic life criteria revealed 20% of sampling sites exhibited DO levels below recommended thresholds. The observed threshold exceedances are attributed to elevated biochemical oxygen demand (BOD) from agricultural runoff and municipal sewage loads, dense algal biomass and aquatic vegetation, coupled with minimal water circulation that reduces turbulent aeration and oxygen transfer at the air-water interface (U.S. Environmental Protection Agency, Dissolved Oxygen Criteria).

Gogabil Wetland

In the present study, observed dissolved oxygen concentrations ranged from 5.01 to 14.38 mg/L (mean 10.22 ± 1.35 mg/L). All recorded DO levels remained within permissible limits for aquatic life survival (>5 mg/L), indicating optimal oxygen conditions conducive to maintaining a healthy aquatic ecosystem.

Kabartal Wetland

In the present study, dissolved oxygen concentrations in Kabartal wetland ranged from 2.33 to 9.87 mg/L (mean 5.10 ± 1.21 mg/L). Approximately 14% of sampling stations recorded DO levels below the permissible threshold for aquatic life (>5 mg/L), indicating localized oxygen stress potentially attributable to organic pollution loads and reduced water circulation. Despite these isolated instances of suboptimal conditions, the



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overall dissolved oxygen profile suggests moderately healthy water quality conditions suitable for supporting agricultural and aquaculture activities within the wetland system.

Udhwa Lake Bird Sanctuary

The range of DO extends from 5.88 - 13.93mg/L (8.85 ± 1.19). Comparing the measured values with aquatic life criteria (>5 mg/L) reveals optimum oxygen levels for aquatic life and signifies a well-oxygenated water body capable of supporting a diverse and healthy aquatic ecosystem.

East Kolkata Wetland

In the present study, dissolved oxygen concentrations ranged from 1.36 to 11.11 mg/L (mean 3.42 ± 1.20 mg/L). Comparison with established aquatic life criteria (>5 mg/L) revealed 63% of sampling sites recorded suboptimal DO levels below acceptable thresholds. These critically low dissolved oxygen concentrations are attributed to elevated organic loading from sewage discharge, industrial effluents, waste inputs, and nutrient runoff, which stimulate microbial decomposition processes and increase oxygen consumption rates. Such hypoxic conditions adversely impact aquatic biodiversity by reducing species richness, altering community composition, and increasing mortality rates among oxygen-sensitive taxa including fish and macroinvertebrates, thereby compromising overall ecosystem integrity.

Sunderban Wetland

In the present study, the DO in Sunderban ranged from 0.73 - 7.54mg/L (5.71 ± 0.42). DO concentration lower than the threshold for supporting aquatic life (≥ 5 mg/L; ≥ 3.5 mg/L always). Exceedance was observed at 7% of the sites which can adversely

affect sensitive species. The extremely low values may be due to localized organic pollution, high biological oxygen demand, or stagnant water zones. Stress and decreased survival are the results of low DO levels, which negatively impact species such as *Macrobrachium rosenbergii* and catfish like *Mystus gulio* (Ghosh et al., 2018). Long-term hypoxia also inhibits the development of mangroves, such as *Avicennia alba* (Kathiresan & Bingham, 2001). Seasonal and human-induced changes in DO have a direct impact on patterns of biodiversity, particularly during the monsoon season (Chakraborty et al., 2015). However, the overall mean DO in the present study indicates that the system generally supports good oxygen availability. Tidal flushing and mangrove-driven aeration likely help maintain water quality in most parts of the Sundarbans.

3. CONDUCTIVITY

The ability of water to pass an electrical current is defined as conductivity and it is measured in microsiemens per centimetre ($\mu\text{S}/\text{cm}$) or micromhos per centimetre ($\mu\text{mhos}/\text{cm}$). The temperature affects the conductivity measurements therefore the standard method for reporting conductivity is the measurement of conductivity recorded at or corrected to 25°C and is defined as specific conductance ($\mu\text{S}/\text{cm}$). One of the important factors that can affect conductivity in water is the presence of dissolved solids or ions. Similarly, conductivity is directly proportional to change in temperature i.e. elevated water temperatures results in higher conductivity. Industrial, agricultural and sewage discharges to streams can change the conductivity due to the presence of ions.

Udhwa



Symbol (physical parameter)	Conductivity
Units Used for Analytical Results	$\mu\text{S}/\text{cm}$
Method(s) used for analysis	Digital calibrated water quality probe meter with conductivity sensitive probe
Occurrence/Origin	Urban wastewater, agricultural runoff, and industrial discharges
Aquatic Life Criteria	150-500 $\mu\text{S}/\text{cm}$ is preferable

The aquatic life criteria suggest that fresh water systems that have conductivity in the range of 150 to 500 $\mu\text{S}/\text{cm}$ support good mixed fisheries (U.S. Environmental Protection Agency, n.d.-a; U.S. Environmental Protection Agency, n.d.-b). Electrical conductivity (EC) in coastal and estuarine wetlands, as it naturally varies with salinity. For general water use, EC below 2250 $\mu\text{S}/\text{cm}$ is considered acceptable (CPCB/BIS), but in brackish and saline wetlands, values can range from 1500 to over 30,000 $\mu\text{S}/\text{cm}$ (Chowdhury et al. 2021).

Conductivity levels were estimated in six identified priority wetlands during the current study, with the findings summarized as follows:

Haiderpur Wetland

In the present study, conductivity in Haiderpur wetland ranged from 215 to 510.33 $\mu\text{S}/\text{cm}$ (312.23 ± 37.70 $\mu\text{S}/\text{cm}$), exceeding the aquatic life criteria (150-500 $\mu\text{S}/\text{cm}$) by 20%. Elevated conductivity indicates higher ionic concentration, often linked to agricultural runoff and urban discharge (Singh et al., 2020). Such conditions may stress freshwater biota and alter ecological balance.

Gogabil Wetland

In the present study conductivity in Gogabil wetland ranged from 185.00 - 247.63 $\mu\text{S}/\text{cm}$ (204.87 ± 8.88 $\mu\text{S}/\text{cm}$). The conductivity values were recorded to be within the permissible limit throughout the wetland.

Kabartal Wetland

In the present study conductivity concentration in Kabartal wetland were within the permissible aquatic life criteria (150-500 $\mu\text{S}/\text{cm}$) with a mean value of 328.19 ± 20.65 $\mu\text{S}/\text{cm}$. The observed conductivity concentrations fell within the acceptable range for aquatic life criteria (150-500 $\mu\text{S}/\text{cm}$) throughout the wetland area.

Udhwa Lake Bird Sanctuary

In this study, conductivity values observed during the pre-monsoon season ranged from 135.80 to 310.03 $\mu\text{S}/\text{cm}$, with a mean of 178.04 ± 16.86 $\mu\text{S}/\text{cm}$, indicating relatively low to moderate ionic concentrations. An 11% exceedance rate was

recorded, suggesting that only a small proportion of samples exceeded the acceptable threshold, likely attributable to localized pollution sources particularly sewage and agricultural runoff.

East Kolkata Wetland

In this study, conductivity in EKW ranged from 926.33 to 2286.00 $\mu\text{S}/\text{cm}$, with a mean of 1251.10 ± 166.10 $\mu\text{S}/\text{cm}$, indicating moderately high ionic concentrations. The exceedance rate for this parameter was 50%. Given that EKW operates as one of the world's largest sewage-fed aquaculture systems, these elevated levels result from continuous inputs of urban wastewater, industrial effluents, and associated dissolved salts, and are elevated compared to natural wetland environments. However, the high conductivity can disrupt osmotic regulation in aquatic organisms and may compromise the safety and quality of fish products destined for human consumption. The findings indicate an urgent need for improved wastewater treatment protocols and stricter industrial discharge regulations to ensure both environmental sustainability and food safety standards in this economically important aquaculture system.

Sunderban Wetland

In this study, conductivity values ranged from 2276.50 to 46794.00 $\mu\text{S}/\text{cm}$, with a mean of 28546.37 ± 3373.75 $\mu\text{S}/\text{cm}$, reflecting the high salinity characteristic of estuarine environments. Seventy-three percent (73%) of sampling sites exceeded 30,000 $\mu\text{S}/\text{cm}$, the upper threshold for optimal aquatic life conditions, suggesting conditions of ecological stress. These elevated conductivity levels are attributed to tidal saltwater intrusion, diminished freshwater inflow, and seasonal evaporation processes. High conductivity poses particular challenges for freshwater-adapted species through disruption of osmoregulatory mechanisms, potentially altering community structure and species composition. The data indicate that managing freshwater-saltwater dynamics within natural variation ranges is critical for maintaining ecological resilience in the Sundarbans estuarine system.



4. TOTAL DISSOLVED SOLIDS (TDS)

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

Environmental Protection Agency, n.d.-b). For freshwater ecosystems 150-500 mg/L is preferable. As per, the desirable limit for TDS in water is ≤500 mg/L, and the permissible limit in the absence of an alternate source is 2000 mg/L (BIS, 2012).

However, in coastal and estuarine wetlands, TDS naturally exceeds these limits due to tidal saltwater intrusion and salinity. While no strict TDS limit exists for such ecosystems, values over 3000 mg/l to 10000 mg/l classify as brackish water and above 10000 mg/l to 50000 mg/l as saline water (Ji, 2025). Elevated levels of TDS can serve as transporters of toxicants, which can readily adhere to suspended particles. This is particularly problematic in areas such as in agricultural belts where high amounts of pesticides are being used and areas where there is high discharge of untreated industrial effluents.

Symbol (physical parameter)	Total Dissolved Solids (TDS)
Units Used	mg/L Dissolved Solids
Method(s) used for analysis	Digital calibrated water quality probe meter with TDS sensitive probe
Occurrence/Origin	Agricultural runoffs, industrial and sewage discharge
Aquatic Life Criteria	150-500 mg/L is preferable

Haiderpur Wetland

In this study, TDS ranged from 146.00 to 336.00 mg/L, with a mean of 214.46 ± 24.97 mg/L, indicating generally low to moderate levels of dissolved solids. Twenty percent of samples exceeded acceptable limits, likely due to runoff containing fertilizers, salts, or domestic waste. Elevated TDS levels can adversely affect aquatic organisms by disrupting osmotic balance and reducing water clarity. However, the overall mean suggests that the wetland generally maintains water quality conditions suitable for aquatic ecosystems.

Gogabil Wetland

In the present study, TDS ranged from 124.67 to 171.00 mg/L (mean: 137.92 ± 6.31 mg/L), indicating low to moderate levels of dissolved substances. However, exceedance was observed in 71% of the samples, indicating localized water quality deterioration. This may be attributed to agricultural runoff (rich in fertilizers and salts) and leaching from locally dumped solid waste, a common practice in rural areas lacking formal waste management. Elevated TDS can disrupt aquatic ecosystems and reduce the utility of water for both ecological and domestic uses. Even where average concentrations remain moderate, the frequency of

exceedance calls for site-specific pollution control interventions and routine monitoring.

Kabartal Wetland

In the present study, Total Dissolved Solids (TDS) ranged from 188.00 to 261.33 mg/L (mean: 224.20 ± 12.07 mg/L), indicating moderate levels of dissolved substances, with no exceedance of the permissible range (150-500 mg/L). While TDS alone does not fully reflect overall water quality, values within the acceptable range suggest an absence of salinity-related stress and indicate conditions generally supportive of aquatic life.

Udhwa Lake Bird Sanctuary

In the present study, TDS ranged from 94.67 - 201.67mg/L(118.66 ± 10.51) indicating generally low to moderate mineral content. TDS values exceeded at 89% sites, this may be attributed to agricultural runoff, domestic waste discharge, and leaching from solid waste, contributing to elevated dissolved solids. High TDS can impair water quality by affecting aquatic organisms' osmoregulation and reducing habitat suitability. Despite a low average, the high exceedance rate signals the need for targeted pollution control and catchment management.



East Kolkata Wetland

In this study, TDS in East Kolkata Wetlands ranged from 595.67 to 1486.67 mg/L, with a mean of 814.26 ± 109.18 mg/L, indicating moderately high concentrations of dissolved substances. TDS levels exceeded permissible limits at 50% of sampling sites, reflecting significant water quality degradation. Given the wetland's function as a sewage-fed aquaculture system, elevated TDS levels result from continuous inputs of urban wastewater, industrial effluents, and leachate from solid waste disposal areas. High TDS concentrations can disrupt aquatic ecosystems by altering osmotic balance, reducing water clarity, and compromising habitat quality for both cultured and wild species. The widespread exceedance indicates an urgent need for improved pre-treatment of sewage inputs and enhanced monitoring protocols to ensure both aquaculture productivity and environmental safety.

Sunderban Wetland

TDS levels in Sundarbans wetland ranged from 1446.50 to 29770.00 mg/L, with a mean of 18310.09 ± 2199.05 mg/L. While these values remain below the saline water threshold of 50,000 mg/L, 68% of samples exceeded freshwater standards, reflecting the brackish nature of this estuarine environment. The elevated TDS concentrations result from tidal saltwater intrusion, seasonal variations in

freshwater discharge, and natural evaporation processes typical of mangrove ecosystems.

5. NITRATES (NO₃⁻, mg/L)

Nitrates are essential plant nutrients that are present in several different forms in aquatic and terrestrial ecosystems. Some of these forms of nitrogen include nitrites, ammonia, and nitrates. Mineral origin nitrates (NO₃⁻) in water bodies are relatively little. Though microbacterial oxidation and nitrogen fixation by plants can also produce nitrates, most of the nitrates found in rivers is from organic and inorganic sources, like agricultural runoffs and waste discharges. In excess amounts Nitrates can cause substantial water quality problems like enhanced eutrophication, and variations in the different plants and animals that inhabit the water systems. This sequentially can affect the other important water quality parameters and indicators like temperature and dissolved oxygen. Excessive levels of NO₃⁻ may result in hypoxia due to low levels of dissolved oxygen and under specific conditions it may result in toxicity to animals at levels >10 mg/L. The natural level of nitrate and ammonia in fresh water systems is usually at low concentration of < 1 mg/L, however with untreated wastewater effluents, it can shoot up to 30 mg/L (U.S. Environmental Protection Agency, n.d.-a; U.S. Environmental Protection Agency, n.d.-b).

Symbol (physical parameter)	Nitrate
Units Used for Analytical Results	mg/L of N or mg/L of NO ₃ ⁻
Method(s) used for analysis	Digital calibrated water quality probe meter with NO ₃ ⁻ sensitive probe
Occurrence/Origin	Oxidation of ammonia, Agricultural fertiliser runoffs, industrial and sewage discharge
Aquatic Life Criteria	<10 mg/L is preferable

Haiderpur wetland

In the present study nitrate levels ranged from 0.75 - 2.30mg/L (1.28 ± 0.27).The recorded values were found to be within recommended limits (<10 mg/L) for sustaining aquatic life.

Gogabil Wetland

In this study, nitrate levels in Gogabil wetland ranged from 0.81 to 5.64 mg/L, with a mean of 2.25 ± 0.60 mg/L. The recorded values were within recommended limits for aquatic life (<10 mg/L), suggesting that current nutrient loading from potential sources such as agricultural runoff and sewage inputs remains at manageable levels..

Kabartal Wetland

In this study, nitrate levels in Kabartal wetland ranged from 4.69 to 7.86 mg/L, with a mean of 5.78 ± 0.52 mg/L. The recorded values were within permissible limits for aquatic life criteria. However, these concentrations are consistent with an increasing trend in nitrate levels documented over time, as observed in assessments from 1989-91, 1996, and 2000-01 (Ramsar Site Information Service, 2020). While current levels remain acceptable, the upward trend warrants continued monitoring to prevent potential eutrophication and maintain water quality standards in this protected wetland ecosystem.



