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Zooplankton Bio-indicators Against Changing Hydrological Parameters at Bidyadhari River of Indian Sundarbans

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Abstract: Sundarban Estuarine System is influenced by periodic tidal input and fresh water inflow. It is surrounded by world's largest mangrove ecosystem and harbour naturally grown fishery. The total system is intersected by a network of many rivers and creeks. Bidyadhari is one of the major rivers of Sundarbans that is surrounded by human habitation on both banks. The dynamic condition of the river due to tidal inflow and fresh water input which is further increased many folds due to human interventions. In the present study, 26 zooplankton taxa have been recorded where 16 taxa were found perennial in all three seasons. 19 species showed its highest density in the monsoon season, 4 in post-monsoon and 3 in pre-monsoon season. Considering all seasons, *Pseudodiaptomus serricaudatus* was found to be the most abundant species in monsoon when there was a marked increase in temperature, nitrate, phosphate, silicate and a decrease in salinity, DO, TDS, EC and chlorophyll-a concentration. On the other hand, *Acrocalanus longicornis* was most abundant during the post-monsoon season when pH, EC, DO, chlorophyll-a were found to be highest and temperature was lowest of all seasons. Only 3 of the 26 taxa were found in highest concentration during pre-monsoon season when salinity was found in highest concentration. The Shannon-Weiner Diversity Index, Simpson 1_D Index and Margalef Richness Index of zooplankton diversity were found highest in station 3 (nearest to the sea) during all the three seasons. Pearson Correlation Analysis showed some significant correlation between different hydrological parameters and zooplankton diversity indices. The result of the study indicates the presence of organic pollutants and eutrophication in Bidyadhari river that demands regular monitoring of water quality for maintenance of long-term sustainability of one the largest naturally grown fisheries in the world.

Introduction

Among many types of ecosystems, an estuarine ecosystem remains a great choice of interest to ecologists for being a common site of interface of seawater, freshwater, land as well as environment factors (Day et al., 2012; Sardar et al., 2016; Roy et al., 2022). The combined effect of river discharge, tide, sedimentation and climate changes bring about a dynamic and unstable condition in the estuarine ecosystem (Fadlillah et al., 2019). This dynamic state causes constant fluctuations in physicochemical factors that further enhance many times due to considerable human interventions if any (Biancalana et al., 2014). An estuary is characteristically much different than an open sea or a river in terms of water quality parameters, light penetration capacity, and water movement. Besides, it supports different plants like phytoplankton, salt marsh plants and submerged grasses - all at a time (Day et al., 2012; Biswas et al., 2023). Additionally, if it is surrounded by mangroves, the surrounding ecosystem contributes to the accumulation of

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additional organic matter and thereby controls plankton diversity (Rodríguez, 1975).

Like other estuaries, Sundarbans Estuarine System (SES) shows periodic as well as short-term variations in physicochemical parameters (Dutta et al., 2017; Nandy et al., 2018). Constant changes in hydrological parameters like pH, salinity and nutrient concentration caused due to periodic tidal inputs and river discharge result in major variations in plankton composition in the whole estuarine system as well as in individual tidal creeks or channels (Basu et al., 2021). Different species of zooplankton serve as an intermediate between phytoplankton and planktivorous fishes as well as respond quickly to any change in physicochemical parameters that occurs due to anthropogenic waste disposal or any other reason (Biancalana et al., 2014). Additionally, the diversity of zooplankton supports many biological organisms, including commercially beneficial organisms that ultimately support the livelihood of millions of people of Sundarbans Biosphere Reserve. Rivers of Sundarbans Estuarine System exhibit different geographical distributions and differences in exposure to anthropogenic waste that can be reflected in spatiotemporal fluctuations in zooplankton dynamics. The "Proposed action plan for rejuvenation of river Vidyadhari" proposed by River Resource Committee, West Bengal and published by West Bengal Pollution Control Board on 12th July 2019, reported that water of Bidyadhari river is vastly used in fishery and a larger number of fisherman family depends on that river for their livelihood. On the other hand, it takes up a huge sewage disposals and municipal waste products from nearby townships. Additionally, surrounding agricultural lands also play a major role in adding organic pollutants to the river. So, it is inevitable from the report that river Bidyadhari requires regular monitoring for the maintenance of water quality and long-term sustainability.

Materials and Methods

Study Site

Sundarbans Estuarine System (SES) is a complex network of many rivers and creeks which are also surrounded by the world's largest mangrove ecosystem as well as characterized by naturally grown fishery influenced by both periodic tidal input and massive freshwater input (Dutta el al., 2017). The present study was conducted on river Bidyadhari, one of the major rivers of Sundarbans that originates near Haringhata subdivision of Nadia district of West Bengal, India and it flows along several parts of North 24 Parganas till it meets Raimangal river at Sundarbans. Bidyadhari river is surrounded by human habitation on both banks and also known to carry huge domestic and industrial waste products from North 24 Parganas district. In the present study, 3 sampling sites were selected at a distance of around 5 kms along the direction from south to north - Station 1 (Lat. 22.130930, Long. 88.742361) which is farthest from bay the Bay of Bengal, Station 2 (Lat. 22.078169, Long. 88.696143) near Amlamethi and Station 3 (Lat. 22.049859, Long. 88.732902) which is nearest to the Bay of Bengal.

