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RESEARCH ARTICLE ZOOPLANKTON DIVERSITY IN WETLAND

Zooplankton Diversity as a Bioindicator of Water Quality Degradation: A Study in *Silsako Beel*, Guwahati, Assam, India

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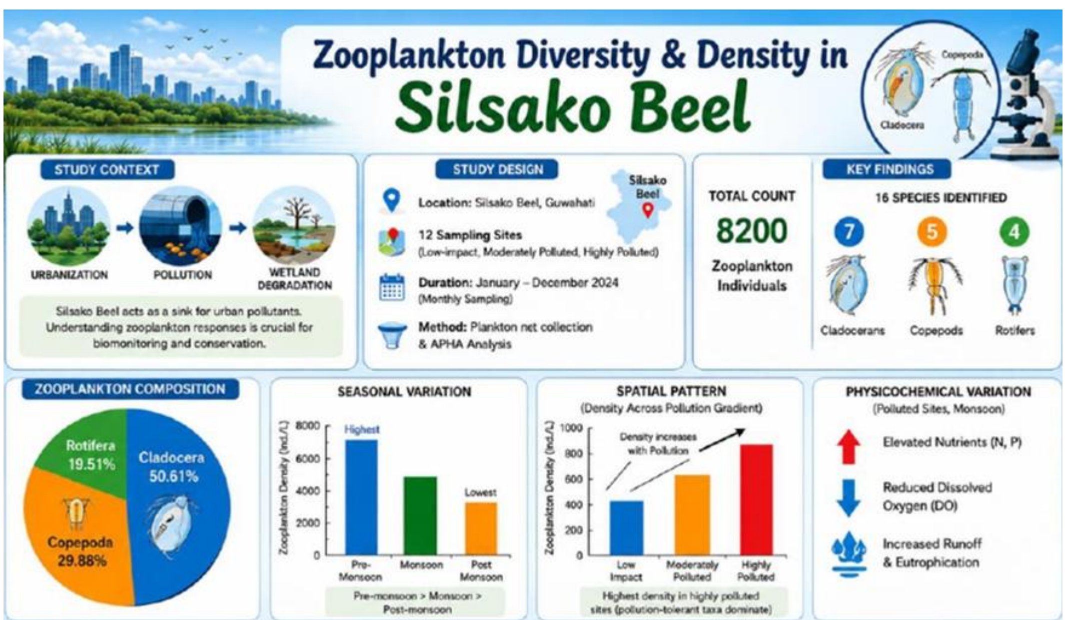
Graphical Abstract

(Zooplankton diversity, density, and environmental influences in 'Silsako Beel')



Abstract

Freshwater wetlands are increasingly threatened by urbanization and associated anthropogenic disturbances, leading to deteriorating water quality and biodiversity loss. This study investigated zooplankton diversity, abundance, and community composition in relation to physicochemical characteristics along a pollution gradient in Silsako Beel, an urban wetland on the Brahmaputra River floodplain in Assam, India. Monthly sampling was conducted from January to December 2024 at twelve stations categorized as low-impact, moderately polluted, and highly polluted. Zooplankton samples were collected with a 60 µm plankton net and identified to the lowest possible taxonomic level, while key physicochemical parameters were analyzed using standard methods. A total of 16 zooplankton taxa,

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belonging to Cladocera, Copepoda, and Rotifera, were recorded. Cladocera was the most diverse and abundant group, accounting for 50.61% of the 8,200 individuals collected. Species richness declined with increasing pollution intensity, whereas overall zooplankton density increased from 2,070 ind./L at low-impact sites to 3,860 ind./L at highly polluted sites, indicating a shift toward communities dominated by pollution-tolerant taxa. Sensitive species such as *Daphnia magna* and *Mesocyclops pehpeiensis* were absent from highly polluted areas, whereas rotifers were more prevalent under degraded conditions. Elevated nutrient concentrations, increased total dissolved solids, and reduced dissolved oxygen, particularly during the monsoon season, were identified as the primary environmental drivers of zooplankton community structure. The study demonstrates that zooplankton diversity and abundance provide valuable indicators of ecological condition and highlights their utility for biomonitoring and the sustainable management of urban freshwater wetlands.