Udhwa Lake Bird Sanctuary

In the present study nitrate levels ranged from 0.01 - 4.20 mg/L the recorded values were found to be within recommended limits for sustaining aquatic life. The relatively low nitrate levels (0.91 ± 0.57 mg/L) observed may indicate effective protection of this Ramsar wetland from nitrogen-rich anthropogenic sources, though comprehensive nutrient monitoring would be needed to fully assess nutrient status.

East Kolkata Wetland

In the present study, nitrate levels ranged from 0.71 - 2.72 mg/L (1.21 ± 0.24), recorded nitrate levels to be falling within established aquatic life criteria.

Sunderban Wetland

In this study, nitrate concentrations in the Sundarbans wetland ranged from 1.28 to 63.27 mg/L, with a mean of 20.05 ± 5.66 mg/L, indicating pronounced nutrient enrichment. Given the ecological sensitivity of the Sundarban wetland, a conservative nitrate threshold of 1.6 mg/L (equivalent to 0.25 mg/L as N) has been adopted, in line with eutrophication control guidelines for brackish and estuarine ecosystems. A 93% exceedance rate relative to the ecological threshold (≤ 1.6 mg/L) underscores the widespread prevalence of nitrate pollution and its potential threat to the estuarine ecosystem. These elevated concentrations are likely driven by agricultural runoff, sewage discharge, and decomposition of organic matter within the wetland.

Elevated nitrate levels can fuel phytoplankton blooms that, while initially boosting primary productivity, often lead to eutrophication (Chowdhury et al., 2019). This process disrupts nutrient cycling, degrades mangrove health, particularly affecting species like *Avicennia marina* and reduces dissolved oxygen levels during bloom decay. Such hypoxic conditions threaten estuarine biodiversity, including economically important

species such as shrimp (*Penaeus monodon*) and Hilsa (*Tenualosa ilisha*). Agricultural runoff remains the dominant source of nitrate loading in estuarine systems.

These conditions pose a serious threat to the ecological balance, biodiversity, and fisheries productivity of the Sundarbans, a globally important and climate-sensitive estuarine wetland.

6. SALINITY (PARTS PER THOUSAND: PPT)

Salinity represents the total concentration of dissolved salts in freshwater ecosystems, commonly measured in parts per thousand (ppt) or milligrams per liter (mg/L). Optimal freshwater conditions typically maintain salinity levels below 0.5 ppt (500 mg/L), creating environments where aquatic life thrives, although species tolerance ranges vary significantly. However, species sensitivity to salinity varies, and even modest increases can adversely affect survival, reproduction, and behavior. Salinity levels between 0.5 and 2 ppt may induce osmotic stress in sensitive taxa such as amphibians and certain macroinvertebrates. When salinity exceeds 2 ppt, changes in community composition are often observed, with a decline in sensitive species and a rise in salt-tolerant organisms. At concentrations above 5 ppt, freshwater fish, particularly during vulnerable life stages like egg and larval development, may experience significant mortality unless they possess specific physiological adaptations to tolerate higher salinity (U.S. Environmental Protection Agency, n.d.-a; U.S. Environmental Protection Agency, n.d.-b). Coastal and estuarine wetlands in India exhibit wide salinity variation due to tidal influence and freshwater inflow. Salinity typically ranges from 10.6-27.3 ppt in brackish and estuarine wetlands, and can exceed 30 ppt in coastal marine wetlands (Chowdhury et al. 2021).

Haiderpur



Symbol (physical parameter)	Salinity
Units Used for Analytical Results	Parts per thousand or mg/L
Method(s) used for analysis	Digital calibrated water quality probe meter with NO ₃ - sensitive probe
Occurrence/Origin	Agricultural fertiliser runoffs, industrial and sewage discharge
Aquatic Life Criteria	<0.5 ppt is preferable

Haiderpur Wetland

In the present study, salinity ranged from 0.11 to 0.25 ppt (mean: 0.16 ± 0.02 ppt), confirming its freshwater character. Such low salinity levels are typical of inland wetland ecosystems and provide suitable conditions for the persistence of freshwater flora and fauna. However, overall biodiversity is influenced by a broader set of ecological and water quality parameters.

Kabartal Wetland

Salinity levels in Kabartal ranged from 0.14 - 0.20 ppt and a mean value of (0.17 ± 0.01 ppt), which meets the concentrations necessary for aquatic life, and indicates a freshwater ecosystem, and suitability to aquatic life.

Gogabil Wetland

Salinity levels in Gogabil Wetland ranged from 0.09 to 0.12 ppt, with a mean value of 0.10 ± 0.00 ppt, indicating a freshwater environment. These low salinity levels fall within the range considered suitable for sustaining freshwater aquatic life and supporting the wetland's ecological integrity.

Udhwa Lake Bird Sanctuary

In the present study, salinity levels ranged from 0.07 - 0.15 ppt (0.09 ± 0.01 ppt). The recorded salinity values fall within the acceptable range of <0.5ppt, and follow aquatic life criteria.

East Kolkata Wetland

In the present study, salinity ranged from 0.45 to 1.17 ppt, with a mean of 0.62 ± 0.09 ppt, showing exceedance at 50% of the sampling sites. Although classified as a freshwater ecosystem, the East Kolkata Wetlands has functioned as a natural sewage treatment system for the city of Kolkata for over a century, receiving inflows from multiple urban drains (Botanical Survey of India, 2020). The elevated salinity levels observed in some locations may reflect prolonged inputs of domestic wastewater and organic loading, which can alter the wetland's physicochemical balance and influence aquatic community structure.

Sunderban Wetland

In the present study, salinity levels in the Sundarban Wetland ranged from 1.14 to 29.68 ppt, with a mean of 17.46 ± 2.24 ppt, reflecting typical estuarine variability. However, exceedance at 68% of sampling sites indicates that salinity frequently surpassed the ecological tolerance range for many freshwater and estuarine species, particularly during the dry season.

Although moderate to high salinity is a key driver of mangrove ecosystem function, the observed exceedance is increasingly influenced by climate change impacts-including reduced upstream freshwater discharge, rising sea levels, increased tidal intrusion, and erratic monsoon patterns. These changes intensify salinity intrusion into inland zones, compounding existing pressures from anthropogenic activities. Elevated salinity can exclude or stress sensitive species, disrupt breeding cycles, and alter aquatic food webs, thereby affecting overall biodiversity and ecological balance.

Empirical data from the Indian Sundarban Biosphere Reserve show surface water conductivity ranging from 14,000 to 36,000 $\mu\text{S}/\text{cm}$, corresponding to salinities of 10.6 to 27.3 ppt, spanning from brackish to near-marine conditions (Chowdhury et al., 2021).

Salinity also shapes mangrove distribution: *Heritiera fomes* (Sundari) declines in high-salinity areas, while *Excoecaria agallocha* (Gewa) and *Ceriops decandra* (Goran) are more salt-tolerant and dominate such zones. Among aquatic fauna, *Tenualosa ilisha* (Hilsa) prefers lower salinity for migration and spawning, whereas *Scylla serrata* (mud crab) thrives in saline conditions (Iftekhar & Saenger, 2008; Giri et al., 2007).

These findings highlight the urgency of addressing climate-induced salinity shifts through integrated estuarine management, freshwater flow regulation, and ecosystem-based climate adaptation strategies to safeguard the ecological integrity of the Sundarbans.



**STATUS OF
SELECT
WETLANDS
IN THE
GANGA RIVER
BASIN**

**POLLUTION THREATS AND
HOTSPOT ASSESSMENT**

CONTAMINATION STATUS OF ENDOCRINE DISRUPTING CHEMICALS (EDCs) IN SURFACE WATER AND SEDIMENT

Endocrine Disrupting Chemicals (EDCs) Contamination Profiles in Surface Water

Understanding the contaminant profile of endocrine-disrupting chemicals (EDCs) in ecologically important wetlands is essential for effective wetland conservation and pollution mitigation strategies. The February-March 2024 sampling campaign captured the lean season conditions, representing the transitional period between dry and wet seasons, providing baseline

data during a critical period when pollutant concentrations are typically elevated due to reduced dilution effects and accumulated anthropogenic inputs. The present analysis provides a comparative overview of various classes of EDCs, including phthalates (Σ PAEs), bisphenol A (BPA), pesticides, pharmaceuticals (Σ Pharma), personal care products (Σ PCPs), hormones (Σ Hormones), and heavy metals (Σ HMs), across six priority wetlands of the GRB. The cumulative EDC burden was estimated using mean $\pm$ standard error (SE), revealing considerable spatial heterogeneity that reflects differences in land use, anthropogenic pressures, and hydrological connectivity (Table 5; Figures 2-5). The data suggest strong spatial variability in EDC occurrence across GRB wetlands, with East Kolkata Wetlands showing the highest chemical burdens, and Udhwa Lake the lowest. (Table 5; Figures 2-5). The data suggest strong spatial variability in EDC occurrence across GRB wetlands, with East Kolkata Wetlands showing the highest chemical burdens, and Udhwa Lake the lowest.

Table 5: EDC levels (ng/L) in the surface water of priority wetlands of GRB based on 2024 (Feb-Mar)

Category	Kabartal Wetland	Udhwa Wetland	Gogabil Wetland	Haiderpur Wetland	East Kolkata Wetland	Sundarban Wetland
Σ PAEs	231- 5181	131- 1883	253- 95961	120- 2606	121- 81901	108- 2308
BPA	BDL - 276.12	48.31 - 200	46.45 - 482	0.42 - 333	10.94 - 461	41.47 - 975
Σ Pesticides	BDL - 171	16.65 - 95.97	8.76 - 53	18.26 - 81.34	25.86 - 793	14.15 - 244
Σ Pharma	4.46 - 203	1.73 - 37.40	6.21 - 179	4.05 - 20.63	7.59 - 809	4.20 - 397
Σ PCPs	BDL - 27.04	0.59 - 18.80	1.92 - 30.83	BDL - 10.14	4.05 - 17.27	0.77 - 65.19
Σ Hormones	BDL - 15.70	BDL - 17.95	BDL - 3.08	BDL - 2.50	BDL - 195	BDL - 33.01
Σ HMs	3943- 61830	8226- 36263	5827- 15281	34000- 215597	25916- 236399	17656- 472735
Σ EDCs Mean $\pm$ SE	23448 $\pm$ 3370	19835 $\pm$ 3379	26790 $\pm$ 13424	89091 $\pm$ 33685	95315 $\pm$ 26582	98636 $\pm$ 34650

*BDL=Below Instrument Detection Limits; Σ = Summation; PCPs= Personal Care Products; BPA: Bisphenol A; PAEs: Phthalates; HMs: Heavy Metals; Pharma: Pharmaceuticals; Mean EDCs represents Mean $\pm$ Std Error

East Kolkata Wetland





STATUS OF
SELECT
WETLANDS
IN THE
GANGA RIVER
BASIN

POLLUTION THREATS AND
HOTSPOT ASSESSMENT

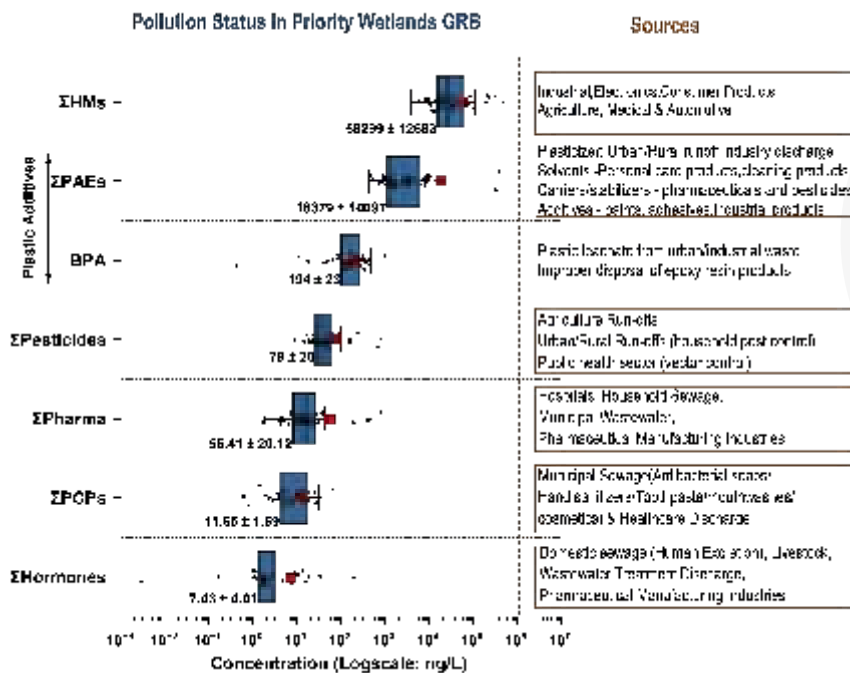


Figure 2: Endocrine-Disrupting Chemicals (EDCs) contamination profile in Surface Water of the priority wetlands of GRB based on 2024 (Feb-Mar). EDCs levels (ng/L) presented on a log scale (to account for the wide range of observed values for different EDCs group) with Mean $\pm$ SE (labels); black dots indicate distribution of EDCs concentration across six wetlands

Heavy metals emerge as the dominant EDC class across all wetlands, contributing 60-85% of total contamination burden (Table 5; Figures 2). This pattern indicates widespread industrial pollution and inadequate heavy metal discharge controls throughout the basin.

PAEs constitute the second major contaminant group, with East Kolkata (12645 $\pm$ 11547 ng/L) and Gogabil (14914 $\pm$ 13514 ng/L) showing exceptionally high levels, reflecting severe plastic pollution in urban-industrial and rural areas. The subsequent section presents a comprehensive wetland-wise assessment of EDC contamination in the six priority sites. Contaminant distribution analysis across wetland ecosystems revealed East Kolkata Wetland as a pollution hotspot across multiple contaminant categories, indicating severe anthropogenic pressure (Figure 3). EKW functions as a terminal drainage basin for metropolitan Kolkata, receiving a complex mixture of point and non-point source pollutants, which explains the diverse and elevated contaminant profile observed.