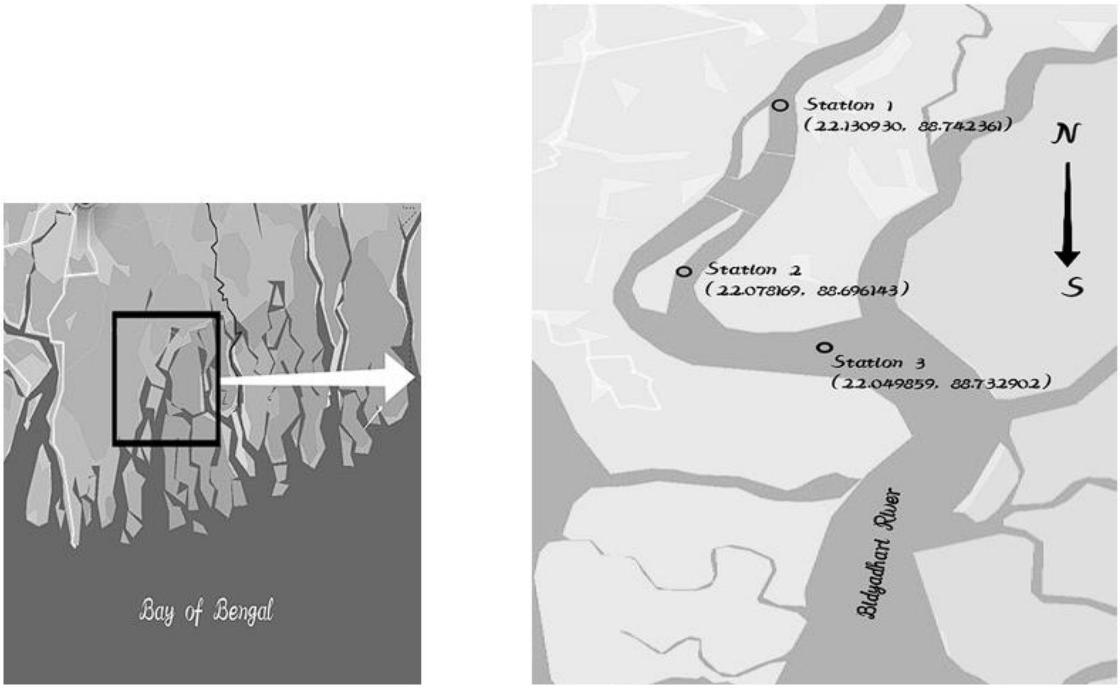

Figure 1. Map showing the selected sampling stations in Bidyadhari river.

Sampling and Processing

The data of physicochemical parameters (Temperature, pH, dissolved oxygen, TDS, electrical conductivity, salinity, nitrate, phosphate, silicate and chlorophyll-a concentration) were collected on monthly basis from

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November 2021 to October 2022. The tenure of 12 months was separated into 3 phases – Post Monsoon phase (November 2021 to February 2022), Pre Monsoon phase (March 2022 to June 2022), Monsoon phase (July 2022 to October 2022). Water samples were collected twice a month and the average value was taken for consideration. Water samples were collected using 5-1 Niskin bottles at a depth of 0.5 meter. Temperature, pH, electrical conductivity (EC), total dissolved solids (TDS) were measured with the help of digital instrument of HANNA (Model No- HI98130). Salinity was measured using HANNA's Salinity tester (Model no- HI98319). Dissolved oxygen (DO) of water was measured as per standard protocols of Winkler's method (Winkler 1888). Total Phosphate, nitrate and silicate were measured following standard protocol used by Grasshoff (Grasshoff et al., 1999). Chlorophyll-a was measured following the acetone extraction procedure by the use Whatman GF/F filter paper (Pore size: 0.7 µm, diameter: 47 mm) and absorbance was measured in a UV-Vis spectrophotometer, Model No – LMSP UV1200 following the protocol used by Parsons et al. 1984 (Parson et al., 1984).

Zooplankton samples were collected in the early morning from each sampling site on a weekly basis ~~for~~ during the above-mentioned tenure. On each collection, 200 litres of water sample was collected from each sampling site using a transparent plastic bucket (25 liter capacity). The collected water was then filtered with a plankton net having mesh size of 200 µm and a diameter of 60 cm. Following that, the filtrates were preserved in 4% buffered formalin and examined under compound microscope using Sedgewick-rafter counting chamber for identification, counting and further analysis of zooplanktons following standard procedures (Battish, 1992, Khan, 2003 and Kasturirangan, 1963). The average value of five aliquots of 5ml, expressed as number of individuals per cubic meter was considered for measuring the abundance of zooplankton.

Data Analysis

Different hydrological parameters, spatial and seasonal variations were analyzed using one-way ANOVA followed by Post-hoc analysis. The variability in parameters was analyzed using PCA (Principle Component Analysis) and relation of one parameter with other parameters was examined using Pearson Correlation Analysis.

The monthly zooplankton count from each sampling site was collected from November, 2021 to October, 2022. The density of different zooplankton species was recorded and compared spatially as well as seasonally. Season wise and station-wise diversity of zooplankton was measured using different diversity indices and compared accordingly. The correlation matrix measured the correlation between different diversity indices and water parameters. Season wise and station wise cluster analysis was done and the Bray-Curtis dissimilarity metrics were chosen to quantify the dissimilarity between zooplankton communities at different sites over different months.

Results

Hydrological parameters

The station-wise and season-wise obtained data of all hydrological parameters are presented in Tables 1 and 2.

The result of one-way ANOVA shows significant differences between stations in the case of DO, salinity and phosphate with p-values 0.016, 0.003 and 0.01, respectively (the level of significance was set at $P<0.05$). The results of Post hoc test also show a significant difference between DO ($P= 0.012$), salinity ($p=0.004$) and phosphate ($p=0.012$) between Station 1 and Station 3. Post hoc analysis also shows the significant difference between Station 2 and Station 3 in the case of salinity ($p=0.025$) and phosphate ($p=0.044$). In the case of seasonal variation, all physicochemical factors except TDS show significant differences ($p<0.05$) between different seasons as per the result of one-way ANOVA. Post hoc analysis shows significant temperature, dissolved oxygen, electrical conductivity and Chl-a differences in all pair-wise comparisons among three seasons. Significant difference in the mean pH was observed between Monsoon and Pre-monsoon seasons. Similarly, significant differences in the mean salinity are observed between Monsoon and Pre-monsoon seasons. In the case of nitrate and phosphate concentration, significant differences were observed between Monsoon and Pre-monsoon seasons and between monsoon and post-monsoon seasons. Silicate concentration showed significant difference between post-monsoon and pre-monsoon seasons. The level of significance was set at $p<0.05$ in all cases. In Principal component analysis, Component 1 (combination of temperature, dissolved oxygen, PH, Chl-a)represents 50.156% of the total variance. Component 2 **(**dominated by TDS, EC, and salinity shows less influence from other variables) adds 16.696% of the variance. Component 3 (dominated by Silicate, with some contribution from Nitrate) adds 13.877% of the variance. Together, the three components explain 80.729% of the total variance.

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Table 1. Station-wise variation of hydrological parameters.