Keywords: *Urban wetland, Anthropogenic pollution, Zooplankton density, Cladocera, Copepoda, and Rotifers*

1 Introduction

Freshwater ecosystems support a significant proportion of global biodiversity despite covering only a small fraction of the Earth's surface. They provide essential ecosystem services, including nutrient cycling, water purification, flood regulation, and habitat provision. However, increasing anthropogenic pressures, such as urbanization, pollution, habitat modification, and nutrient enrichment, have accelerated freshwater biodiversity loss worldwide [1,2]. Among these stressors, urbanization is a major driver of ecological degradation, altering hydrological processes and increasing pollutant inputs into aquatic environments [3,4]. Urban wetlands are highly vulnerable because they receive runoff, sewage, sediments, and contaminants from surrounding catchments. Nevertheless, they continue to provide critical ecosystem functions, including water quality improvement, flood regulation, and biodiversity conservation [5-7]. Therefore, effective monitoring of these ecosystems is essential for their sustainable management. Zooplankton are key components of freshwater biodiversity and aquatic food webs, transferring energy from primary producers to higher trophic levels and contributing to nutrient cycling [7]. Their short life cycles, rapid reproduction, and sensitivity to environmental conditions make them reliable indicators of ecological change and water quality [8,9].

Environmental disturbances, particularly nutrient enrichment and organic pollution, can alter zooplankton community structure by reducing the abundance of sensitive species and favoring pollution-tolerant taxa, thereby lowering biodiversity and altering trophic interactions [10]. Although species richness and community composition are widely used in ecological assessments, population density may offer additional insight into community responses and resilience under environmental stress [11,12]. In tropical freshwater ecosystems, monsoon-driven fluctuations in rainfall, nutrient loading, turbidity, and dissolved oxygen strongly shape zooplankton dynamics and community structure [13]. Silsako Beel, an important urban wetland within the Brahmaputra River floodplain, serves as a natural rainwater reservoir and supports diverse aquatic flora and fauna, thereby contributing to ecosystem functioning and biodiversity conservation. However, rapid urbanization and associated anthropogenic pressures, including encroachment, sewage discharge, garbage dumping, and polluted runoff, have severely degraded the wetland [14]. These disturbances have led to deteriorating water quality, habitat loss, reduced wetland area, and declining biodiversity [15]. Recent studies have documented a significant decline in aquatic macrophyte diversity and abundance, raising concerns about the long-term ecological sustainability of the wetland [16].

Although previous research has primarily focused on wetland degradation, water quality, and macrophyte communities, studies of zooplankton assemblages remain scarce. Zooplankton are highly sensitive to environmental changes and play a crucial role in aquatic food webs, making them valuable indicators of ecosystem health. Therefore, understanding how physicochemical characteristics relate to zooplankton community structure is essential for assessing ecological conditions in urban wetlands. This study aims to evaluate zooplankton diversity, community composition, and abundance in relation to physicochemical parameters along a pollution gradient in Silsako Beel. It is hypothesized that increasing pollution levels will alter zooplankton community structure, reduce species diversity, and favor the proliferation of pollution-tolerant taxa. The findings will provide baseline information on the wetland's ecological status and support the use of zooplankton as effective bioindicators for monitoring and managing freshwater ecosystems.

2 Materials and Methods

2.1 Study Area and Sampling Design

The Silsako Beel (Figure 1), a freshwater wetland in Guwahati, Kamrup Metro district, Assam, is located at 26°11′ N - 91°48′ E, encircled by Amchang Wildlife Sanctuary to the east, VIP Road and Chachal to the west, Narengi to the north, and Panjabari to the south. Based on pollution intensity and surrounding land-use characteristics, the twelve sampling sites were grouped into three categories: low-impact sites (Site I: SBM1, SBM2, and GGS6), moderately polluted sites (Site II: SGR7, SGL8, SGOF9, and SGOB10), and highly polluted sites (Site III: SBMD3, BVD4, GGDS5, MPSF11, and MPSB12). The spatial distribution of these sites was mapped in QGIS version 3.34, using OpenStreetMap (OSM) as the base layer and field-recorded GPS coordinates for site localization [17] (Figure 2). Sampling was conducted monthly from January to December 2024 and grouped into three seasonal periods: pre-monsoon (March–May), monsoon (June–September), and post-monsoon (October–February).