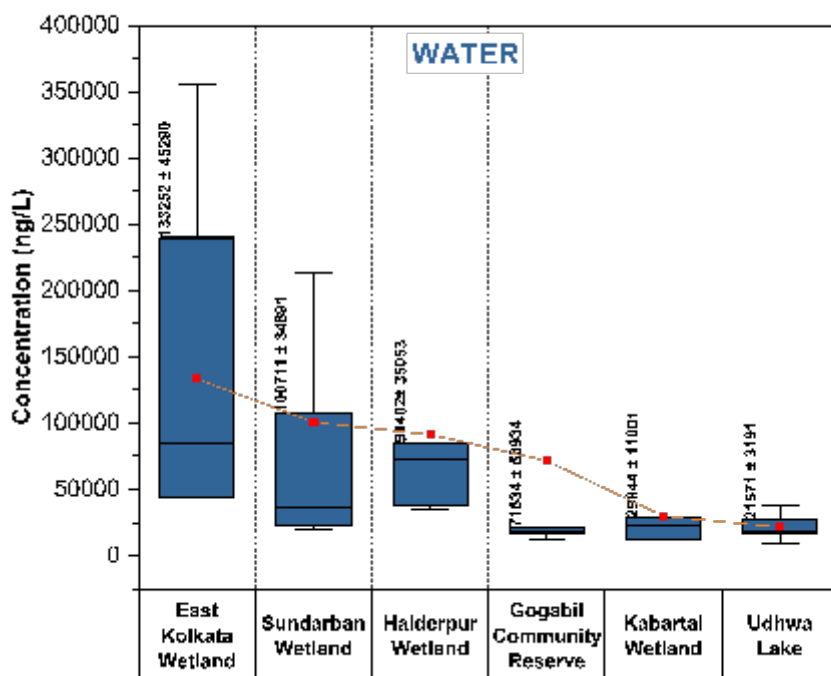


Figure 3: Endocrine-Disrupting Chemicals (EDCs) contamination profile in Water of the priority wetlands of GRB based on 2024 (Feb-Mar). EDCs levels (ng/L; log scale) with Mean $\pm$ SE (labels); black dots show distribution; red squares indicate mean. Pie diagram represents contaminant distribution (%) in sediment across six priority wetlands of GRB



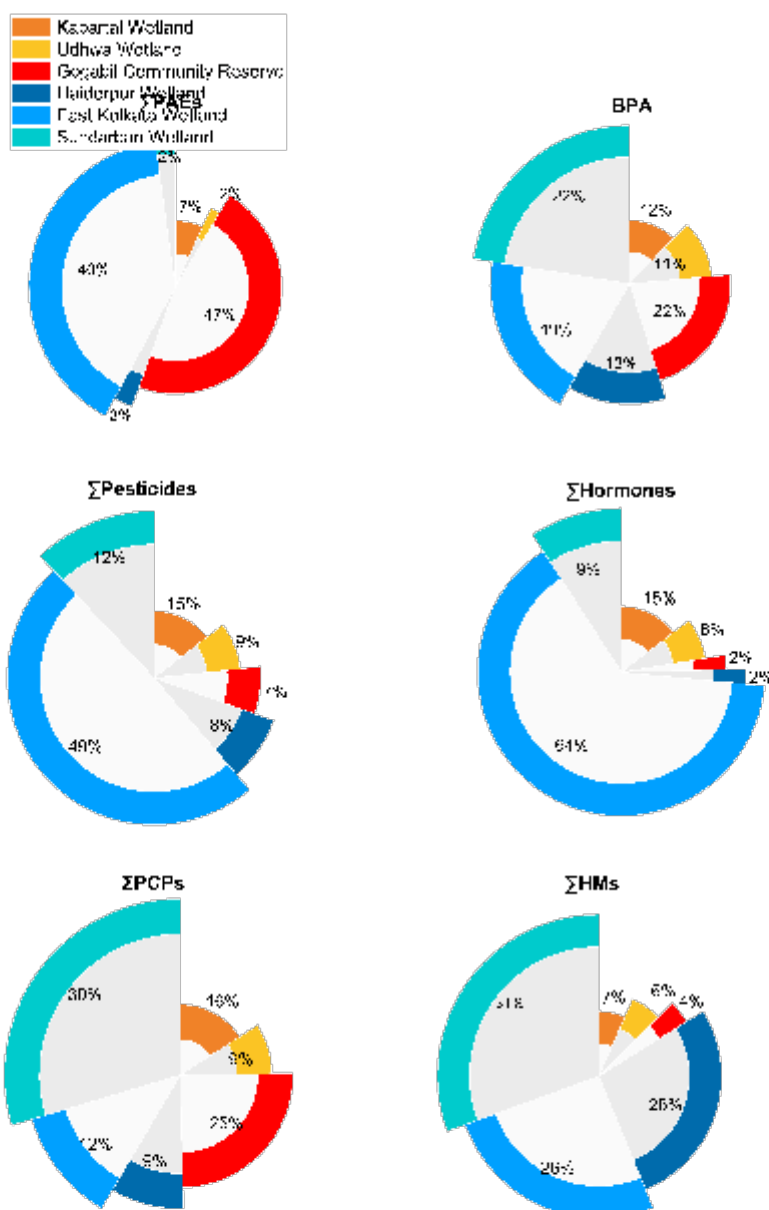


Figure 3: Endocrine-Disrupting Chemicals (EDCs) contamination profile in Water of the priority wetlands of GRB based on 2024 (Feb-Mar). EDCs levels (ng/L; log scale) with Mean $\pm$ SE (labels); black dots show distribution; red squares indicate mean. Pie diagram represents contaminant distribution (%) in sediment across six priority wetlands of GRB

WETLAND-WISE ANALYSIS OF EDC CONTAMINATION

Sundarban Wetland

Sundarbans wetland exhibits the highest total EDC burden ($98636 \pm 34,650$ ng/L), predominantly driven by heavy metal contamination (17656 - 472735 ng/L; mean 97574 ± 34540 ng/L). The extreme spatial variability in metal concentrations reflects heterogeneous pollution sources, including industrial effluents, ship traffic, estuarine sediment resuspension, and upstream discharges, and indicates the presence of strong spatial gradients within the mangrove-dominated estuary.

Detection of pharmaceutical residues (Σ Pharma:

4.20 - 397 ng/L), personal care products (Σ PCPs: 0.67 - 65.37 ng/L), and natural and synthetic hormones (up to 33.01 ng/L) in this remote deltaic system suggests dual pathways of contamination: (i) long-range transport of anthropogenic pollutants via the Ganga-Brahmaputra riverine network and tidal exchange, and (ii) localized inputs from untreated sewage and tourism activities. The presence of phthalate esters (PAEs) (108 - $2,308$ ng/L; mean: 691 ± 141 ng/L) points to plastic degradation and leachate infiltration, a growing concern in tropical estuarine environments. In addition to upstream and urban plastic waste sources, fishing activities appear to be a key local contributor. The widespread use of synthetic fishing nets, ropes, and gear, typically composed of polyvinyl chloride,

polypropylene, and polyethylene introduces plasticizers such as DEHP, DBP, and BPA into the aquatic system. Chronic exposure to saline water, UV radiation, and mechanical stress leads to polymer degradation and in-situ leaching of plastic additives. Furthermore, discarded and abandoned fishing nets ("ghost nets") exacerbate this contamination, serving as a continuous source of secondary microplastics and leached chemical additives. These factors collectively contribute to the elevated levels of PAEs and BPA (124.68 ± 16.44) detected in this estuarine environment. These trends are consistent with recent findings that document plasticizers, pharmaceuticals, and steroidal compounds in Sundarbans' surface waters, despite the area's remote location and protected status (Chakraborty et al., 2020). Further, the detection of agricultural pesticides ($14.15\text{--}244\text{ ng/L}$) indicates diffuse agrochemical runoff transported from upstream catchments, supported by hydrological connectivity across the basin and extensive river network inside the protected area. Collectively, the co-occurrence of legacy pollutants (e.g., heavy metals, pesticides) and emerging contaminants (e.g., pharmaceuticals, PAEs, BPA, hormones) highlights the complex

pollution landscape of the Sundarbans. The wetland's function as a terminal sink for the Ganga-Brahmaputra-Meghna basin makes it particularly vulnerable to cumulative contaminant loads, despite its protected status under national and international frameworks. These findings emphasize the urgent need for integrated pollution management, with targeted action on plastic additive regulation, fishing gear retrieval, and basin-wide contaminant source control to protect the ecological integrity of this critical estuarine ecosystem.

East Kolkata Wetland

East Kolkata Wetlands (EKW) exhibit the second-highest overall EDC contamination ($95,315 \pm 26,582$ ng/L), with heavy metals dominating the pollutant profile ($25,916\text{--}236,399$ ng/L; mean $81,979 \pm 28,255$ ng/L). EKW's role as Kolkata's natural sewage treatment system is reflected in exceptionally elevated pharmaceutical concentrations ($7.59\text{--}809$ ng/L; mean 408 ng/L), indicating incomplete biodegradation of therapeutic compounds during wastewater treatment.

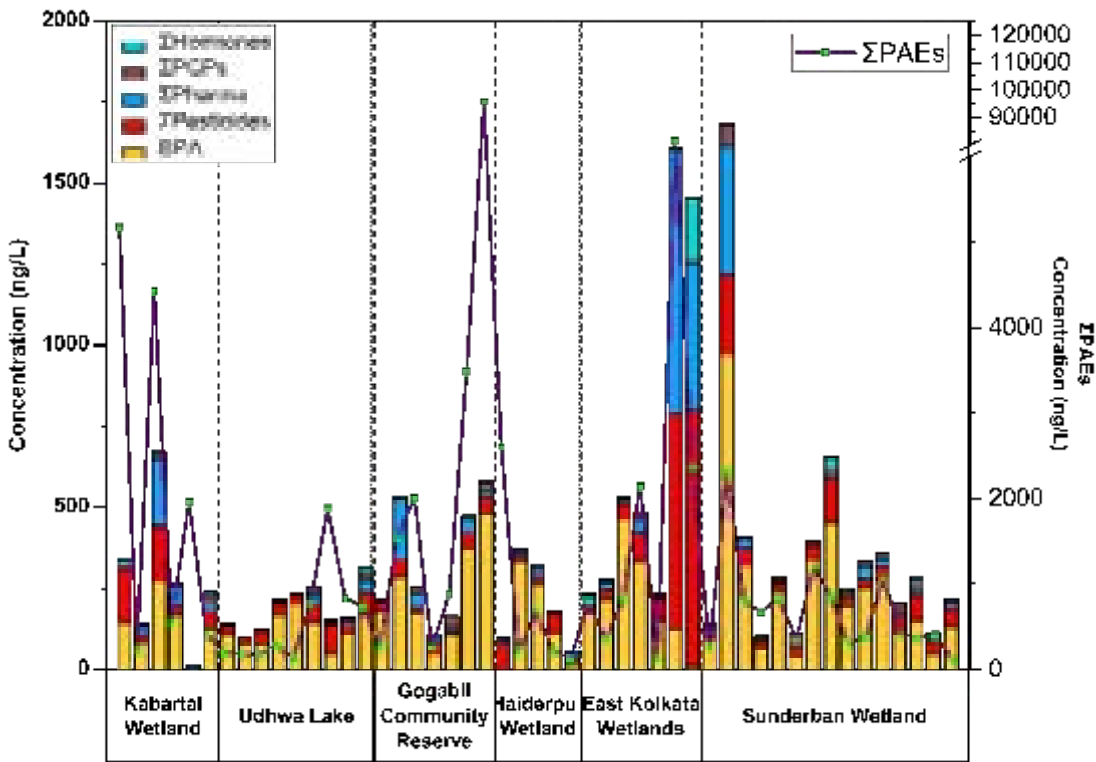


Figure 4: Wetland-wise distribution of various contaminants in surface water based on 2024 (Feb-Mar) Concentrations. Left Y-Axis (Primary, vertical) presents EDCs concentrations (ng/L); Right Y-Axis (Secondary, vertical), presents concentration (ng/L) of Phthalates (PAEs; violet line) and Heavy Metals (HMs; red line)



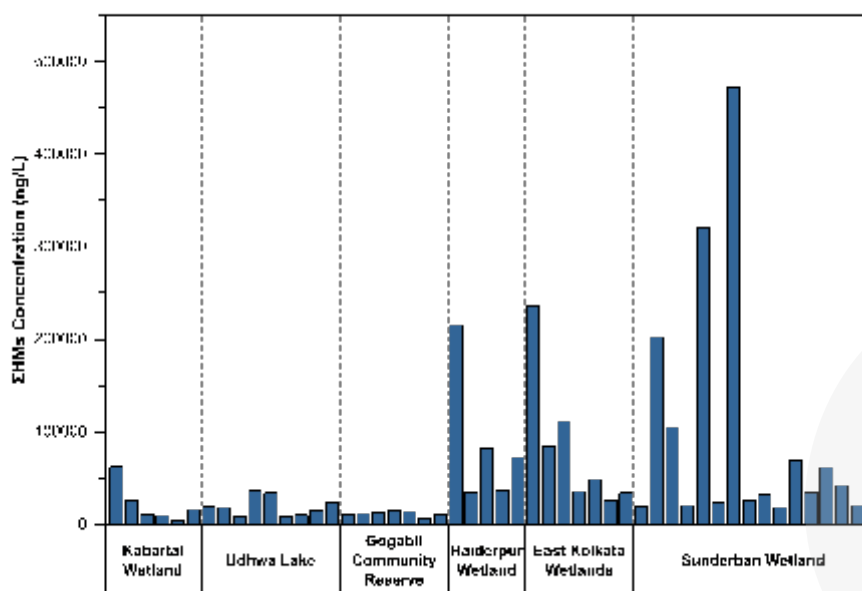


Figure 5: Wetland-wise distribution Heavy Metals (HMs) in Surface Water based on 2024 (Feb-Mar) Concentrations

Plastic additive levels, particularly phthalate esters (PAEs; $12,645 \pm 11,547$ ng/L) and bisphenol A (BPA; $10.94\text{--}461$ ng/L), exhibit substantial variability, reflecting fluctuating inputs from urban stormwater runoff and industrial effluents. These compounds have significant endocrine-disrupting potential, raising concerns given the wetland's extensive aquaculture activities and associated food chain transfer.

The elevated pesticide burden ($25.86\text{--}793$ ng/L; mean 246.06 ± 125.66 ng/L) likely stems from peri-urban agriculture and domestic pesticide use. Collectively, the contamination profile underscores EKW's dual role as a terminal wastewater sink and a food production system, creating multiple exposure pathways to humans and aquatic biota. The Tolly Nallah's northern catchment, channeling domestic and industrial wastewater through seven pumping stations to the Ballygunge Drainage Pumping Station and ultimately discharging into the Vidyadhari River via the East Kolkata Wetlands also emerges as a major conduit of hormonal, pharmaceutical, personal care, and pesticide pollutants, significantly contributing to the EKW's contaminant load and associated ecological and human health risks.

Functioning as one of the world's largest sewage-fed aquaculture systems, EKW receives continuous inflow of untreated or partially treated effluents, resulting in the accumulation of persistent pollutants in its water and sediment. The dual role of EKW as a wastewater filtration system, critical ecological infrastructure and a hub for aquaculture further elevates concerns of trophic transfer of EDCs and related human health risks, and highlights the urgent need for integrated pollution mitigation strategies.

Haiderpur Wetland

Haiderpur wetland exhibits mean EDC concentrations of 89091 ± 33685 ng/L, with heavy metals constituting the dominant fraction ($34000\text{--}215597$ ng/L; mean 88113 ± 33260 ng/L). The elevated heavy metal burden suggests proximity to industrial point sources, possibly metallurgical or electroplating industries, and agricultural settlements. Pharmaceutical contamination (12.76 ± 2.76 ng/L) indicates domestic sewage inputs, though levels are lower than urban wetlands, suggesting partial treatment or dilution effects. PAE concentrations ($120\text{--}2606$ ng/L; mean 770 ± 468 ng/L) and BPA (146.42 ± 66.19 ng/L) concentrations demonstrate moderate plastic pollution, likely from agricultural plastic mulching, fishing gears, and packaging waste. The pesticide contamination pattern ($18.26\text{--}81.34$ ng/L) reflects intensive agricultural practices in the catchment area. Concentrations of other EDC classes including pharmaceuticals (ΣPharma), personal care products (ΣPCPs), and natural and synthetic hormones ($\Sigma\text{Hormones}$) were relatively low, indicating limited direct discharge of untreated urban wastewater. The contamination signature suggests mixed industrial-agricultural pollution sources with heavy metal point source contamination being the primary concern.

Gogabil Community Reserve

Gogabil Community Reserve, despite its rural setting and conservation status, demonstrates significant EDC contamination (26790 ± 13424 ng/L). The heavy metal profile is characterized by arsenic dominance (68%), followed by zinc (13%) and copper (8%), with total concentrations ranging from $5827\text{--}15281$ ng/L (mean: 11541 ± 1138 ng/L). Arsenic

accounts for the highest contribution (68%) among heavy metals in Gogabil, followed by zinc (13%) and copper (8%). This pattern is partly attributable to geogenic enrichment, as arsenic-rich sediments derived from the Himalayas and the Shillong Plateau foothills are deposited across the Gangetic Plain, including Bihar (Chakraborti et al., 2003). These deposits, shaped by the Ganga's meandering dynamics, may lead to localized arsenic accumulation. Notably, agricultural practices, particularly Arsenic-based pesticide use and irrigation runoff may further mobilize arsenic into surface waters, exacerbating its loading into the wetland system. Additionally, the wetland exhibits alarmingly high plastic additive levels, with Σ PAEs (14914 ± 13514 ng/L) and BPA (238 ± 58 ng/L) concentrations surpassing values reported for several urban wetlands. This suggests that rural landscapes, often lacking formal waste management systems, may be substantially contributing to contamination through informal burning, direct dumping, or uncontrolled leakage of plastic waste in and around the conservation zone. The data underscore that pollution in rural and semi-natural settings can rival or even exceed urban counterparts, particularly in the absence of integrated waste governance and community-based stewardship. The presence of pharmaceutical residues (mean: 43.98 ± 23.03 ng/L) and pesticides (mean: 35.55 ± 6.58 ng/L) further signals anthropogenic inputs likely originating from nearby village sewage, agricultural drainage, and tourism-related discharge in the absence of treatment infrastructure. Despite being a Community Reserve, Gogabil is under considerable ecotoxicological pressure, with both legacy contaminants (e.g., arsenic, pesticides) and emerging pollutants (e.g., plastic additives and pharmaceuticals) present at ecologically significant levels. The dominance of arsenic, in particular, poses serious risks to aquatic biota, especially benthic organisms and fish species vulnerable to chronic exposure and bioaccumulation.