Parameter	Stations	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Temp (C)	Station 1	28.1	3.98771	1.15115	21.4	32.8
	Station 2	27.7917	3.90791	1.12812	21.3	32.4
	Station 3	27.5667	4.06299	1.17288	21	32.3
	Avg	27.8194	3.87747	0.64624	21	32.8
pH	Station 1	7.9683	0.44086	0.12727	7.19	8.34
	Station 2	7.7208	0.55536	0.16032	6.98	8.25
	Station 3	7.6108	0.55497	0.16021	6.91	8.23
	Avg	7.7667	0.52707	0.08785	6.91	8.34
DO (mg/L)	Station 1	5.95	0.66127	0.19089	4.8	6.9
	Station 2	5.4417	0.63311	0.18276	4.6	6.4
	Station 3	5.0833	0.79067	0.22825	3.9	6.5
	Avg	5.4917	0.76807	0.12801	3.9	6.9
TDS (ppT)	Station 1	11.7236	1.19433	0.34477	9.71	13.79
	Station 2	12.0992	1.11256	0.32117	10.11	13.87
	Station 3	12.8506	0.3986	0.2301	11.22	13.98
	Avg	12.2244	0.0918	0.2986	9.71	13.98
EC (mS/cm)	Station 1	22.8967	3.90734	1.12795	17.97	28.39
	Station 2	24.4925	4.96572	1.43348	19.13	31.31
	Station 3	26.44	4.84057	1.39735	20.23	33.24
	Avg	24.6097	4.69804	0.78301	17.97	33.24
Salinity (PSU)	Station 1	15.6583	1.65445	0.4776	13.2	18
	Station 2	16.15	1.7433	0.50325	13.4	18.1
	Station 3	17.9167	1.29041	0.37251	15.9	20.1
	Avg	16.575	1.81822	0.30304	13.2	20.1
Nitrate (uM)	Station 1	36.5083	6.42855	1.85576	28.7	46.9
	Station 2	38.4917	6.14469	1.77382	31.8	50.6
	Station 3	40.2083	5.27351	1.52233	32.6	50.3
	Avg	38.4028	5.9955	0.99925	28.7	50.6
Phosphate (MM)	Station 1	1.5567	0.23715	0.06846	1.13	1.89
	Station 2	1.6033	0.18188	0.0525	1.35	1.89
	Station 3	1.8167	0.20155	0.05818	1.48	2.09
	Avg	1.6589	0.23241	0.03874	1.13	2.09
Silicate (pM)	Station 1	75,775	18.85582	5.44321	39.1	101.7
	Station 2	81.2167	19.86495	5.73452	39.7	108
	Station 3	87.7083	19.48204	5.62398	47.7	107.8
	Avg	81.5667	19.48143	3.24691	39.1	108
Chl-a (mg/mm3)	Station 1	2.0483	0.55448	0.16007	1.31	2.72
	Station 2	2.1667	0.56049	0.1618	1.36	2.92
	Station 3	2.2608	0.52076	0.15033	1.39	2.94
	Avg	2.1586	0.537	0.0895	1.31	2.94

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Table 2. Seasonal variation of hydrological parameter.

Parameter	Seasons	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Temp (C)	Postmonsoon	23.75	3.11725	0.89987	21	29.1
	Premonsoon	28.075	1.92501	0.5557	25.8	31.2
	Monsoon	31.6333	0.64008	0.18477	30.7	32.8
	Avg	27.8194	3.87747	0.64624	21	32.8
pH	Postmonsoon	8.1642	0.11658	0.03365	7.9	8.34
	Premonsoon	7.8925	0.50462	0.14567	6.98	8.34
	Monsoon	7.2433	0.35676	0.10299	6.91	7.98
	Avg	7.7667	0.52707	0.08785	6.91	8.34
DO (mg/L)	Postmonsoon	6.175	0.50295	0.14519	5.3	6.9
	Premonsoon	5.4667	0.43345	0.12513	4.8	6.2
	Monsoon	4.8333	0.6733	0.19437	3.9	6.2
	Avg	5.4917	0.76807	0.12801	3.9	6.9
TDS (ppT)	Postmonsoon	12.8224	0.64133	0.2141	10.1	13.98
	Premonsoon	12.2992	0.53888	0.15556	10.97	12.91
	Monsoon	11.8058	1.14998	0.33197	9.71	13.67
	Avg	12.3091	0.77	0.2338	9.71	13.98
EC (mS/cm)	Postmonsoon	28.0483	5.1419	1.48434	19.13	33.24
	Premonsoon	25.6233	2.3459	0.6772	22.92	29.64
	Monsoon	20.1575	1.62517	0.46915	17.97	22.46
	Avg	24.6097	4.69804	0.78301	17.97	33.24
Salinity (PSU)	Postmonsoon	16.8333	1.78597	0.51557	13.2	18.9
	Premonsoon	17.7667	1.40799	0.40645	15.2	20.1
	Monsoon	15.125	1.1963	0.34534	13.8	17.5
	Avg	16.575	1.81822	0.30304	13.2	20.1
Nitrate (uM)	Postmonsoon	36.3167	5.45291	1.57412	28.7	45.5
	Premonsoon	34.6833	3.77379	1.0894	28.9	41.2
	Monsoon	44.2083	3.71348	1.07199	40.1	50.6
	Avg	38.4028	5.9955	0.99925	28.7	50.6
Phosphate (uM)	Postmonsoon	1.5308	0.21794	0.06291	1.13	1.87
	Premonsoon	1.575	0.1763	0.05089	1.41	1.92
	Monsoon	1.8708	0.13681	0.03949	1.61	2.09
	Avg	1.6589	0.23241	0.03874	1.13	2.09
Silicate (uM)	Postmonsoon	86.9333	7.93122	2.28955	72.9	100.5
	Premonsoon	61.6167	18.78887	5.42388	39.1	92.4
	Monsoon	96.15	9.69775	2.7995	76.6	108
	Avg	81.5667	19.48143	3.24691	39.1	108
Chl-a (mg/mm3)	Postmonsoon	2.6808	0.11057	0.03192	2.53	2.89
	Premonsoon	2.0417	0.5092	0.14699	1.49	2.94
	Monsoon	1.7533	0.39295	0.11343	1.31	2.49
	Avg	2.1586	0.537	0.0895	1.31	2.94