2.2 Zooplankton Collection and Analysis

Zooplankton samples were collected with a standard conical

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plankton net (60 µm mesh). At each station, horizontal surface tows were conducted with uniform sampling effort to ensure comparability across sites. Samples were fixed in 4% buffered formaldehyde solution following standard methods [18] and then transported to the laboratory for further analysis. In the laboratory, samples were concentrated by sedimentation and homogenized before analysis. Quantitative analysis was conducted using a Sedgwick–Rafter counting chamber under a compound microscope. Counts were performed in triplicate, and mean values were reported as individuals per liter (ind./L) to estimate zooplankton density.

2.3 Taxonomic Identification

Zooplankton were identified to the lowest taxonomic level using morphological characteristics and standard identification keys [18]. Species were classified into three major taxonomic groups: Cladocera, Copepoda, and Rotifera. Diagnostic features, including body structure, appendages, carapace morphology, and lorica characteristics, were used in identification.

2.4 Physicochemical Analysis

Water temperature, pH, and dissolved oxygen (DO) were measured in situ at each plankton sampling station with calibrated portable instruments to accurately reflect ambient field conditions. Water samples for analysis of ammonium chloride, nitrate, nitrite, total dissolved solids (TDS), alkalinity, and hardness were collected simultaneously and transported to the laboratory under appropriate conditions for further analysis, following standardized methods [18,19].

2.5 Data Analysis

Zooplankton density (ind./L) was estimated for major taxonomic groups. Spatial comparisons were conducted across the three pollution categories, and seasonal variation was evaluated across hydrological periods. All data were compiled and analyzed using spreadsheet software [20]. Descriptive statistics and graphical representations summarized patterns in zooplankton communities and physicochemical parameters.

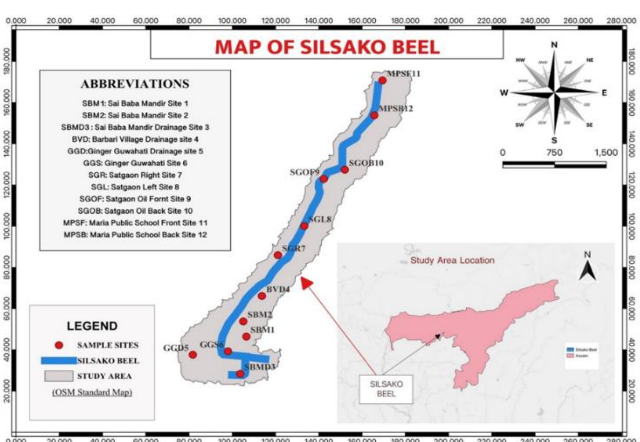

Figure 1: Spatial distribution of sampling sites in Silsako Beel, Guwahati, Assam, India.

3 Results and Discussion

3.1 Physicochemical Characteristics of Study Sites

Physicochemical parameters showed marked seasonal and spatial variation across the study sites. Table 1 summarizes seasonal changes in nutrient concentrations, water quality parameters, and dissolved oxygen along the pollution gradient. During the monsoon season, ammonium chloride, alkalinity, and TDS increased substantially, particularly at moderately and highly polluted sites, likely due to enhanced runoff and urban pollutant inputs. Similar increases in chemical contamination during monsoon periods have been reported in urbanized catchments, where stormwater runoff mobilizes pollutants from built-up areas and transports them into adjacent water bodies [21]. In contrast, dissolved oxygen (DO) declined as pollution intensity increased. The lowest DO concentration (2.64 mg/L) was recorded at Site III during the monsoon period, indicating hypoxic conditions associated with elevated organic loading. Monsoon runoff increased nutrient and suspended-solids loading, while post-monsoon conditions showed partial recovery via dilution and sedimentation. However, DO remained comparatively low at polluted sites, suggesting continued decomposition of organic matter [21].