Kabartal Wetland

Kabartal Wetland shows moderate yet consistent EDC contamination ($23,448 \pm 9,202$ ng/L), with limited spatial variability suggesting diffuse, homogeneous inputs. The contamination profile (Figure) reflects the rural catchment and agriculturally dominated buffer zones, where domestic wastewater and agricultural runoff are the primary contributors. Heavy metals dominate the contamination profile ($3943\text{--}61830$ ng/L; mean 21036 ± 8690 ng/L), presence primarily to runoff from agricultural fields, fertilizer inputs, and domestic waste, rather than industrial discharges. In Kabartal Wetland water samples, arsenic (As),

chromium (Cr), and zinc (Zn) are the predominant heavy metals, contributing approximately 40%, 29%, and 15% respectively to the total dissolved metal load. The elevated arsenic levels are likely a result of natural geogenic release from alluvial sediments, compounded by the use of arsenic-laden pesticides and irrigation-driven groundwater-surface water interactions. Chromium and zinc are associated with phosphate fertilizers, pesticide residues, and domestic runoff, highlighting the influence of intensive agriculture and rural waste inputs in the absence of industrial sources. The moderate yet consistent chromium contamination observed in Kabartal Wetland reflects the combined influence of intensive agriculture as the dominant source, supplemented by domestic waste inputs, natural geogenic processes, and rural infrastructure-related contributions. Plastic additives, primarily phthalates (Σ PAEs $231\text{--}5181$ ng/L; mean 2132 ± 885 ng/L), are present at moderate concentrations, likely originating from household plastic waste, agricultural mulching films, and packaging materials, reflecting plastic pollution in the absence of formal waste management infrastructure. Pharmaceutical residues ($4.46\text{--}203$ ng/L; mean 55 ± 31 ng/L) indicate ongoing inputs from domestic sewage, with elevated levels during the monsoon season reflecting enhanced surface runoff. The presence of personal care products (BDL-27 ng/L) corroborates wastewater influence, though concentrations remain modest. Pesticide contamination (BDL-171 ng/L; mean 73 ± 30 ng/L) displays significant seasonal variability, corresponding with crop cycles and agrochemical application. Agriculture remains the predominant land use around Kabartal and the principal source of livelihood for local communities, thereby intensifying the risk of agrochemical-laden runoff and associated pollutant influx into the wetland system (Ambastha et al., 2007; Chaturvedi & Avishek, 2024).

Udhwa Lake

Udhwa Lake registered the lowest total EDC load (19835 ± 3379 ng/L), though Σ HMs ($8226\text{--}36263$ ng/L) remained substantial. Phthalates ($131\text{--}1883$ ng/L) and BPA ($48.31\text{--}200$ ng/L) suggest moderate plastic and consumer product contamination. Pharmaceuticals ($1.73\text{--}37.40$ ng/L) and PCPs ($0.59\text{--}18.80$ ng/L) were relatively lower, aligning with minimal urban activity near the site. Despite the presence of pesticide residues ($16.65\text{--}95.97$ ng/L), the overall pollution burden remains comparatively limited.

The relatively pristine condition of Udhwa Lake likely stems from multiple protective factors operating at landscape and governance levels. The



waterbody's spatial separation from concentrated urban development zones has effectively minimized pharmaceutical and personal care product inputs, as reflected in substantially reduced contamination loads. Hydrological characteristics that limit direct hydraulic connectivity to intensive agricultural drainage networks have further restricted contaminant transport pathways.

The preservation of natural wetland ecosystem functions, including sediment filtration and biogeochemical attenuation processes, enables effective management of diffuse pollution sources while preventing point-source contamination accumulation. These natural purification mechanisms maintain system resilience despite moderate agricultural chemical presence from regional farming activities. Regulatory frameworks governing protected area management, coupled with enhanced community environmental stewardship and awareness programs, provide

additional protective mechanisms that significantly contribute to maintaining reduced endocrine-disrupting chemical concentrations. This integrated approach demonstrates the effectiveness of combining spatial planning, ecosystem conservation, and community engagement strategies in achieving measurable water quality improvements in sensitive aquatic ecosystems.

Endocrine Disrupting Chemicals (EDCs) Contamination Profiles in Sediments

The sediment analysis of priority wetlands across the Ganga River Basin during February-March 2024 reveals significant variability in EDC concentrations, reflecting diverse pollution profiles and source contributions. In all wetlands, sediments play a critical role in trapping nutrient pollution and chemical contaminants, functioning as long-term reservoirs.

Table 6: EDC levels (µg/kg) in sediment of priority wetlands of GRB (Feb-Mar 2024)

Category	Kabartal Wetland	Udhwa Wetland	Gogabil Wetland	Haiderpur Wetland	East Kolkata Wetland	Sundarban Wetland
ΣPAEs	7542 - 27182	4198- 23424	BDL - 13340	1051- 10323	6887- 36939	BDL - 24198
BPA	BDL - 125.22	BDL - 100.32	BDL - 22.48	BDL - 12.01	1.88 - 20.89	BDL - 72.31
ΣPesticides	2.51 - 13.83	2.00 - 13.15	BDL - 10.05	3.09 - 12.22	1.56 - 25.97	BDL - 13.24
ΣPharma	12.07 - 59.40	3.24 - 35.03	BDL - 33.16	2.90 - 53.71	2.80 - 31.87	BDL - 33.44
ΣPCPs	BDL - 0.17	BDL - 11.20	BDL - 4.20	BDL - 5.15	BDL - 153.78	BDL - 0.27
ΣHormones	BDL - 0.78	BDL - 0.42	BDL - 0.00	BDL - 0.19	BDL - 0.74	BDL - 0.42
ΣHMs	43149- 94932	25916- 54259	35138- 69068	34304-113379	47957- 292193	13652- 120895
Mean ΣEDCs	70245± 8233	51308± 4110	42710± 14935	58472± 17705	125040± 30936	56691± 8205

*BDL= Below Instrument Detection Limits; Σ= Summation; PCPs= Personal Care Products; BPA: Bisphenol A; PAEs: Phthalates; Hms: Heavy Metals; Pharma: Pharmaceuticals; Mean EDCs represents Mean±Std Error

However, under changing redox, hydrological, or biological conditions, these sediments can also become secondary sources, releasing previously stored pollutants back into the overlying water column. The contamination status in sediment highlights critical evidence that wetlands have transitioned from pollution sinks to secondary contamination sources when their natural buffering capacity becomes overwhelmed (Table 6; Figure 6-8).

East Kolkata Wetlands (EKW)

The EKW recorded the highest mean sedimentary

EDC burden (125040 ± 30936 µg/kg), predominantly driven by heavy metals (47,957-292,193 µg/kg; mean: 105099 ± 33264), PAEs (up to 36,939 µg/kg), and PCPs (up to 153.78 µg/kg). These levels reflect persistent inflows of untreated or partially treated sewage and domestic effluents. The wetland sediment functions as a dynamic sink, continuously accumulating pollutants. Yet, this contamination pattern indicates sediment saturation where continued inputs overwhelm retention capacity, causing direct advance to and potential remobilization of stored contaminants in water phase. Despite being a high-capacity sink,

the elevated water concentrations across all EDC groups strongly indicate sediment oversaturation and active pollutant release, making EKW a critical case of secondary pollution that could compromise both ecological and human health.

Kabartal Wetland

Kabartal Wetland exhibited a substantial EDC load (mean: $70245 \pm 8233 \mu\text{g/kg}$), with prominent levels of ΣPAEs (up to $27182 \mu\text{g/kg}$; mean: $15759 \pm 3393 \mu\text{g/kg}$), ΣHMs (up to $94932 \mu\text{g/kg}$; $54415 \pm 8183 \mu\text{g/kg}$), BPA ($125.22 \mu\text{g/kg}$) and pharmaceuticals (up to $59.40 \mu\text{g/kg}$). The sediment here reflects sustained agricultural runoff and sewage influence. While acting as a key sink for agrochemicals and plastic-related pollutants, Kabartal's seasonal flooding and fluctuating pH/oxygen conditions may

promote pollutant remobilization, underscoring its dual role as a source and sink.

Haiderpur Wetland

At Haiderpur Wetland, the mean sediment EDC burden was $58472 \pm 17705 \mu\text{g/kg}$, with notably high heavy metals ($63594 \pm 18076 \mu\text{g/kg}$), PAEs ($7563 \pm 1671 \mu\text{g/kg}$), and pharmaceutical concentrations (up to $53.71 \mu\text{g/kg}$). This mixed load suggests influence from both urban wastewater and agricultural activity. The sediment's role as a buffering medium is evident; however, due to strong hydrological connectivity with the Ganga, it faces a heightened risk of pollutant re-entry into the water column, especially during monsoon-driven sediment resuspension events.

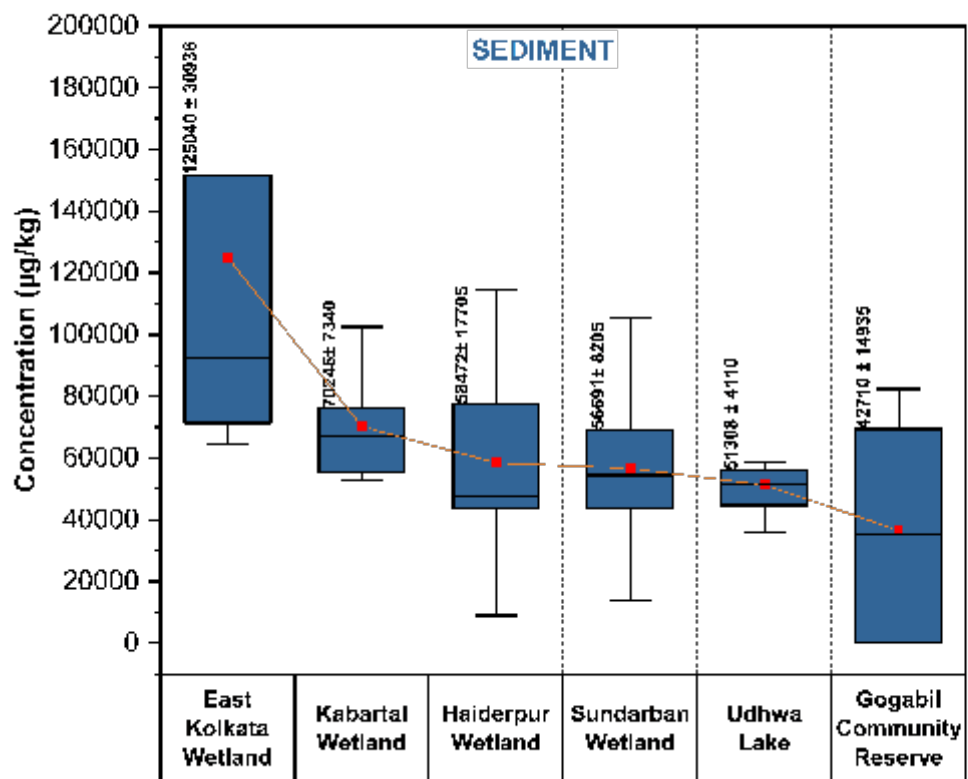


Figure 6: EDCs distribution ($\mu\text{g/kg}$) across six priority wetlands of GRB

Sundarbans Wetland

Sundarbans Wetland showed moderate mean EDC levels ($56691 \pm 8205 \mu\text{g/kg}$) with considerable variability in heavy metals ($50574 \pm 7048 \mu\text{g/kg}$), plastic additives including PAEs ($12915 \pm 2349 \mu\text{g/kg}$) and high BPA levels (up to $72.31 \mu\text{g/kg}$). The estuarine dynamics introduce complexity, where tidal mixing and saline conditions may trigger desorption and redistribution of contaminants.

These pollutant profiles indicate complex, multi-source inputs from upstream industrial discharge, agricultural runoff, and untreated domestic sewage entering through a dynamic river network including the Hooghly, Bidyadhari, Matla, Dutta, and Ichamati rivers. These tidal rivers facilitate the widespread dispersal, mixing, and deposition of pollutants across the deltaic wetland landscape.



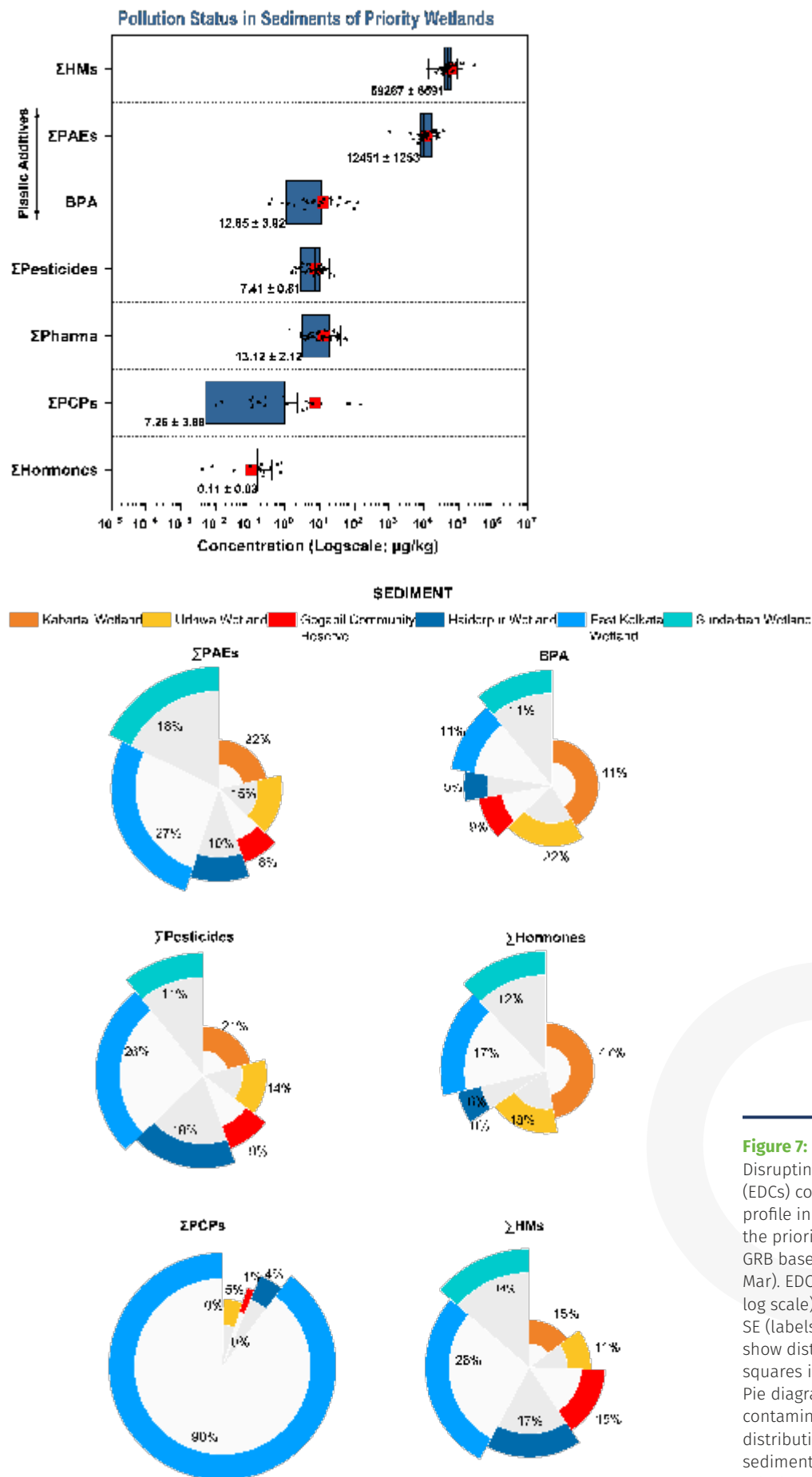


Figure 7: Endocrine-Disrupting Chemicals (EDCs) contamination profile in sediment of the priority wetlands of GRB based on 2024 (Feb-Mar). EDCs levels (µg/kg; log scale) with Mean ± SE (labels); black dots show distribution; red squares indicate mean. Pie diagram represents contaminant distribution (%) in sediment across six priority wetlands of GRB

Sediment sampling reveals substantial accumulation of both inorganic and organic EDCs, affirming the Sundarbans' critical function as a chemical sink. However, sediment-water interactions driven by tidal flushing, estuarine salinity gradients, and bioturbation from benthic fauna can remobilize stored contaminants into the water column. This reactivation of legacy pollution, especially under conditions of sediment overload, transforms the wetland from a passive sink into an active secondary source of pollution. More critically, the Sundarbans' mangrove sediments, characterized by high organic matter and fine-grained textures, are integral to "blue carbon" sequestration. These sediments store significant quantities of organic carbon derived from mangrove litter and allochthonous inputs. However, sustained contamination by heavy metals and organic pollutants can disrupt microbial communities responsible for organic matter breakdown and hinder the burial efficiency of carbon. Such interference compromises the long-term stability of carbon pools, potentially leading to greenhouse gas emissions and reducing the wetland's role as a climate regulation system. Therefore, sediment contamination in the Sundarbans is not only an ecological and toxicological concern but also a climate risk amplifier. It undermines both biodiversity conservation and the wetland's resilience in contributing to global climate mitigation via carbon sequestration.