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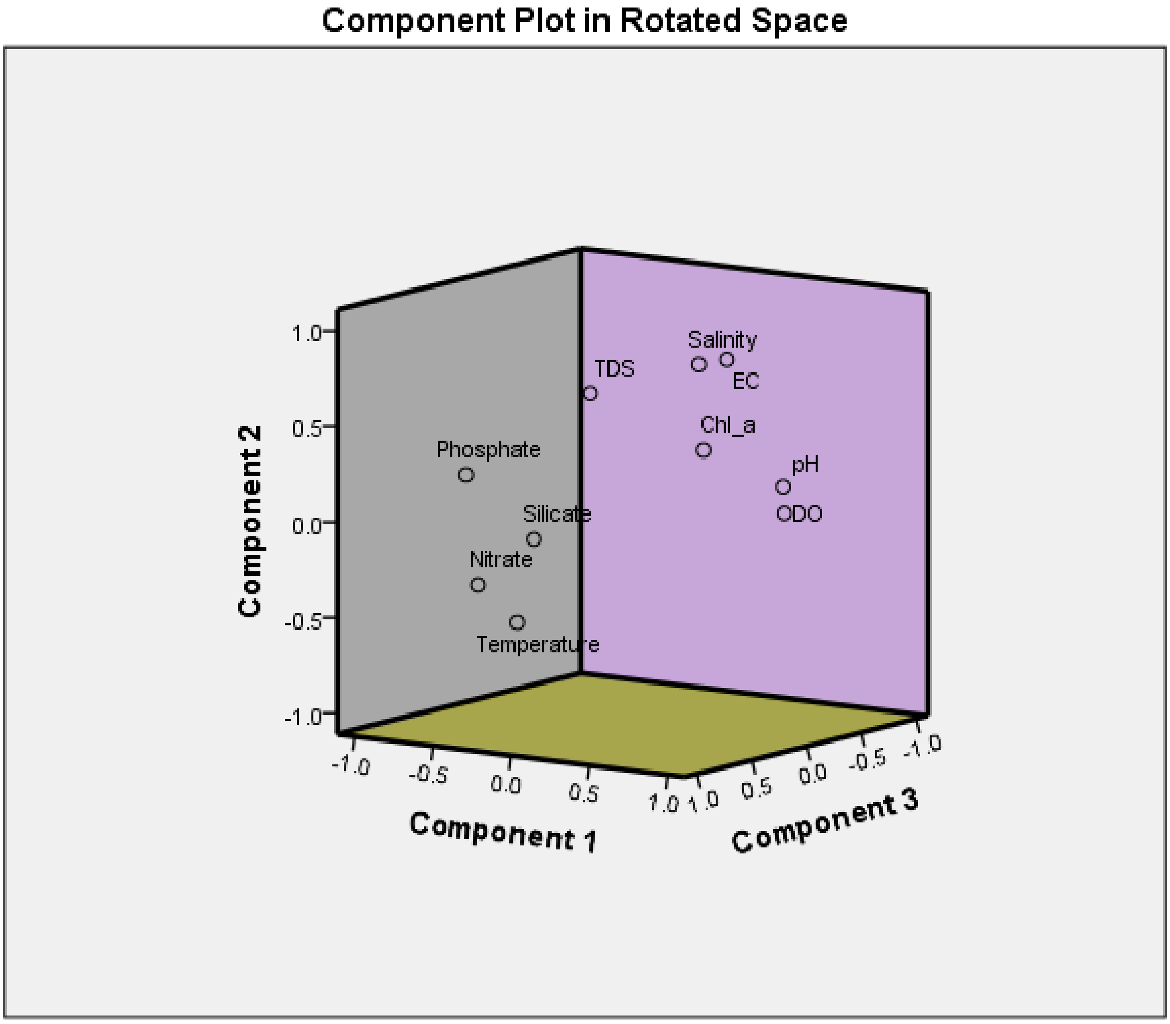

Figure 2. Rotated Component Matrix Plot combining 3 components that represent different environmental parameters.

B. Composition of Zooplankton Community

In this study, a total of 26 taxa of zooplankton were recorded considering all three stations. Station 1 showed the presence of 25 taxa, while 23 taxa were recorded in both station 2 and station 3. The overall mean density of zooplankton indicated highest density of *Pseudodiaptomus serricaudatus* followed by *Oithona similis*. 23 species were found in all 3 stations, whereas Tintinids were found only in station 3. In all 3 stations, *Pseudodiaptomus serricaudatus* showed highest overall mean density. Maximum number of species was found to be present during Monsoon in all sampling stations. 16 species had been recorded as perennial in all three seasons. Considering all sampling stations, 19 species showed their highest density in Monsoon, 4 species in post-monsoon and 3 in pre-monsoon season. Considering all sampling stations, highest mean species density was recorded in the case of *Pseudodiaptomus serricaudatus* (937.08 ind/met^3) followed by *Oithona similis* (903.33 ind/met^3) comprised more than 38% of total zooplankton density in monsoon season. Tintinnids and Paracalanus were found only in Monsoon. There was a notable rise in the density of *Oithona similis* in Monsoon. Among 16 perennial taxa, 11 taxa were recorded with the highest density in monsoon while 3 taxa during pre monsoon and 4 taxa during post monsoon season. Freshwater species like *Daphnia* and *Moina* were mostly found during post monsoon season. In post-monsoon season, highest mean density was shown by *Bestiolina similis* while in pre-monsoon season, *Acartia clausi* appeared with the highest mean density.