3.2 Zooplankton Diversity, Community Structure, and Environmental Drivers

Sixteen (16) zooplankton taxa, representing three major groups, were recorded from Silsako Beel during January–December 2024. Cladocera was the most diverse group (7 species), followed by Rotifera (5 species) and Copepoda (4 taxa, including naupliar stages) (Table 2). The species distribution across the three sampling sites indicates moderate zooplankton diversity within the wetland (Table 3). Pollution-sensitive taxa such as *Daphnia magna* and *Mesocyclops pehpeiensis* were absent from highly polluted sites, whereas several rotifer species were more frequent in moderately and highly polluted areas, indicating that environmental stress influences community composition. Representative micrographs of selected taxa are shown in Figure 2. A total of 8,200 zooplankton individuals were recorded, comprising Cladocera (4,150; 50.61%), Copepoda (2,450; 29.88%), and Rotifera (1,600; 19.51%). Species richness progressively reduced with increasing pollution, whereas total abundance increased, indicating a shift toward communities dominated by pollution-tolerant taxa. Similar findings have been documented in eutrophic freshwater ecosystems, where nutrient enrichment promotes opportunistic, fast-reproducing species [22].

Table 4 and Figure 3 illustrate seasonal shifts and spatial variation in the density of major zooplankton groups across the three sites, highlighting the influence of seasonal hydrology and water quality on community dynamics. Zooplankton abundance was generally highest during the pre-monsoon and lowest during the post-monsoon periods. While Site I declined from the pre-monsoon (975 ind./L) to the post-monsoon (335 ind./L), Site III consistently recorded the highest densities, reaching 1,470 ind./L during the

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Table 1: Seasonal variation of physicochemical parameters across study sites in Silsako Beel

Parameters	**Site I**		
	Pre- Monsoon	**Monsoon**	**Post - Monsoon**
Ammonium chloride (mg/L)	16.65±9.61	156.26±18.75	110±5.77
Nitrite (mg/L)	1.15±0.66	0.5±0.28	0.11±0.05
Nitrate (mg/L)	5.07±4.05	6.5±6.17	0.47±0.23
Hardness (mg/L)	87.8±20.71	143.75±25.52	23.73±11.86
pH	7.05±0.02	7.34±0.26	7.87±0.025
Alkalinity (mg/L)	408.4±20.3	175±6.12	23.28±11.64
TDS (mg/L)	407.7±20.83	457.25±29.33	28.90±14.45
Temperature (°C)	24.63±0.93	25.88±0.91	25.31±0.93
DO (mg/L)	5.72±0.34	5.0±0.5	5.35±0.52
	Site II		
	Pre- Monsoon	**Monsoon**	**Post - Monsoon**
Ammonium chloride (mg/L)	16.65±11.78	112.5±16.13	95.82±4.17
Nitrite (mg/L)	3.15±2.82	0	2.97±1.73
Nitrate (mg/L)	2.82±2.41	0	2.75±2.42
Hardness (mg/L)	57.45±9.15	52.18±9.76	62.47±9.92
pH	6.7±0.13	7.87±0.02	7.32±0.11
Alkalinity (mg/L)	145.82±15.21	150±1.03	168.3±3.45
TDS (mg/L)	195.9±6.36	220.5±29.5	215.6±4.79
Temperature (°C)	32.85±1.02	32.9±0.66	24.15±1.41
DO (mg/L)	8.05±0.23	6.72±0.64	4.61±0.47
	Site III		
	Pre- Monsoon	**Monsoon**	**Post - Monsoon**
Ammonium chloride (mg/L)	21.7±3	110± 5.77	167.5± 11.08
Nitrite (mg/L)	0.1±0.05	0	0.2±0.1
Nitrate (mg/L)	0.3±0.23	0	1.1±0.63
Hardness (mg/L)	145.75±11.86	95±15.07	94±5.59
pH	7.87±0.02	7.92±0.22	8.34±0.15
Alkalinity (mg/L)	198.5±11.6	171.75±26.47	184.5±10.53
TDS (mg/L)	484.7±14.4	289.85±27.55	386.75±37.74
Temperature (°C)	25.31±0.93	29.73±1.72	24.65±1.31
DO (mg/L)	5.35±0.52	2.64±0.41	4.06±1.17