Udhwa Lake

Udhwa Lake, with a mean sedimentary EDC load of $51308 \pm 4110 \mu\text{g/kg}$, reflects moderate



Sunderban

contamination primarily from heavy metals ($40002 \pm 3205 \mu\text{g/kg}$) and PAEs ($11267 \pm 1913 \mu\text{g/kg}$) and scattered occurrences of personal care products and pharmaceuticals. Given its relatively enclosed nature and reduced flushing capacity, the sediment here serves as a persistent reservoir for pollutants. However, organic matter decomposition and microbial activity could lead to diffusive release, particularly of metal species, highlighting potential internal loading concerns.



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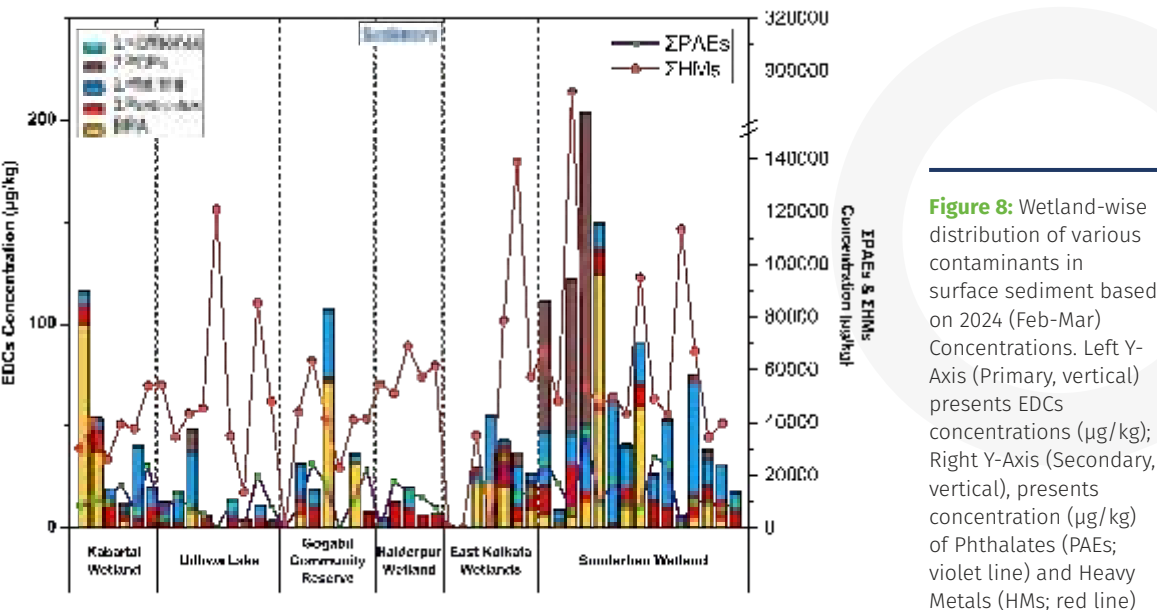


Figure 8: Wetland-wise distribution of various contaminants in surface sediment based on 2024 (Feb-Mar) Concentrations. Left Y-Axis (Primary, vertical) presents EDCs concentrations ($\mu\text{g/kg}$); Right Y-Axis (Secondary, vertical), presents concentration ($\mu\text{g/kg}$) of Phthalates (PAEs; violet line) and Heavy Metals (HMs; red line)

Gogabil Community Reserve

Gogabil Community Reserve exhibited the lowest EDC burden ($42710 \pm 14935 \mu\text{g/kg}$). Most contaminants were near detection limits, with sporadic elevations in ?HMs (up to $69068 \mu\text{g/kg}$). However, minor disturbances-such as livestock intrusion or agricultural runoff-may trigger the remobilization of these bound pollutants, particularly within finer sediment fractions, as

reflected by elevated concentrations in the corresponding water samples, calves to elevated early-life risks. This persistence, despite regulatory bans and improved water conditions, highlights shortcomings in legacy pollutant management and sediment remediation. The continued detection of PCBs and OCPs calls for stricter enforcement of sediment quality standards and proactive measures to safeguard ecologically sensitive stretches of these Wetlands.

BIOACCUMULATION PROFILES OF EDCs AND HEAVY METALS IN FISH BIOTA FROM PRIORITY WETLANDS OF THE GRB

This section presents a comparative analysis of EDCs accumulation in fish species sampled from six priority wetlands of the Ganga River Basin (Figures 9-12; Table 7).

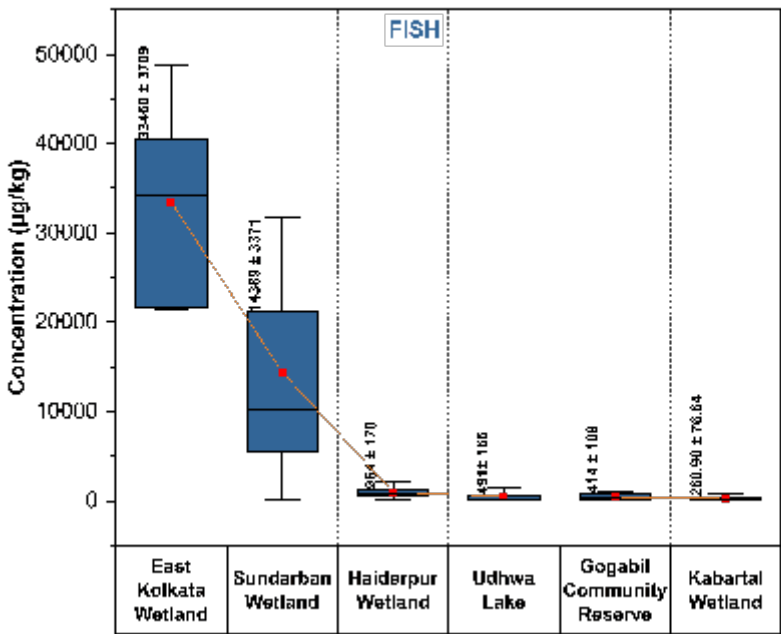


Figure 9: Bioaccumulation Patterns of Endocrine Disrupting Chemicals in fish species from priority wetlands of the GRB (2024)

East Kolkata Wetland- Narayanpur Khaal



Table 7: Bioaccumulation Profile of EDCs (µg/kg) in fish species from priority wetlands of the GRB (2024)

Category	Kabartal Wetland	Udhwa Wetland	Gogabil Wetland	Haiderpur Wetland	East Kolkata Wetland	Sundarban Wetland
ΣPAEs	BDL - 251.33	BDL - 97.73	28.09 - 306.03	66.89 - 2181.31	7.81 - 3126.06	4.93 - 784.58
BPA	BDL	BDL - 0.95	BDL	BDL - 0.34	BDL	BDL - 0.02
ΣPesticides	8.11 - 17.98	BDL - 67.64	2.13 - 14.25	9.44 - 28.71	1.59 - 13.66	0.35 - 15.03
ΣPharma	BDL - 47.11	BDL - 118.40	BDL - 43.67	0.06 - 8.70	0.38 - 68.90	BDL - 47.01
ΣPCPs	BDL - 0.15	BDL - 0.25	BDL - 6.70	0.12 - 0.42	BDL - 0.10	BDL - 0.19
ΣHormones	BDL - 0.19	BDL - 0.91	BDL	BDL - 0.06	BDL - 0.18	BDL - 0.13
ΣPCBs	BDL - 3.89	BDL - 1.94	BDL - 1.95	0.06 - 6.55	BDL - 8.90	BDL - 3.16
ΣHMs	BDL - 592.69	BDL - 2016.18	0.13 - 888.13	BDL - 69.81	21197- 48781	35.69 - 62872
ΣEDCs Mean±SE	260.90 ± 76.64	491 ± 166	414.35 ± 108.81	964.67 ± 170.27	33460 ± 3709	14389 ± 3371

*BDL=Below Instrument Detection Limits; Σ= Summation; PCPs= Personal Care Products; PCBs= Polychlorinated Biphenyls; BPA: Bisphenol A; PAEs: Phthalates; HMs: Heavy Metals; Pharma: Pharmaceuticals; Mean EDCs represents Mean±Std Error

The results reveal that EDC contamination is widespread across all studied wetlands, with East Kolkata Wetland (33460 ± 3709 µg/kg) and Sundarban Wetland (14389 ± 3371 µg/kg) exhibiting the highest total EDC loads in biota. Heavy metals (ΣHMs) and phthalates (PAEs) consistently emerged as the dominant contaminant groups across all sites, while BPA was largely undetected. Notably, even Ramsar and conservation-designated wetlands exhibited substantial EDC burdens, underscoring the transboundary and diffuse nature of pollutant influx into these ecosystems.

Wetland-specific profiles highlight distinct contaminant signatures. Urban and peri-urban wetlands, such as East Kolkata, and Haiderpur, appear heavily influenced by untreated domestic sewage, industrial effluents, and solid waste, whereas wetlands like Kabartal Gogabil, and Udhwa wetlands exhibit notable pharmaceutical, personal care products and pesticide contamination, likely stemming from diffuse rural agricultural runoff and domestic wastewater sources.

These rural catchments, though often overlooked in routine monitoring frameworks, contribute substantially to emerging contaminant loads, underscoring the need for expanded surveillance and source tracking in non-urban landscapes. Although not urban, the Sundarban Wetland reflects contamination from transboundary riverine inputs, estuarine industrial activities, and local anthropogenic pressures. The concurrent enrichment in abiotic and biotic compartments underscores the potential for trophic transfer and chronic ecological stress, particularly in long-resident and higher trophic aquatic species.



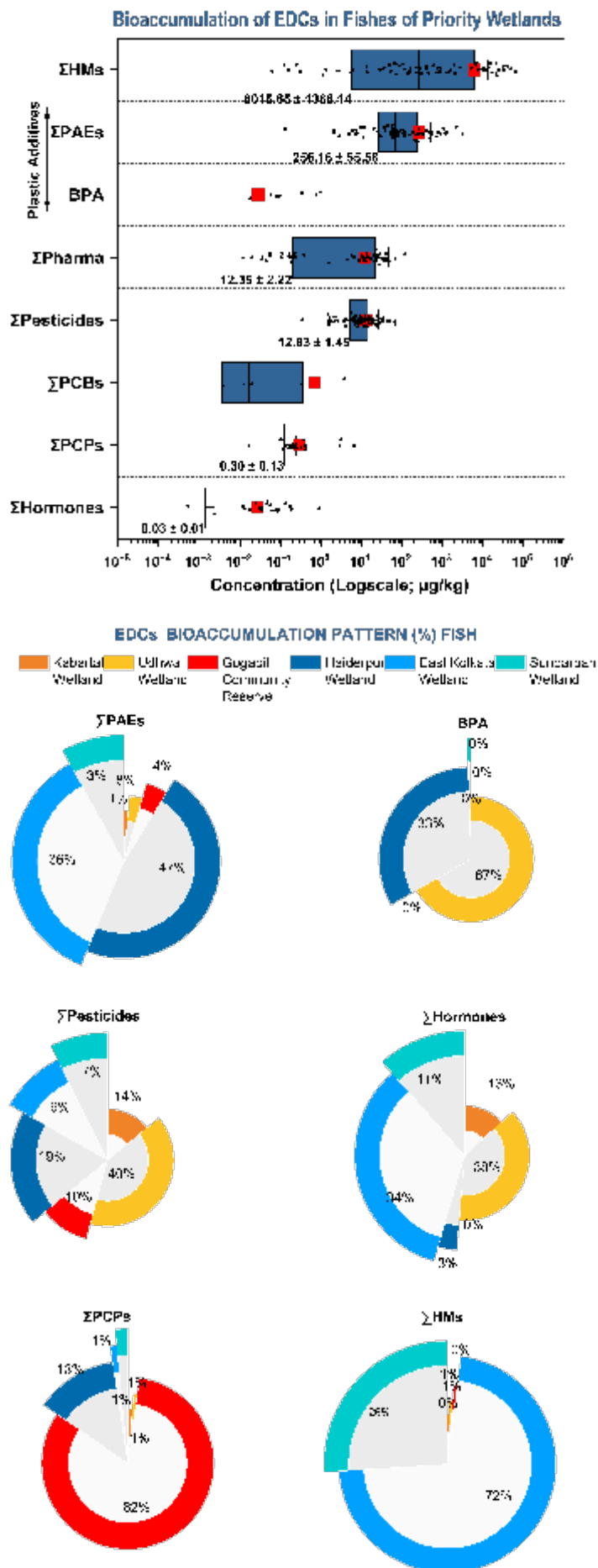
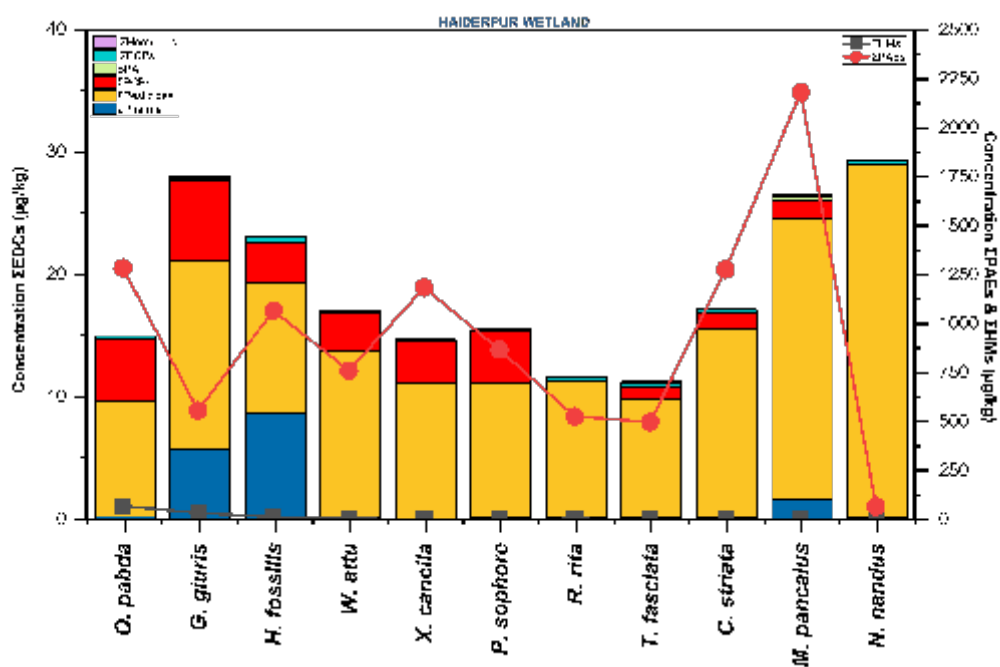
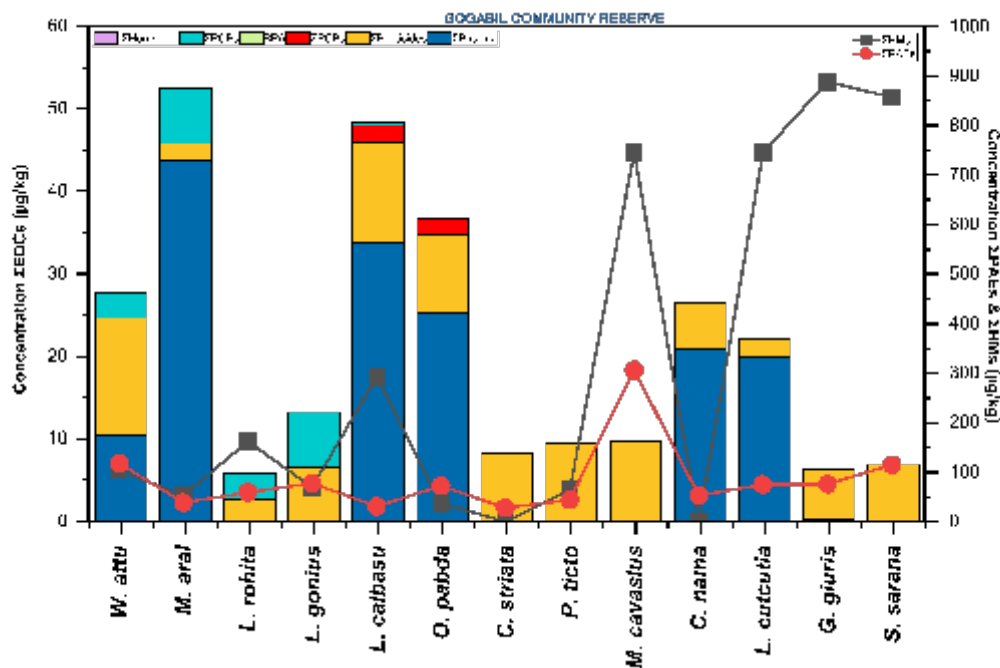