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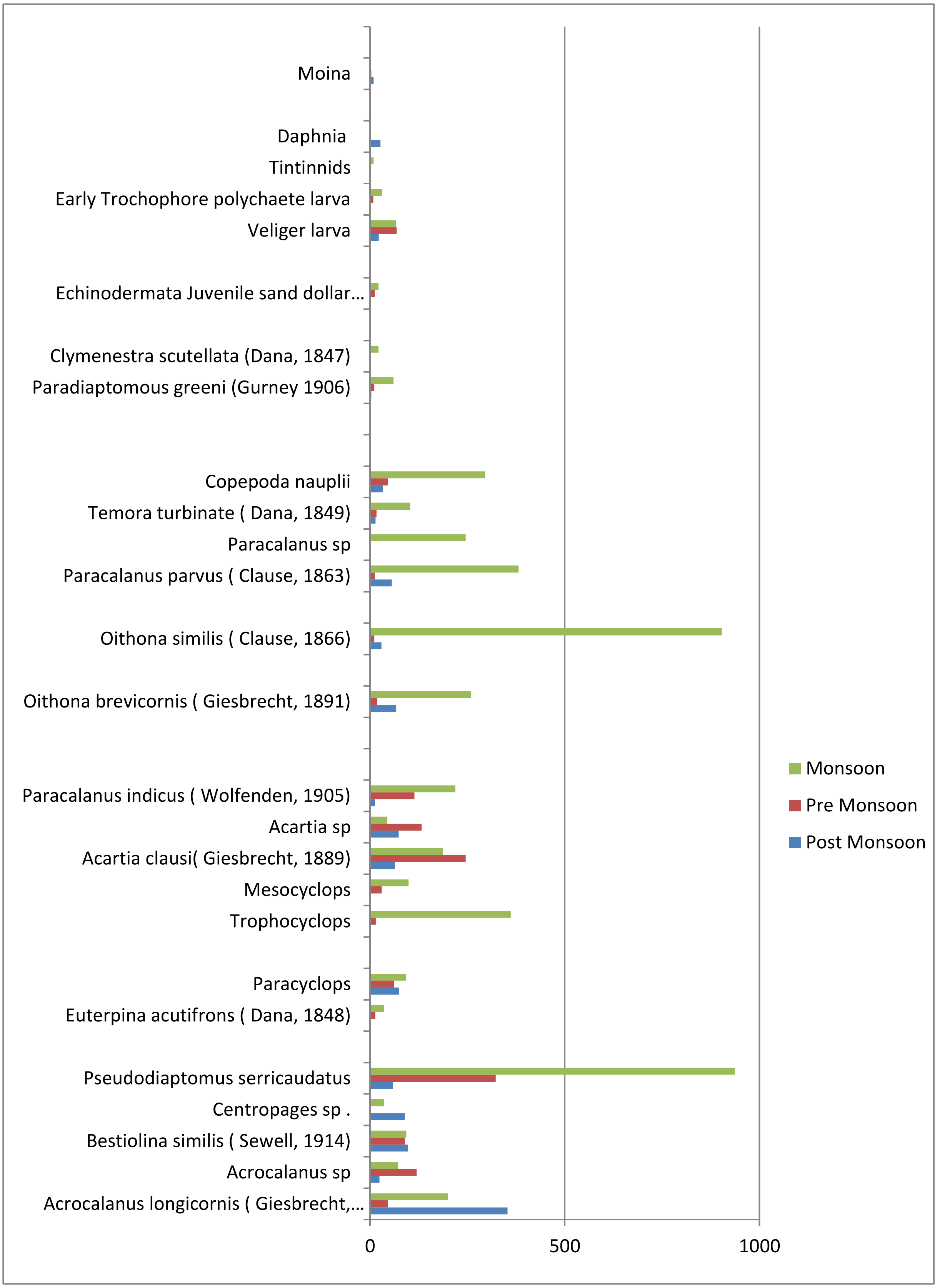

Figure 3. Seasonal Variation of zooplanktons combining mean zooplankton density of all selected stations (density in Individuals / meter ^{3}).