Table 2: Taxonomic classification of recorded zooplankton species in Silsako Beel based on order and family.

Sl. No	**Zooplankton Groups**	**Order name**	**Family Name**	**Name of the species**
1	Cladocera	Cladocera	Daphniidae	*Simocephalus vetulus*
		Anomopoda		*Simocephalus larva*
				Daphnia magna
			Moinidae	*Moina micrura*
				Moina macrocopa
			Eurycercidae	*Eurycercus lamellatus*
		Ctenopoda	Sididae	*Diaphanosoma sari*
2	Copepoda	Cyclopoida	Cyclopidae	*Thermocyclops crassus*
				Mesocyclops pehpeiensis
				Acanthocyclops robustus
		Calanoida	Calanoidae	*Naupalius sp*
3	Rotifers	Ploima	Lecanidae	*Lecane ludwigii*
				Lecane luna
				Plationus patulus patulus
			Brachionidae	*Branchionus urceolaris urceolaris*
				Branchionus rotundiformis

Note: Taxonomic classification follows standard freshwater zooplankton identification keys. *Nauplius sp.* represents copepod larval stages and is included as a functional taxonomic unit.

Table 3: Distribution of zooplankton species across sampling sites in Silsako Beel

Sl. No.	Zooplankton Groups	Species	Sampling stations		
			I	II	III
1	Cladocera	*Simocephalus vetulus*	+	+	+
		Simocephalus larva	+	–	+
		Diaphanosoma sari	+	+	+
		Moina micrura	+	+	+
		Moina macrocopa	+	+	+
		Daphnia magna	+	–	–
		Eurycercus lamellatus	+	–	+
2	Copepoda	*Thermocyclops sp*	+	+	+
		Mesocyclops pehpeiensis	+	–	–
		Acanthocyclops robustus	+	+	+
		Naupalius	+	+	+
3	Rotifers	*Lecane ludwigii*	–	+	+
		Lecane luna	–	+	+
		Plationus patulus patulus	–	+	–
		Branchionus urceolaris urceolaris	+	–	–
		Branchionus rotundiformis	+	–	+

Note: "+" indicates presence of species; "–" indicates absence of species. *Nauplius* represents the larval stage of copepods. Site I-Low impact Polluted; Site II-Moderately Polluted; Site III-Highly Polluted).

Table 4: Seasonal and spatial variation in zooplankton density (ind./L) across sampling sites in Silsako Beel During 2024**.**

Site	Season	Numbers/Litre			
		Cladocera	Copepoda	Rotifers	Total
I	Pre-Monsoon	575 (58.97)	240 (24.62)	160 (16.41)	975(11.89)
	Monsoon	290 (38.16)	240 (31.58)	230 (30.26)	760 (9.27)
	Post-Monsoon	195(58.87)	140 (41.79)	0 (0)	335 (4.09)
II	Pre-Monsoon	460(52.87)	110 (12.64)	300 (35)	870 (10.61)
	Monsoon	200(37.74)	240 (45.28)	90 (16.97)	530 (6.46)
	Post-Monsoon	410(47.13)	390 (44.83)	70 (8.05)	870 (10.61)
III	Pre-Monsoon	810(60.90)	380 (28.57)	140 (10.53)	1330 (16.22)
	Monsoon	740(50.34)	390 (26.53)	340 (23.13)	1470 (17.93)
	Post-Monsoon	470(44.34)	320 (30.19)	270 (25.47)	1060 (12.93)
Grand Total	**All Season & Sites**	4150(50.61)	2450 (29.88)	1600 (19.51)	8200 (100)