Figure 10: Endocrine-Disrupting Chemicals (EDCs) bioaccumulation profile in fishes of the priority wetlands of GRB based on 2024 (Feb-Mar). EDCs levels (µg/kg; log scale) with Mean ± SE (labels); black dots show concentration; red squares indicate mean. Pie diagram represents EDCs distribution (%) in fishes across six priority wetlands of GRB

The presence of multiple EDC classes further increases the risk of synergistic and sub-lethal effects on aquatic biota, including endocrine disruption, reproductive impairment, and developmental anomalies.

The elevated levels of EDCs in edible fish tissue across all sites also raise serious concerns to human exposure through dietary intake. The findings suggest that current wastewater treatment infrastructure is insufficient to mitigate EDC pollution, particularly for unregulated sources such as pharmaceuticals, plastics additives, and persistent organic pollutants.

In Kabartal Wetland, the total EDC concentration was recorded at $260.90 \pm 76.64 \mu\text{g/kg}$. The contamination was primarily driven by heavy metals ($213.05 \pm 64.50 \mu\text{g/kg}$), phthalates ($27.26 \pm 22.52 \mu\text{g/kg}$). Pesticides and pharmaceutical residues up to $17.98 \mu\text{g/kg}$ and $4711 \mu\text{g/kg}$ respectively. Other EDC categories such as BPA, PCPs, hormones, and PCBs were mostly below detection limits.



STATUS OF SELECT WETLANDS IN THE GANGA RIVER BASIN

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STATUS OF SELECT WETLANDS IN THE GANGA RIVER BASIN POLLUTION THREATS AND HOTSPOT ASSESSMENT

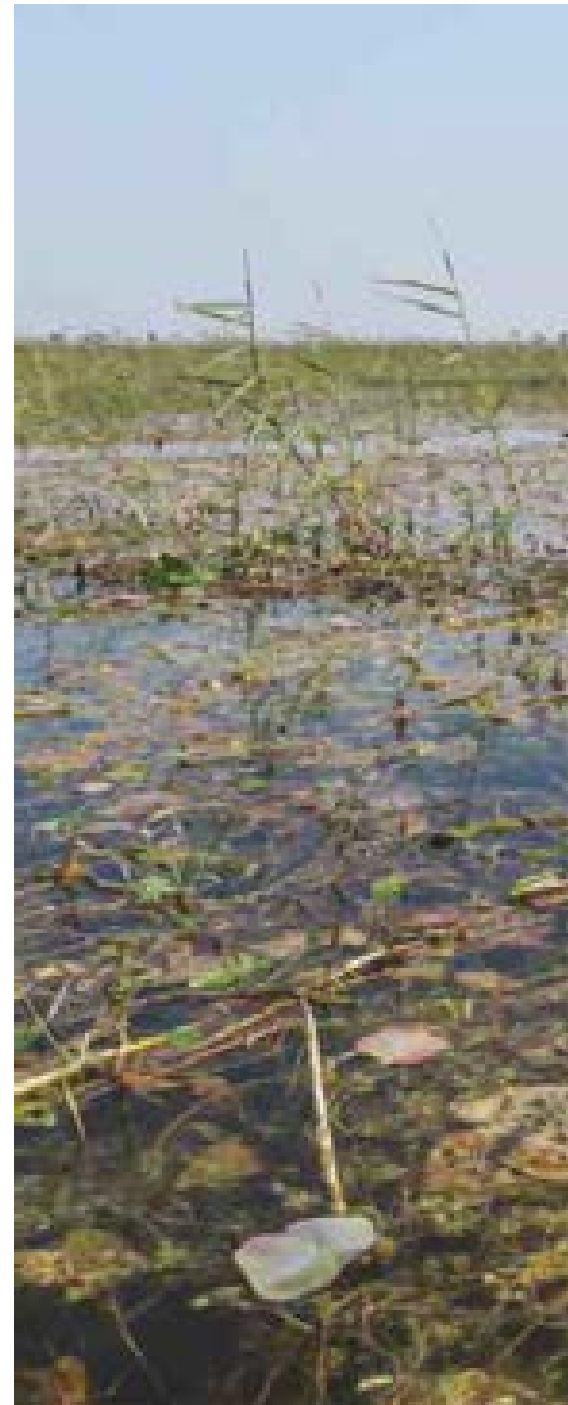
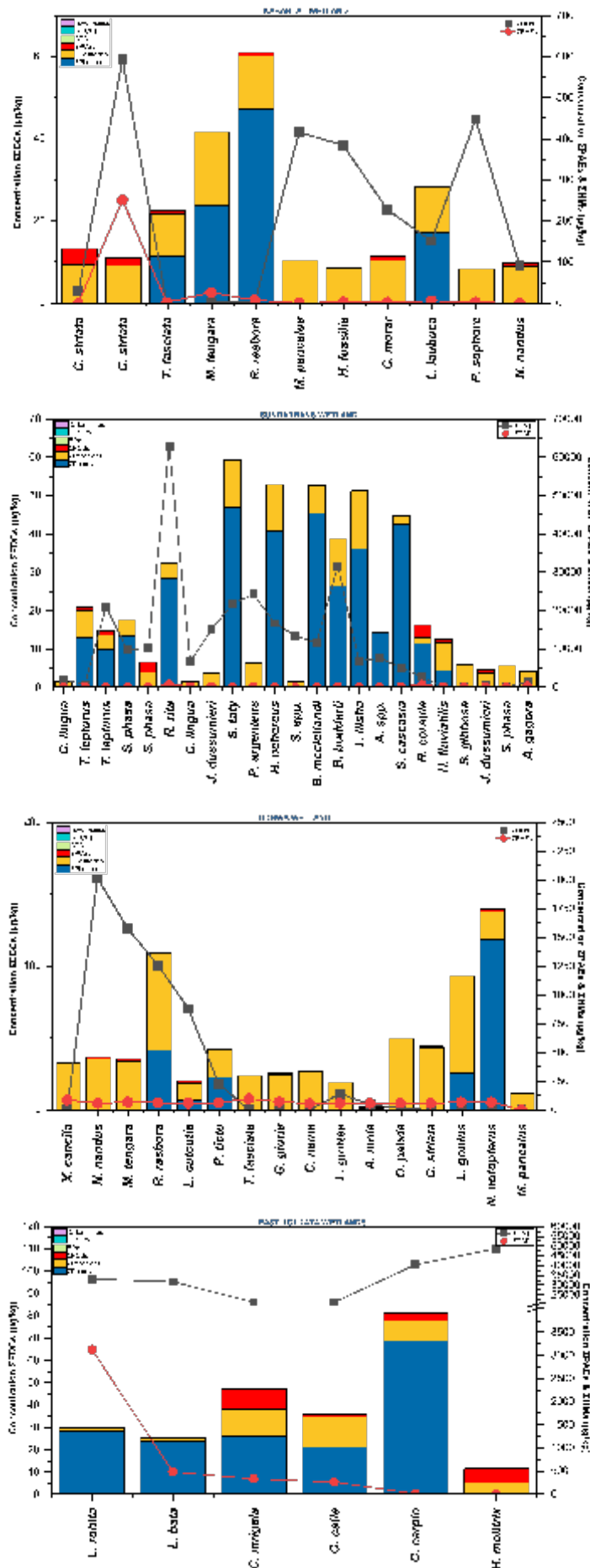


Figure 11: Species-wise Bioaccumulation Patterns of Endocrine Disrupting Chemicals and Heavy Metals in fish species across six priority wetlands of GRB



Udhwa Lake showed a higher total EDC burden of $491 \pm 166 \mu\text{g/kg}$, dominated by heavy metals with levels up to $2016.18 \mu\text{g/kg}$. Plastic additives (PAEs; $61.56 \pm 4.99 \mu\text{g/kg}$) and pesticides ($30.30 \pm 4.76 \mu\text{g/kg}$) were also detected in considerable amount. Moderate levels of Pharmaceuticals and PCPs indicate mixed influence from household wastewater and agricultural inputs. BPA was below detection limits.

In Gogabil Community Reserve, the total EDC concentration reached $414.35 \pm 108.81 \mu\text{g/kg}$. Significant contributions came from phthalates, which ranged up to $306.03 \mu\text{g/kg}$, and heavy metals, which peaked at $888.13 \mu\text{g/kg}$. BPA and hormones were below detection limits, while pesticides and pharmaceuticals appeared at low to moderate levels.

Haiderpur Wetland exhibited a comparatively higher contamination profile, with total EDC levels reaching $964.67 \pm 170.27 \mu\text{g/kg}$. This was largely due to elevated phthalates (up to $2181.31 \mu\text{g/kg}$), in addition to significant pesticide and heavy metal accumulation. While BPA and hormones were present in relatively low concentrations, nearly all categories of EDCs were detected. The findings suggest that Haiderpur receives inputs from multiple sources, including industrial discharge, untreated municipal waste, and agricultural effluents.

East Kolkata Wetland (EKW) recorded the highest EDC bioaccumulation among all wetlands studied, with a total EDC concentration of $33460 \pm 3709 \mu\text{g/kg}$. The extremely high levels of heavy metals, which ranged up to $48781 \mu\text{g/kg}$, and phthalates, which reached $3126.06 \mu\text{g/kg}$, suggest intense contamination. Other EDC groups, with the exception of BPA, were also detected. Despite being

a Ramsar site, EKW appears to be under severe ecological stress, likely due to the inflow of untreated sewage, solid waste, and industrial effluents from urban Kolkata.

The Sundarban Wetland exhibited a total EDC concentration of $14389 \pm 3371 \mu\text{g/kg}$, with heavy metals reaching an alarming peak of $62872 \mu\text{g/kg}$. Phthalates ($157.58 \pm 44.04 \mu\text{g/kg}$) and pharmaceuticals ($14.49 \pm 3.59 \mu\text{g/kg}$) and were also present in substantial concentrations. BPA was detected, but only in trace amounts. Despite its global ecological significance and protected status, the contamination profile suggests inputs from upstream riverine flows, marine-industrial activities, and localized anthropogenic pressure within the deltaic zone.

These contamination patterns have significant ecological and human health implications. The elevated EDC levels, particularly phthalates and PCBs, pose serious concerns for endocrine disruption in both aquatic organisms and human consumers, potentially affecting reproductive health, developmental processes, and immune function. The high heavy metal concentrations, particularly in the East Kolkata Wetlands and Sundarbans, indicate severe anthropogenic pollution from industrial effluents, urban runoff, agricultural run-offs inputs and wastewater discharge. The bioaccumulation of these persistent contaminants in fish tissue represents a direct pathway for biomagnification through the food web, with apex predators and human consumers facing the greatest exposure risks. The data suggests urgent need for enhanced pollution control measures and remediation strategies, to mitigate the ongoing contamination of this critical freshwater ecosystem and protect public health.



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POLLUTION HOTSPOT ASSESSMENT

East Kolkata Wetland- Tolly Nallah

Table 8: Ecological Risk, Management Priorities, and Pollution Threat Drivers in Select Wetlands of the Ganga Basin

Wetland	State (District)	Ecological Risk (%)	Risk Category	Biodiversity Status
East Kolkata Wetlands	West Bengal (Kolkata)	86	Critically High	Moderate- High (Ramsar)
Gogabil Community Reserve	Bihar (Katihar)	71	High (Community Reserve)	High
Kabartal Wetland	Bihar (Begusarai)	67	High	High (Ramsar)
Sundarban Wetland	West Bengal (South 24 Parganas)	67	High	Very High (Ramsar)
Haiderpur Wetland	Uttar Pradesh (Bijnor and Muzaffarnagar)	60	Moderate High	High (Ramsar)
Udhwa Lake	Jharkhand (Sahebganj)	56	Moderate High	High (Ramsar)



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The ecological risks posed by water quality parameters and chemical pollutants in the priority wetlands of GRB were systematically evaluated using a deterministic risk quotient (RQ) approach. This methodology provides a quantitative framework for assessing the potential adverse effects of pollutants on aquatic ecosystems. Pollution hotspots, identified through this risk-based assessment, highlight an alarming distribution of ecological risk levels in six priority wetlands, wherein multiple pollutants were found to exceed safe thresholds across wetlands. Briefly, the risk assessment categorized pollution levels into three distinct risk classifications: insignificant risk ($RQ < 0.1$), moderate risk ($0.1 \leq RQ < 1$) and, high risk ($RQ \geq 1$). Ecological risk assessment reveals that 67% of the six evaluated wetlands are in poor ecological condition. Key stressors include compromised water quality (e.g., low dissolved oxygen, elevated salinity, and nitrate levels), heavy metal contamination (notably lead and cobalt), plastic additives (such as phthalates and BPA), pesticides (including chlorpyrifos and DDT metabolites), and personal care products like triclocarban. These findings indicate that the wetlands are acting as sinks for chemical pollutants originating from industrial, urban, peri-urban, and rural sources.