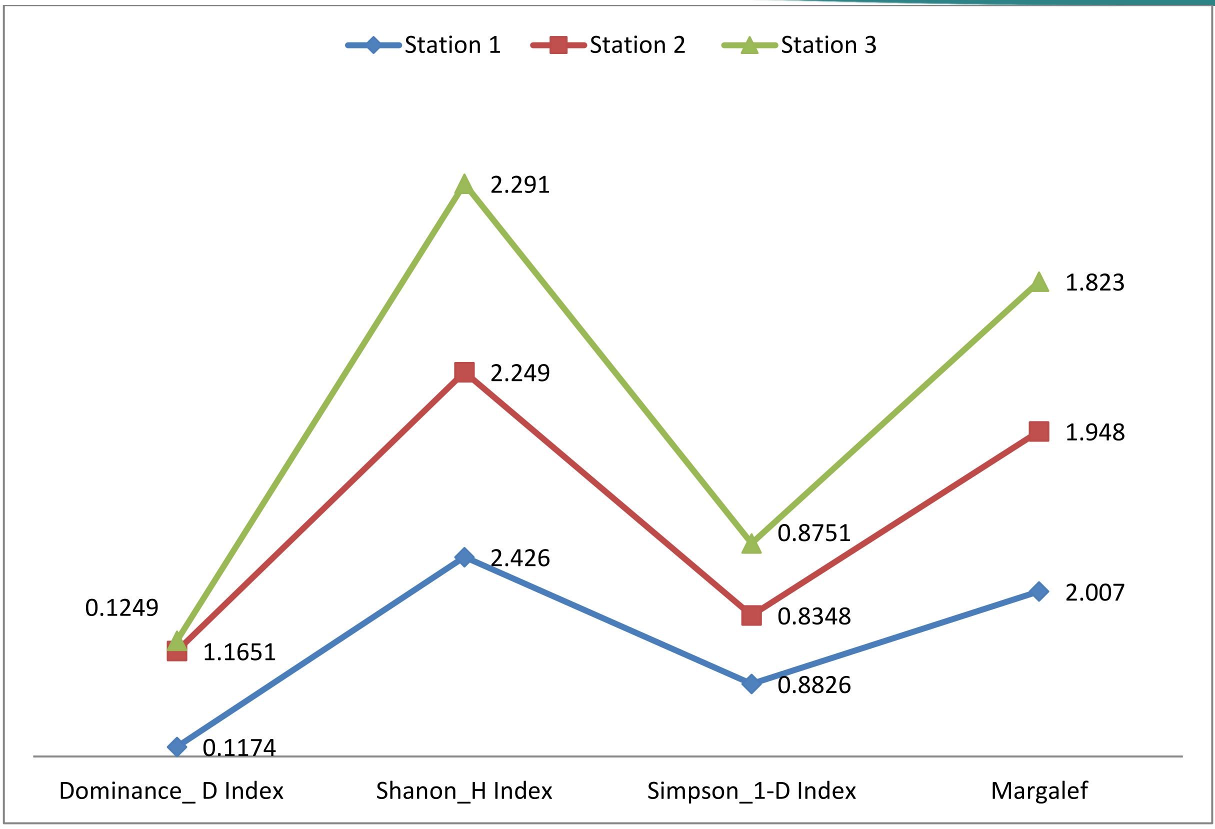

Figure 4. Station-wise diversity indices during post-monsoon season

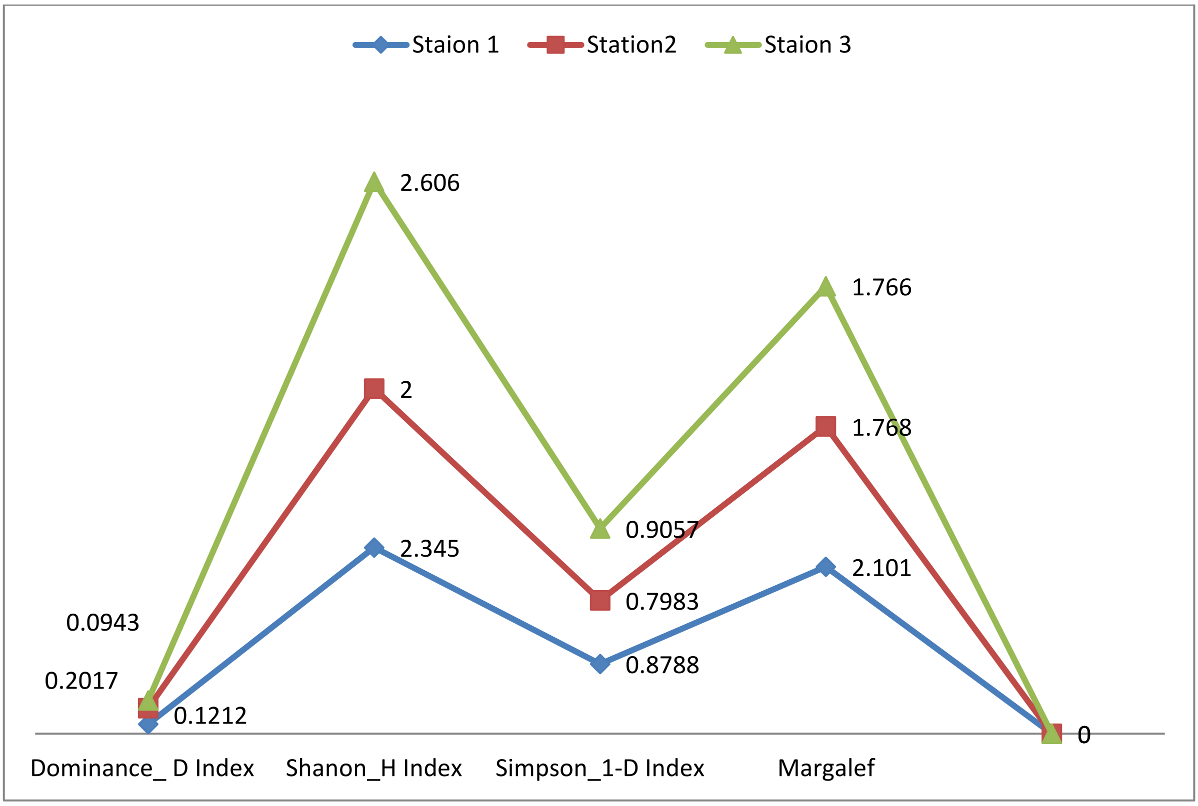

Figure 5. Station-wise diversity indices during pre-monsoon season

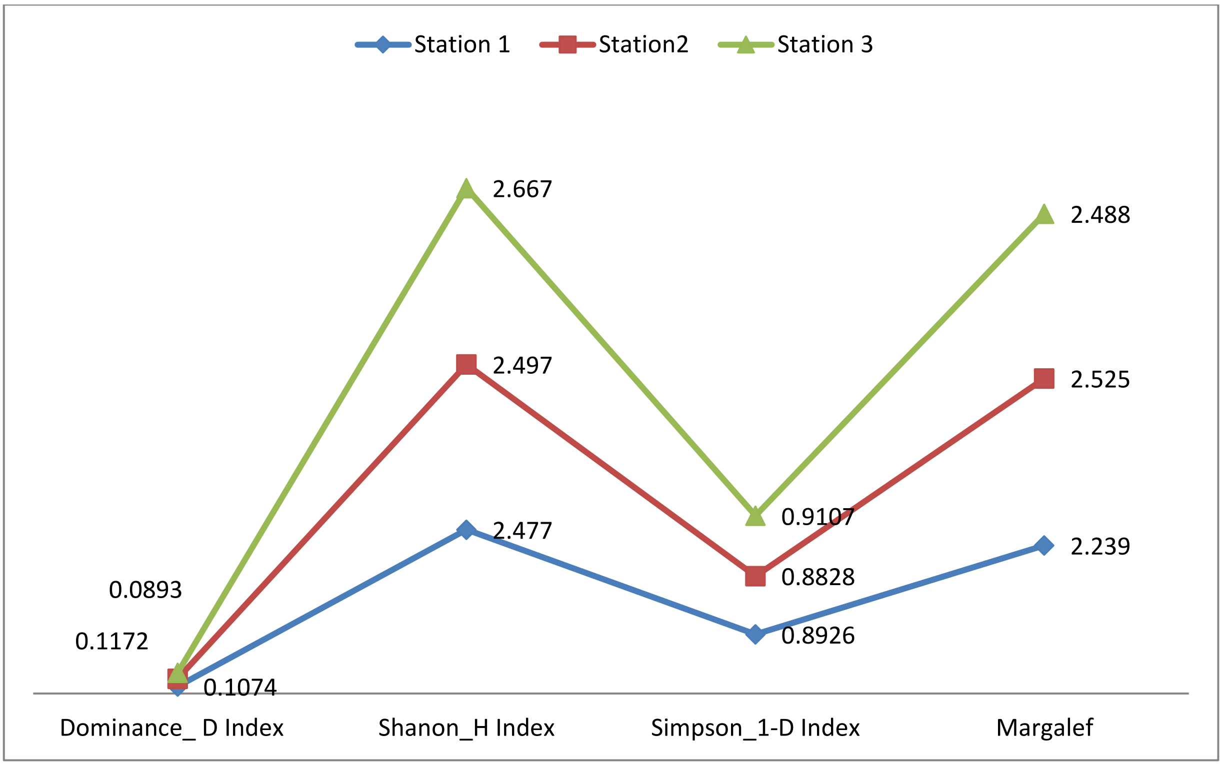