Note: Values are expressed as individuals per liter (ind./L). Data in parentheses express the proportional percentage contribution of each zooplankton group.

monsoon season. The zooplankton community structure observed in Silsako Beel is similar to that reported in nutrient-rich freshwater ecosystems, where Cladocera dominate under nutrient-rich conditions and rotifers increase with pollution intensity [9]. Cladocera dominated the assemblage throughout the study, accounting for over 50% of total abundance in most seasons and at most sites. Their dominance, particularly in polluted areas, reflects their ability to exploit nutrient-rich environments with elevated phytoplankton availability [22]. Copepods were the second most abundant group and increased with pollution intensity, while the widespread occurrence of naupliar stages indicated active reproduction and recruitment. Rotifers showed the strongest association with polluted environments, particularly during the monsoon and post-monsoon periods, reflecting their rapid reproductive capacity and tolerance to eutrophic and low-oxygen conditions. The higher densities of rotifers and cladocerans at polluted sites, coupled with the reduction of sensitive taxa, highlight the influence of environmental stress on community structure. The increasing trend in total zooplankton density from Site I (2,070 ind./L) to Site III (3,860 ind./L) indicates that anthropogenic disturbance favors a small number of tolerant species capable of thriving under nutrient-enriched conditions. Similar findings have been observed in eutrophic aquatic ecosystems, where nutrient enrichment filters communities toward tolerant, fast-growing taxa and reduces overall biodiversity [23].

The observed zooplankton patterns closely matched these physicochemical changes. Pre-monsoon conditions featured higher temperatures and moderate nutrient concentrations, supporting greater biological productivity. Elevated nutrients likely enhanced phytoplankton growth and food availability, leading to higher zooplankton densities. Conversely, reduced DO and increased TDS favored tolerant taxa, particularly rotifers, while sensitive species became less abundant. Similar relationships among nutrient enrichment, oxygen depletion, and zooplankton restructuring have been widely documented in eutrophic freshwater ecosystems [24, 25]. Anthropogenic disturbances often increase organic loading and promote hypoxic conditions, creating nutrient-enriched environments that selectively favor a limited

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assemblage of pollution-tolerant species. Consequently, sensitive taxa decline in abundance or disappear, driving loss of diversity and shifts in species composition toward organisms adapted to environmental stress and eutrophic conditions [26, 27]. Elevated nutrients, high TDS, and low dissolved oxygen were identified as the primary environmental drivers of zooplankton community structure in Silsako Beel. Higher nutrient concentrations and lower dissolved oxygen levels at polluted sites indicate anthropogenic inputs, resulting in degraded water quality. These changes promoted the dominance of pollution-tolerant taxa and reduced species richness, reflecting greater ecological stress than at non-polluted sites. Similar findings have been documented in other freshwater ecosystems subjected to nutrient enrichment and anthropogenic disturbance, suggesting that the observed community shifts in Silsako Beel are consistent with broader ecological responses to environmental degradation [28].