Table 8 provides the wetland-wise identification of pollution hotspots across six priority wetlands of GRB. This assessment offers a spatially resolved basis for prioritizing regulatory actions. Additionally, the contributions of all the areas of concern (AOCs) noted during the survey activities are presented under "Key Threat Drivers" in Table 8. Key priority chemicals have been identified for immediate regulatory attention and consistent monitoring, as summarized in Table 9.

Ecosystem Services	Management Priority	Key Threat Drivers (Pollution related)
Very High	Emergency Restoration	Land conversion for development, aquaculture ponds replacing natural wetlands. Industrial effluent, agriculture run-offs, municipal waste management crisis, solid waste dumping linked to high urban and peri-urban pressures
High	Urgent Intervention	Agricultural Encroachment: conversion to farmland, fertilizer runoff, pesticide contamination. Water depletion: reduced water inflow, groundwater extraction, drying trends. Overfishing Minimal administrative oversight: Poor enforcement, inadequate conservation funding, EDCs spiked diffuse domestic greywater in a rural catchment.
Very High	Major Restoration	Severe Encroachment: Illegal settlements, agricultural expansion into wetland areas, diffuse agricultural runoff. Water Scarcity: Major sections drying up, reduced monsoon reliability Pharmaceutical and Personal Care Emerging Rural Pollutants: Minimal administrative oversight: Poor enforcement, inadequate conservation funding, EDCs spiked diffuse domestic greywater in a rural catchment.
Critical	Major Restoration	Accelerated salinity intrusion from sea-level rise. Heavy metal pollution from oil spill contamination, nearby shipbreaking and metallurgical industries, untreated waste discharge, navigation activities. Expanding human settlements lacking adequate waste treatment infrastructure. Multi-source inputs from upstream industrial discharge, agricultural runoff, and untreated domestic sewage entering through a dynamic river network (Hooghly, Bidyadhari, Matla, Dutta, Ichamati rivers etc.).
Very High	Targeted Restoration	Untreated Sewage Discharge, Domestic sewage contamination from peri-urban areas, Industrial Effluent Load (Ganga), Heavy infrastructural pressure, solid waste discharge, Soil erosion from catchment area reducing waterdepth
Very High	Protection + Enhancement	Pesticides, pharmaceutical residues, and domestic greywater from rural households contribute to emerging contaminant loads in the absence of treatment infrastructure or monitoring systems.



Table 9: List of High-Priority Chemicals with their Sources and Environmental Impacts

Contaminant	Contaminant category	Potential Sources	Impact on Biodiversity*
DEP (Diethyl phthalate)	Chemical/ Plastic Additives	Plastics, personal care products, industrial effluents	Endocrine disruption, reproductive toxicity in aquatic fauna, Bioaccumulation, gonadal deformities in fish, feminization of male fish, Embryotoxicity, developmental abnormalities in aquatic mammals
DEHP (Di(2-ethylhexyl) phthalate)		PVC plastics, medical tubing, leachates from waste	
DnBP (Dibutyl phthalate)		Adhesives, synthetic fragrances, soft plastics	
BPA (Bisphenol A)	Pesticides	Polycarbonate plastics, epoxy resins, thermal paper leachate	Neurotoxicity in invertebrates and fish, mortality in amphibians, Acetylcholinesterase inhibition, behavioral and developmental defects in fish, Bioaccumulation, eggshell thinning in birds, reproductive failure, Long-term reproductive toxicity, endocrine disruption in aquatic mammals
Malathion		Agricultural runoff, pesticide use in mosquito control	
Chlorpyrifos		Agricultural insecticide runoff, termite control agents	
DDT (Dichlorodiphenyltrichloroethane)		Banned pesticide, legacy pollutant in sediments	
DDE (Dichlorodiphenyldichloroethylene)	Natural Hormones	DDT metabolite, persistent in sediments	Endocrine disruption, intersex condition in fish, skewed sex ratios
E1 (Estrone) E3 (Estrone)		Human excreta: Sewage effluent, hormonal contraceptive residues	
Triclocarban	Personal Care Products-PCPs (Anti-microbials)	Antimicrobial soaps, personal care products, Toothpastes, detergents, antibacterial products	Disruption of thyroid function and reproductive systems in aquatic vertebrates, inhibits algal photosynthesis, alters microbial communities, endocrine effects in fish
Triclosan			
Pb (Lead)	Heavy Metals (HMs)	Automotive/Vehicular emissions, metal-based additives in plastics, Industrial discharge, urban runoff, batteries	Neurotoxicity, growth inhibition, impaired predator avoidance in aquatic organisms
Zn (Zinc)		Galvanization, mining, runoff from urban and industrial sources, Agriculture	Essential trace element, but toxic at high levels-affects gill function and enzyme activity
Cd (Cadmium)		Batteries, pigments, metal-based additives in plastics, Agriculture, electroplating industry waste	Kidney and liver damage in fish, bioaccumulation, skeletal deformities

Contaminant	Contaminant category	Potential Sources	Impact on Biodiversity*
Co (Cobalt)		Mining, metal industries, pigments, metal-based additives in plastics	Toxic at elevated levels, induces oxidative stress and enzyme inhibition in aquatic life
Cr (Chromium)		Tannery waste, electroplating, textile industry	Carcinogenic (Cr VI), gill damage, immunotoxicity, reduced survival in fish and invertebrates

*Reijnders, 1986; Tetreault et al., 2011; Guo et al., 2022; Liu et al., 2022; Wu et al., 2022

East Kolkata Wetland

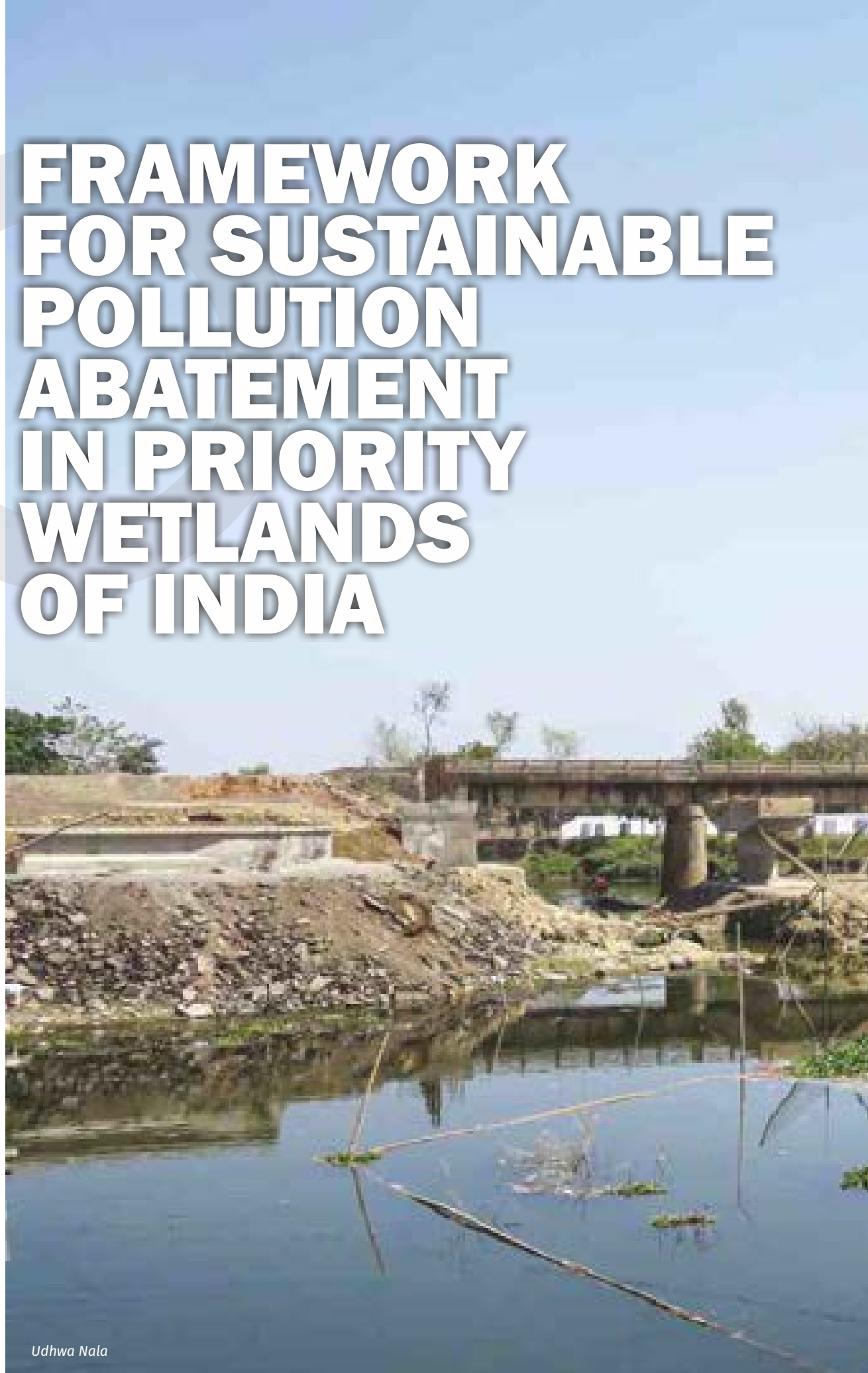


FRAMEWORK FOR SUSTAINABLE POLLUTION ABATEMENT IN PRIORITY WETLANDS OF INDIA



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Udhwa Nala

Drawing on lean-season sampling data, management priorities have been strategically categorized using evidence-based intervention frameworks. These frameworks facilitate targeted resource allocation based on the severity of ecosystem stress. The management framework, presented in Table 10, outlines an integrated and sustainable approach to achieving and maintaining a healthy ecological status of wetlands across India. It defines strategic objectives for pollution control, ecological restoration, and long-term conservation of wetlands. The framework incorporates specific, actionable measures designed to support effective wetland management, enhance ecosystem resilience, and ensure the sustained delivery of ecosystem services. However, it is recognized that assessments based on a single season may capture peak stress conditions, underscoring the need for validation through multi-seasonal monitoring.



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Table 10: Framework for Sustainable Pollution Abatement in Priority Wetlands of India

OBJECTIVE 1: ESTABLISH COMPREHENSIVE WETLAND POLLUTION MONITORING AND EARLY WARNING SYSTEMS

Strategies/Actions	Objectively Verifiable Indicators (OVI)	Means of Verification (MOV)
1.1 Deploy real-time water quality monitoring networks across all priority wetlands	- Number of automated monitoring stations installed (Target: 30 stations across 6 wetlands) - Percentage of wetland area covered by monitoring network (Target: 85%) - Frequency of data collection (Target: Hourly for critical parameters)	- Installation certificates and GPS coordinates - Monthly monitoring reports - Real-time data dashboard analytics - Third-party validation reports
1.2 Implement regular monitoring of priority pollutants (e.g., heavy metals, pesticides, persistent organic pollutants, plastics additives, nutrients, pharmaceuticals, EDCs) across ecologically and socially important wetlands.	- Number of wetlands with active pollutant monitoring systems (Target: ≥ 100) - Frequency of contaminant monitoring (Target: quarterly) - Number of priority contaminants tracked per wetland (Target: 10–15) - Number of risk alerts issued through early warning systems	- Wetland water quality monitoring reports - Analytical lab results with traceable QA/QC protocols - GIS-linked pollutant data dashboards - Records of advisories/alerts shared with authorities and communities
1.3 Establish integrated pollution source tracking and mapping system	- Number of pollution sources identified and geo-referenced (Target: 100% within 2 km radius) - Percentage of industrial discharge points monitored (Target: 90%) - Accuracy of pollution load estimation (Target: $\pm 15\%$)	- GIS-based pollution source database - Satellite imagery analysis reports - Industrial compliance audit reports - Community-based monitoring logs
1.4 Develop wetland-specific water quality standards and pollution thresholds	- Number of wetland-specific standards developed (Target: 6 comprehensive standards) - Percentage reduction in exceedance events (Target: 40% in 3 years) Early warning system response time (Target: <4 hours)	- Approved water quality standards documents - Exceedance monitoring reports - Early warning system logs Stakeholder consultation records



Assumptions	Agencies Responsible	Supporting Organizations
- Continuous power supply and internet connectivity available - Local communities support monitoring infrastructure - Technical expertise available for maintenance	Primary: Central Pollution Control Board (CPCB) Secondary: State Pollution Control Boards (SPCBs); Tate Wetland Authority Tertiary: National Remote Sensing Centre (NRSC)	- Indian Space Research Organisation (ISRO) - Wetlands International-South Asia - Wildlife Institute of India - Local universities and research institutions
- Adequate laboratory and field monitoring capacity - Priority contaminant lists are standardized nationally - Timely data flow and institutional action based on alerts	Primary: Central Pollution Control Board (CPCB) Secondary: State Pollution Control Boards (SPCBs), Wetland Authorities Tertiary: District Environmental Monitoring Cells	- National Environmental Engineering Research Institute (NEERI) - Wildlife Institute of India (WII) - MoEFCC - R&D centers - Academic institutions and analytical labs - Citizen science networks for participatory data collection
- Industries cooperate with disclosure requirements - Satellite data accessibility maintained - Community volunteers trained effectively	Primary: Ministry of Jal Shakti Secondary: State Pollution Control Boards (SPCBs) Tertiary: District Collectors; District Forest Officials	- Local universities and research institutions - Local NGOs and community groups
- Scientific consensus on appropriate standards achieved - Regulatory framework supports enforcement - Stakeholders accept new standards	Primary: Ministry of Jal Shakti Secondary: Central Pollution Control Board (CPCB), Central Water Commission (CWC) Tertiary: Bureau of Indian Standards (BIS)	- Indian Institute of Technology network - Wildlife Institute of India - National Environmental Engineering Research Institute - State IITs or other research/academic institutes



STATUS OF SELECT WETLANDS IN THE GANGA RIVER BASIN

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OBJECTIVE 2: IMPLEMENT SOURCE CONTROL AND POLLUTION PREVENTION MEASURES

Strategies/Actions	Objectively Verifiable Indicators (OVI)	Means of Verification (MOV)
2.1 Establish zero liquid discharge zones around priority wetlands	- Number of industries achieving zero liquid discharge (Target: 80% within 5km radius) - Percentage reduction in industrial effluent discharge (Target: 90%) - Number of common effluent treatment plants operational (Target: >90 % plants)	- Industry compliance certificates - Effluent discharge monitoring reports - CETP operational status reports - Water recycling efficiency audits
2.2 Implement comprehensive municipal sewage treatment infrastructure	- Percentage of municipal sewage treated before discharge (Target: 95%) - Number of sewage treatment plants upgraded/constructed (Target: 24 plants) - Sewage treatment capacity vs. generation ratio (Target: 1.2:1)	- Sewage treatment plant commissioning certificates - Monthly treatment efficiency reports - Municipal sewage audit reports - Performance monitoring by third parties
2.3 Control agricultural runoff and promote sustainable farming practices	- Percentage of agricultural area under integrated nutrient management (Target: 60%) - Reduction in fertilizer and pesticide runoff (Target: 50%) - Number of farmers trained in sustainable practices (Target: 15,000)	- Soil health card data analysis - Fertilizer sales and usage reports - Water quality improvement in agricultural zones - Farmer training completion certificates