Figure 6. Station-wise diversity indices during monsoon season

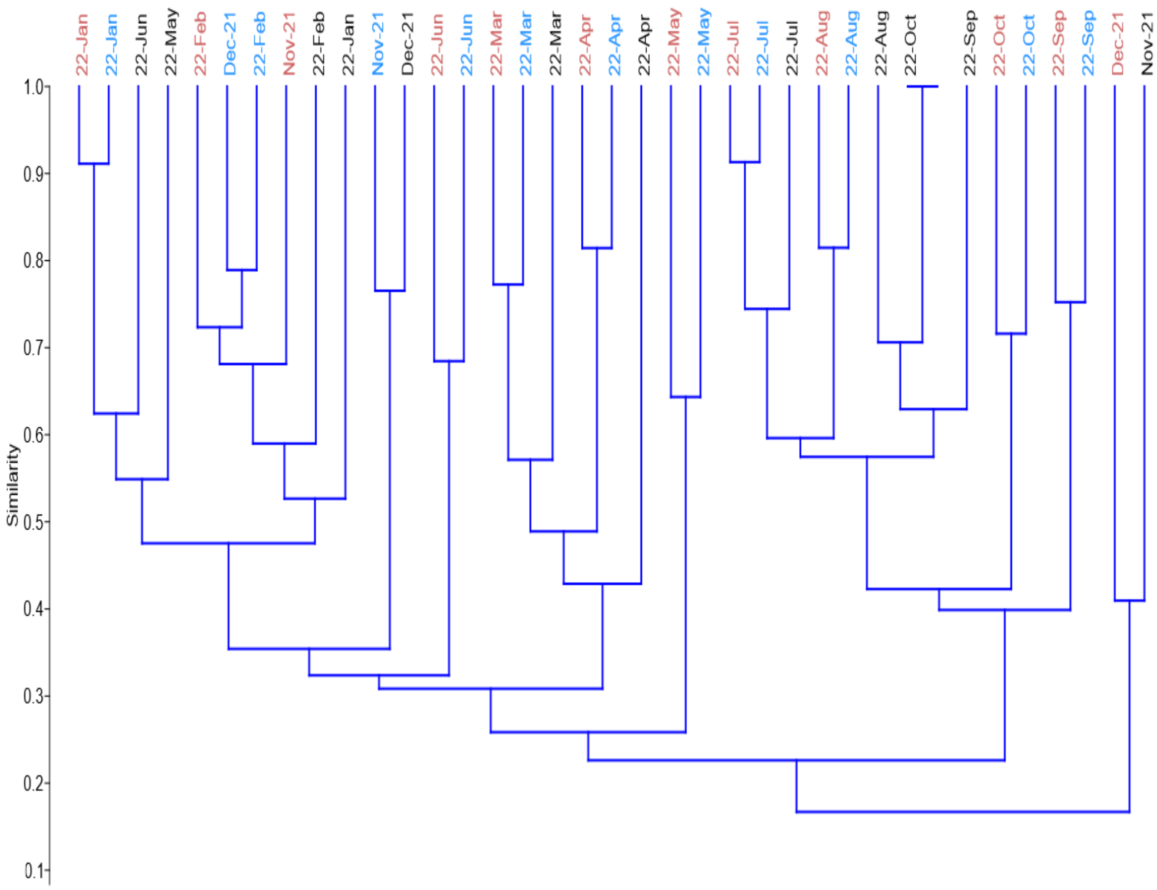

Figure 7. Cluster analysis of community structure of zooplankton (Station 1, Station 2, Station 3)

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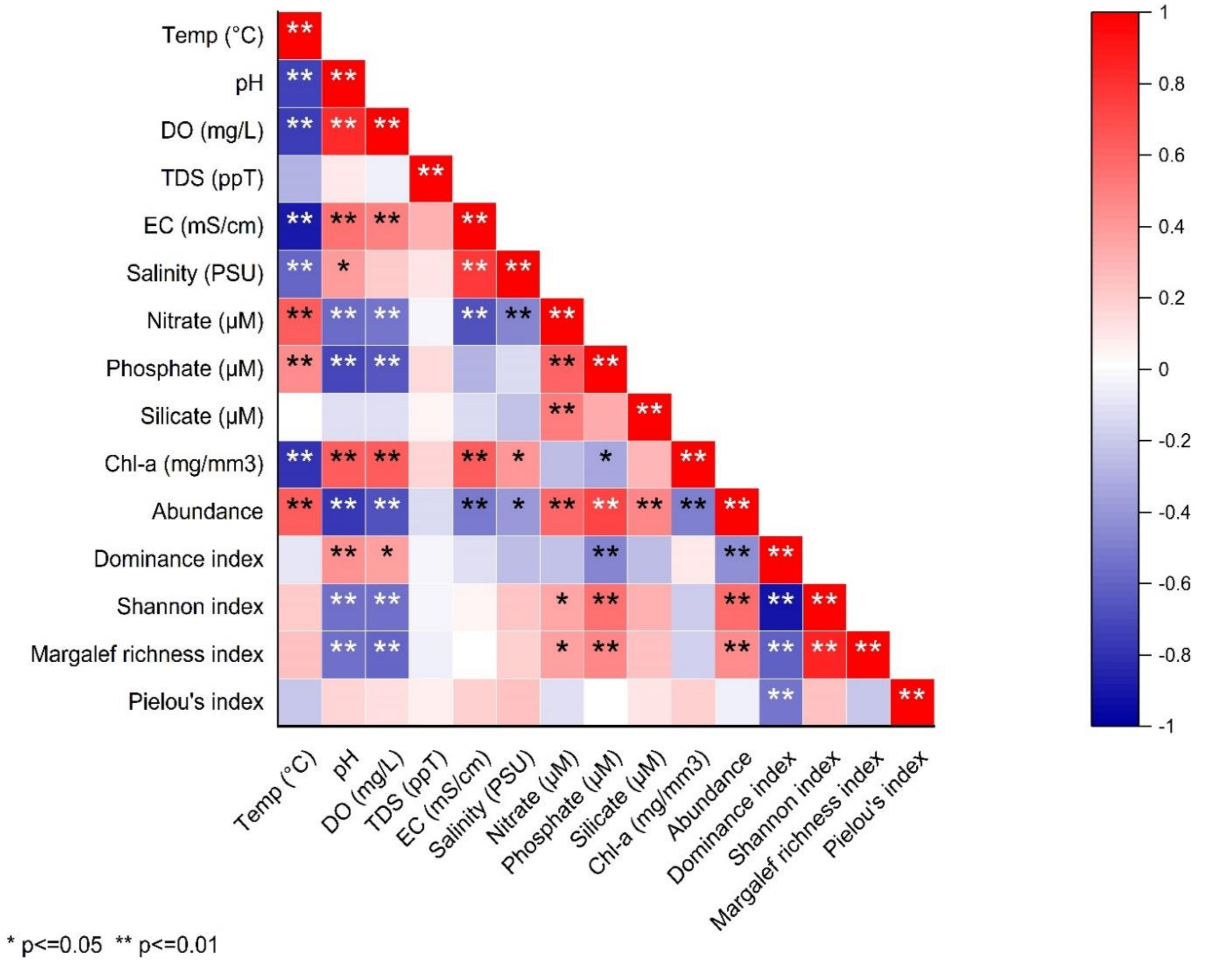