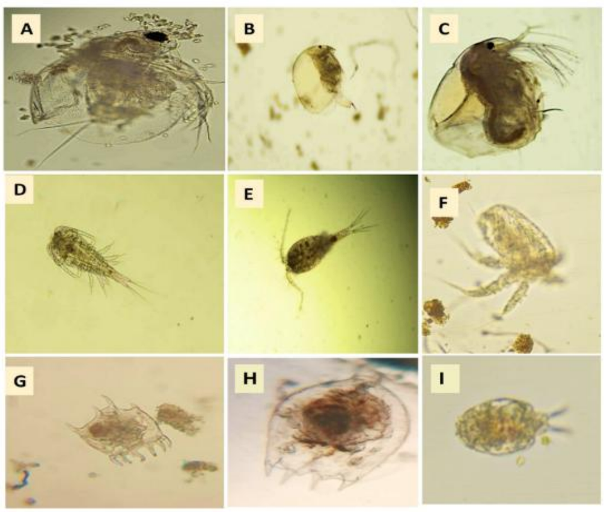

Figure 2: Zooplankton taxa recorded from Silsako Beel. Cladoceran: (A) *Moina macrocopa*, (B) *Eurycercus lamellatus*, and (C) *Simocephalus vetulus*. Copepods: (D) *Thermocyclops crassus*, (E) *Mesocyclops pehpeiensis*, and (F) naupliar stage (Nauplius sp.). Rotifers: (G) *Plationus patulus*, (H) *Brachionus urceolaris*, and (I) *Lecane ludwigii*.

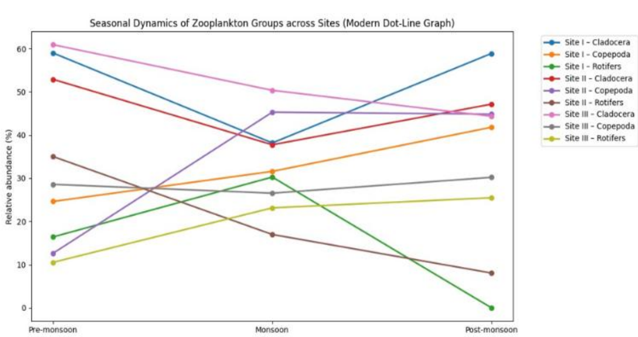

Figure 3: Graphical presentation of seasonal variation in zooplankton abundance across pollution-gradient sites in Silsako Beel, 2024.

4 Ecological Implications

The decline in species diversity, accompanied by increased zooplankton density at polluted sites, indicates a shift from diverse communities to systems dominated by a few pollution-tolerant taxa. These patterns are characteristic of eutrophic and anthropogenically stressed ecosystems, where environmental filtering favors opportunistic, fast-reproducing species while sensitive taxa decline [29]. Although nutrient enrichment can increase zooplankton abundance by boosting phytoplankton production, it simplifies community structure and makes ecological functions increasingly dependent on a limited number of tolerant groups [30]. This reduction in functional diversity and ecological redundancy may lower ecosystem resilience and adaptive capacity in the face of future disturbances. Elevated nutrient concentrations, turbidity, and reduced dissolved oxygen further promote small-bodied generalist taxa while disadvantaging sensitive grazers, thereby altering grazing pressure, nutrient cycling, and energy transfer pathways. Consequently, high zooplankton abundance does not necessarily indicate good ecological conditions, particularly when biodiversity is reduced [31].

The findings underscore the value of combining diversity and density metrics for wetland assessment. Zooplankton-based indicators offer valuable insights into community structure and ecosystem functioning, supporting the monitoring of environmental change. Overall, the observed patterns indicate increasing ecological stress in Silsako Beel and emphasize the need for integrated biomonitoring approaches to support sustainable urban wetland management.

5 Conclusion

This study examined zooplankton diversity and environmental drivers in Silsako Beel, a wetland in Guwahati. A total of 16 zooplankton species were recorded, with Cladocera dominating the community, followed by Copepoda and Rotifera. Species diversity declined while zooplankton density increased along the pollution gradient, reflecting the prevalence of pollution-tolerant taxa under environmental stress. The highest abundance occurred during the pre-monsoon months. Nutrient concentrations, total dissolved solids, and dissolved oxygen were identified as major drivers of zooplankton distribution. The findings highlight the value of integrating diversity and density metrics for biomonitoring and the sustainable management of urban wetland ecosystems.

Conflict of Interest

The authors affirm that they have no conflicts of interest regarding this manuscript's publication. There are no financial, personal, or professional ties that could have affected the study's conclusions.

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Authors' Contribution Statement

RKD: Formal analysis, Data curation, Conceptualization. PPP: Review & editing, Formal analysis. LNK: Validation, Supervision, Conceptualization. JG: Formal analysis, Data curation. Snigdha Chakraborty: Formal analysis, Data curation, Conceptualization.

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