OBJECTIVE 3: RESTORE AND ENHANCE WETLAND ECOSYSTEM FUNCTIONS

3.1 Implement nature-based solutions for pollution remediation	- Area of constructed wetlands established - Percentage improvement in water quality through phytoremediation (Target: at least 40%) - Number of native species reintroduced (Target: 30-60 species)	- Constructed wetland design and performance reports - Water quality monitoring data - Biodiversity assessment reports - Vegetation establishment success rates
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Assumptions	Agencies Responsible	Supporting Organizations
- Industries invest in cleaner technologies - Financial incentives attract private investment - Technical support available for Small and Medium-sized Enterprises (SMEs)	Primary: Central Pollution Control Board (CPCB) Secondary: State Pollution Control Boards, Ministry of Jal Shakti, Ministry of Environment, Forest and Climate Change Tertiary: Industrial associations	- Confederation of Indian Industry - Federation of Indian Chambers of Commerce - Technology providers and consultants - Development finance institutions
- Municipal bodies commit adequate budget - Land acquisition procedures completed - O&M expertise available locally	Primary: Ministry of Housing and Urban Affairs Secondary: State Urban Development Departments Tertiary: Urban Local Bodies	- National Mission for Clean Ganga - Japan International Cooperation Agency - World Bank and ADB - Public-private partnership operators
- Farmers adopt recommended practices - Alternative income sources available - Extension services effectively reach farmers	Primary: Department of Agriculture and Cooperation Secondary: Krishi Vigyan Kendras Tertiary: State Agriculture Departments	- Indian Council of Agricultural Research - NGOs working in sustainable agriculture - Farmer Producer Organizations - International Fund for Agricultural Development
- Native plant species available for restoration - Local communities support restoration activities - Hydrological conditions suitable for NBS	Primary: Ministry of Environment, Forest and Climate Change Secondary: State Forest Departments Tertiary: Wetland management authorities	- Bombay Natural History Society - Botanical Survey of India - Wildlife Institute of India - Forest Research Institute - Foundation for Ecological Research, Advocacy and Learning - International Union for Conservation of Nature - Local community groups



OBJECTIVE 3: RESTORE AND ENHANCE WETLAND ECOSYSTEM FUNCTIONS

Strategies/Actions	Objectively Verifiable Indicators (OVI)	Means of Verification (MOV)
3.2 Restore degraded wetland habitats and connectivity	- Area of wetland habitat restored - Number of ecological corridors established - Improvement in habitat quality index (Target: 30% increase)	- Habitat restoration completion certificates - Ecological corridor mapping reports - Biodiversity monitoring assessments - Remote sensing change detection analysis
3.3 Enhance wetland buffer zones and protective measures	- Area of buffer zones established. Minimum 50-100 meters from wetland edge depending on wetland type - Official land-use maps updated to reflect protected status - Percentage reduction in encroachment incidents (Target: Current baseline vs. target 60%-80%) - Number of community-based protection groups formed (Target: 10-20 groups)	- Buffer zone demarcation surveys - Encroachment monitoring reports Monthly field verification reports with photographic evidence - Community group registration documents - Legal protection status updates - Compliance audit reports: Annual third-party assessments

OBJECTIVE 4: STRENGTHEN GOVERNANCE AND INSTITUTIONAL FRAMEWORKS

4.1 Establish dedicated wetland management authorities for each priority site	- Number of wetland management authorities established Percentage of management plans implemented (Target: 90%) - Stakeholder participation in governance (Target: 80% attendance)	- Authority establishment notifications - Management plan approval documents - Stakeholder meeting minutes and attendance - Annual performance evaluation reports
4.2 Develop integrated enforcement and compliance mechanisms	- Number of successful prosecutions for pollution violations (Target: 200% increase) - Average time for violation response (Target: <48 hours) - Compliance rate among identified polluters (Target: 85%)	- Court case records and judgments - Violation response time logs - Compliance audit reports Penalty collection records

Assumptions	Agencies Responsible	Supporting Organizations
- Land acquisition and community consent obtained - Restoration techniques proven effective - Long-term maintenance funding secured	Primary: National Wetland Management Authority Secondary: State Biodiversity Boards and Wetland management authorities Tertiary: Forest Survey of India	- Wildlife Conservation Society India - Ramsar Convention Secretariat - United Nations Environment Programme - Academic research institutions
- Legal framework supports buffer zone creation - Communities understand buffer zone benefits - Alternative livelihoods available for affected people	Primary: Revenue Departments of States Secondary: District Magistrates Tertiary: Village Panchayats Additional Coordinating Bodies Forest Department: Technical expertise and enforcement support Urban Development Authorities: Land-use planning coordination	- Centre for Science and Environment or national-level NGOs offering advocacy, technical support, and training - Local environmental NGOs - Community-based organizations
- Political will exists for institutional creation - Adequate funding allocated for operations - Qualified personnel available for recruitment	Primary: Chief Ministers of respective states Secondary: Principal Secretaries (Environment) Tertiary: Secretary, Ministry of Environment	- East Kolkata Wetlands Management Authority, other state wetland management authority - Administrative Staff College of India - Indian Institute of Public Administration - International wetland management experts
- Judicial system supports environmental cases - Evidence collection protocols standardized - Penalties serve as effective deterrent	Primary: National Green Tribunal Secondary: State Legal Services Authorities Tertiary: Environmental lawyers' network	- Centre for Environmental Law - Lawyers Environmental Action Team - Indian Environmental Society - International environmental law experts



STATUS OF SELECT WETLANDS IN THE GANGA RIVER BASIN

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OBJECTIVE 4: STRENGTHEN GOVERNANCE AND INSTITUTIONAL FRAMEWORKS

Strategies/Actions	Objectively Verifiable Indicators (OVI)	Means of Verification (MOV)
4.3 Implement participatory monitoring and community engagement programs	- Number of trained community monitors (Target: 300 monitors) - Percentage of violations reported by communities (Target: 60%) - Community satisfaction with engagement process (Target: 80%)	- Community monitor training certificates - Violation reporting database - Community feedback surveys - Participatory monitoring impact assessments

OBJECTIVE 5: DEVELOP SUSTAINABLE FINANCING AND ECONOMIC INSTRUMENTS

5.1 Establish wetland conservation trust funds and payment for ecosystem services (PES)	- Total fund corpus established Number of ecosystem service payment schemes operational (Target: 4 schemes) - Annual revenue generated from ecosystem services (Target: ₹10-₹50 crores; based on wetlands)	- Trust fund establishment documents - PES scheme operational guidelines - Annual financial statements - Ecosystem service valuation reports - Beneficiary registration database - Third-party audits
5.2 Implement polluter pays principle through environmental taxation	- Revenue generated from pollution taxes - Number of polluting industries under tax regime (Target: 100% coverage) - Percentage of tax revenue allocated to wetland restoration (Target: 80%)	- Tax collection records - Industry registration under tax regime - Fund allocation and utilization reports - Environmental improvement correlation analysis - Compliance audit reports
5.3 Promote green bonds and impact investment for wetland conservation	- Total green bond issuance for wetland projects (Target: ₹1,000 crores) - Number of impact investors engaged - Cumulative hectares of wetlands restored/conserved through bond proceeds	- Green bond prospectus and listing documents - Impact investor commitment letters - Project financial performance reports - Third-party impact verification reports

Assumptions	Agencies Responsible	Supporting Organizations
- Communities willing to participate in monitoring - Traditional knowledge respected and integrated - Capacity building programs effective	Primary: State Rural Development Departments Secondary: Panchayati Raj Institutions Tertiary: Self-Help Group federations	- Toxics Link - Development Alternatives - Centre for Community Economics and Development Consultants Society - Local community-based organizations
- Government approves innovative financing mechanisms - Private sector participates in ecosystem payments - Ecosystem services can be accurately valued - Local communities support conservation efforts	Primary: Ministry of Finance Secondary: Planning Commission/NITI Aayog Tertiary: Reserve Bank of India, State Forest Departments	- The Energy and Resources Institute - Observer Research Foundation - International Finance Corporation - Climate finance institutions - World Bank
- Tax rates set at economically viable levels - Tax collection mechanisms effective - Industries do not relocate to avoid taxes - Revenue collection systems are transparent - Political will supports implementation	Primary: Central Board of Direct Taxes Secondary: State Commercial Tax Departments Tertiary: Goods and Services Tax Council, Pollution Control Boards	- Confederation of Indian Industry - Associated Chambers of Commerce and Industry - Environmental economics research institutes - International tax policy experts
- Capital markets receptive to green bonds - Conservation projects generate measurable returns - Regulatory framework supports green financing - Project developers have technical expertise for successful implementation	Primary: Securities and Exchange Board of India Secondary: Development Finance Institutions (NABARD, SIDBI), Ministry of Environment, Forest and Climate Change Tertiary: Stock exchanges; State Wetland Authorities	- Climate Investment Funds - Green Climate Fund - International Finance Corporation - Domestic and foreign institutional investors



OBJECTIVE 5: DEVELOP SUSTAINABLE FINANCING AND ECONOMIC INSTRUMENTS

Strategies/Actions	Objectively Verifiable Indicators (OVI)	Means of Verification (MOV)
	- Return on investment for conservation projects CO₂ equivalent sequestered through funded projects - Species population recovery rates in funded wetlands	- Detailed fund utilization and allocation reports - Environmental Outcomes: Satellite imagery and ground-truth ecological assessments

OBJECTIVE 6: BUILD KNOWLEDGE SYSTEMS AND CAPACITY FOR LONG-TERM SUSTAINABILITY

6.1 Establish wetland research and monitoring centers of excellence	- Number of research centers established - Number of research publications per year (Target: 50 publications) - Number of trained professionals graduated (Target: 200 annually)	- Research center establishment orders - Publication database and citation analysis - Graduate placement and career tracking - Research impact assessment reports
6.2 Develop comprehensive database and knowledge management systems	- Completeness of wetland database (Target: 95% data coverage) - Number of stakeholders accessing knowledge platform (Target: 10,000 users) - Frequency of database updates (Target: Monthly updates)	- Database completeness audit reports - User analytics and access logs - Data quality validation reports - Stakeholder feedback on usability
6.3 Implement public awareness and education programs	- Number of people reached through awareness campaigns (Target: 1 million annually) - Percentage increase in wetland conservation knowledge (Target: 60%) - Number of schools with wetland education modules (Target: 500 schools)	- Campaign reach analytics and media coverage - Pre and post-campaign knowledge surveys - School curriculum integration certificates - Public opinion polling on wetland conservation

Assumptions	Agencies Responsible	Supporting Organizations
• Risk Management: Environmental and financial risks are manageable within acceptable parameters • Market Demand: Growing investor appetite for climate and nature-positive investments		
• Academic institutions commit to long-term programs • Research funding secured sustainably • Industry demand exists for trained professionals	Primary: Ministry of Education Secondary: University Grants Commission Tertiary: Indian Council of Social Science Research	• Wildlife Institute of India • Indian Institutes of Technology • National Institute of Advanced Studies • International wetland research institutions • Private sector research and development divisions
• Data standardization protocols agreed upon • Technology infrastructure reliable • Stakeholders willing to share data	Primary: National Informatics Centre Secondary: Indian Statistical Institute Tertiary: Centre for Development of Advanced Computing	• Biodiversity Information System for India • Global Biodiversity Information Facility • Technology companies specializing in environmental data • International data sharing networks
• Media partners support conservation messaging • Educational authorities approve curriculum changes • Public receptive to conservation messages	Primary: Ministry of Information and Broadcasting Secondary: Department of	



**OBJECTIVE 7: ESTABLISH WETLAND RESEARCH AND MONITORING CENTERS OF EXCELLENCE
WITH INTEGRATED CARBON MONITORING**

Strategies/Actions	Objectively Verifiable Indicators (OVI)	Means of Verification (MOV)
7.1 Establish regional Wetland Centers of Excellence (WCoEs) to serve as hubs for ecological research, carbon flux assessment, and policy-relevant data dissemination	- Number of functional Wetland Centers established (Target: 4–6) - - Number of research studies/publications per center per year (Target: 10+) Number of wetlands with long-term ecological and carbon monitoring (Target: 50 wetlands) - Availability of annual integrated carbon flux datasets - Human Resources: - Number of PhD-level researchers recruited - Technical staff and research assistants hired - International collaboration agreements signed	- Center establishment notifications - Staff recruitment and operational records - Research publication logs Open-access wetland and carbon monitoring datasets - Annual performance and review reports - Staff appointment letters, CV databases, training certificates
7.2 Integrate carbon sequestration monitoring into national wetland assessment frameworks to support climate mitigation goals and reporting.	- Number of wetlands with carbon flux monitoring initiated - Inclusion of wetland carbon data in National GHG Inventory - Number of technical protocols and toolkits developed (Target: 3–5) - Use of carbon data in climate-related policy documents	- Carbon monitoring protocols and instrumentation deployment records - Wetland carbon reports submitted to national GHG compilers - Policy briefs and knowledge products - Technical training workshop reports

Assumptions	Agencies Responsible	Supporting Organizations
- Adequate funding and infrastructure support - Skilled human resources available - Collaboration across scientific and government institutions - Long-term policy support and continuity	Primary: Ministry of Environment, Forest and Climate Change (MoEFCC) Secondary: Indian Space Research Organisation (ISRO), Department of Science & Technology (DST) Tertiary: State Environment and Wetland Authorities; State Universities and research institutes	- Wildlife Institute of India - National Remote Sensing Centre - TERI, ATREE, IISc, IITs, and Central Universities - UNEP, Ramsar Secretariat, Global Wetlands Programme - Carbon finance platforms and climate science networks
- National agencies recognize wetlands as carbon sinks - Coordination between wetland and climate change institutions - Availability of technical expertise in carbon flux assessment - Access to satellite and in-situ monitoring systems	Primary: National Biodiversity Authority and MoEFCC-Climate Change Division Secondary: Indian Institute of Remote Sensing (IIRS), Forest Survey of India (FSI) Tertiary: National Wetland Committee	- ICIMOD, FAO, and IUCN - Indian Institute of Science, NEERI, SACON - National Institute of Hydrology - International peatland and blue carbon networks



OBJECTIVE 9: DEVELOP SUSTAINABLE POLLUTION ABATEMENT WITH FOCUS ON PLASTIC MANAGEMENT

Strategies/Actions	Objectively Verifiable Indicators (OVI)	Means of Verification (MOV)
9.1 Implement wetland-specific plastic waste management plans, including upstream interventions, segregation, and community-based collection systems.	- Number of wetland-specific plastic waste action plans implemented (Target: 50 wetlands) - Volume of plastic waste removed or diverted annually - Number of community clean-up drives organized - Share of waste collected that is recycled or reused (Target: 70%)	- Action plan documents Annual plastic audit reports - Clean-up campaign records Waste segregation and recycling partner reports - Geo-tagged documentation of clean-up outcomes
9.2 Strengthen enforcement and innovation in reducing plastic leakage into wetland catchments, including Extended Producer Responsibility (EPR) and eco-alternatives.	- Number of EPR agreements implemented at wetland/ city level - Number of wetlands monitored for plastic inflow and sources - Number of startups or initiatives promoting bio-based alternatives - Reduction in single-use plastic usage near wetlands (Target: 90% reduction in buffer areas)	- EPR partnership agreements - Wetland plastic source-mapping reports - Market analysis for plastic alternatives - Monitoring and compliance records - Behavior change campaign evaluations



Assumptions	Agencies Responsible	Supporting Organizations
- Local governments prioritize plastic pollution in wetlands - Community participation is sustained - Adequate infrastructure for segregation, collection, and recycling is available	Primary: State Wetland Authorities Secondary: Urban Local Bodies (ULBs), District Pollution Control Committees Tertiary: Village Panchayats / Municipal Wards	- UNDP Plastic Waste Management Programme - National Productivity Council - Local NGOs and recycling enterprises - Swachh Bharat Mission (Urban & Rural) - Citizen science and volunteer networks
- EPR policies are effectively enforced - Market availability of plastic alternatives - Institutional buy-in from industries and local vendors - Public awareness and behavior shift are sustained	Primary: Central Pollution Control Board (CPCB) Secondary: State Pollution Control Boards (SPCBs), Ministry of Environment, Forest and Climate Change (MoEFCC) Tertiary: Local administration and enforcement wings	- Centre for Science and Environment - Plastic Waste Management Council (FICCI/CII) - Social enterprises and green innovation hubs - Behavioral change communication agencies



Gogabil Community Reserve

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