Figure 8. Correlation matrix for diversity indices and water quality parameter.

Zooplankton diversity was measured using different diversity indices. Station-wise variation of different diversity indices is presented in figure 4, 5 and 6. In the present study, cluster analysis (figure 7) was employed to investigate the community structure of zooplankton in Bidyadhari River. The dataset consists of abundance or biomass data for various zooplankton taxa collected monthly from multiple sampling sites along the river over a year. The Bray-Curtis dissimilarity metric was chosen to quantify the dissimilarity between zooplankton communities at different sites at different months.

C. Relationship between environmental variables and zooplankton community

Relation between physicochemical factors and zooplankton composition was measured using Pearson Correlation Analysis. Result shows several significant relations between environmental variables. Besides this, several significant relationships were found between environmental variables and diversity indices. All correlation and their significance level are presented in figure 8.

Discussion

Zooplankton composition was markedly affected by environmental variables in river Bidyadhari. The spatiotemporal variation was related to variations in different water quality parameters, river discharge, and periodic tidal activity. Zhao et al. (2013) reported in their study that very high or low concentration of environmental parameters stands in the way of the growth of the zooplankton community. In spite of the many seasonal dynamics of zooplankton, high precipitation during monsoon season resulted in a higher density of several zooplankton species. The water temperature at all three sampling stations were highest in July, 2022 and lowest in January 2023 (21.3°C). Salinity, one of the most important factors in the regulation of zooplankton dynamics, was higher in station 3 than that in stations 1 and 2 during all three seasons. April showed the highest salinity level (20.1 PSU) in station 3 whereas stations 1 and 2

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showed the highest salinity (18 PSU and 18.1 PSU, respectively) in May. The lowest salinity level was recorded in November, 2021 in Station 1 and Station 2, whereas in Station 3, the lowest salinity was recorded in September, 2022 during our study period. Salinity plays a major role in the regulation of plankton density (Zhou et al., 2009). The evaporation of water results in an increase in salinity in winter and high precipitation during monsoon results in lower salinity of water (Alkawri and Nagappa, 2010), which ultimately shows some limiting effects in zooplankton abundance. In the present study, lower salinity levels of water resulted in marked increase of certain zooplankton species like *Pseudodiaptomus serricaudatus* and *Oithona similis*.

The present study found the lowest mean DO, TDS and EC overall in Monsoon Nutrient content of estuarine water primarily depends on tidal inputs and agricultural or domestic runoff from the surrounding locality. In our study, phosphate, nitrate, and silicate concentrations were found to be highest during monsoon season in all three stations. However, there was a marked rise in silicate and nitrate concentration during monsoon season. The month of October showed considerable rise in the level of nitrate concentration in Station 2 and 3. There was also a considerable rise in silicate concentration in July (84 μM) compared to June (39.7 μM) in all three stations. In all three stations, mean chlorophyll-a concentration was higher during post-monsoon season than pre-monsoon and monsoon, though the highest chlorophyll-a concentration was found in the month of March, 2022. It was seen that highest chlorophyll-a concentration is accompanied by lower phosphate concentration. This result might be due to phosphate consumption by phytoplankton that helps them grow rapidly (Sridhar et al., 2006; Abdulwahab et al., 2015). Salinity is considered the most important parameter in regulation of zooplankton abundance, especially in the estuary (Peruman et al., 2009). In this study, salinity showed significant negative correlation with temperature and positive correlation with EC (at $p<.01$). Generally, higher temperature in summer reduces freshwater inflow in estuary and thereby increases salinity. But in this study, the highest mean temperature was observed during monsoon, accompanied by high seasonal precipitation that decreases salinity. This is why temperature showed an inverse relationship with salinity in the present study. Besides this, salinity showed a significant positive correlation with pH and a negative correlation with species abundance index ($p<0.05$).

Total 26 taxa of zooplanktons were recorded, of which copepods were the most dominant group. 16 taxa were found perennial in all three seasons. 11 taxa were recorded with highest density in monsoon, 3 taxa during pre-monsoon and 4 taxa during post monsoon. *Pseudodiaptomus serricaudatus* was the most abundant species and showed its highest abundance during the monsoon season. These taxa were found in all stations irrespective of seasons in the present study. A report suggests that zooplankton usually prefer mesohaline condition (Perumal et al., 2009). Certain species of calanoid copepod *Pseudodiaptomus* were also also reported as a good indicator of eutrophicated polluted water (Basu et al., 2021). *Acrocalanus longicornis* was the most abundant species during post-monsoon season. It is reported that *Pseudodiaptomus serricaudatus, Paracalanus parvus, Bestiolina.similis, Acartia spinicauda* and *Oithona brevicornis* are so well adapted to varied environmental changes that several cyclonic activities could not hamper their distribution pattern in certain regions of Sundarbans Estuary (Chakrabarty et al., 2022). Presence of *Temora turbinata*, almost perennially, indicated regular tidal inputs in the estuary. Copepod *naupli* may be present in all seasons and stations due to its wide tolerance range to varied environmental parameters (Abdulwahab et al., 2015). The genus *Oithona* is not considered as a typical estuarine species but found in high density in the present study. This scenario can be explained by the presence of *Oithona similis* and *Oithona brevicornis* in high densities was an indicator of organic pollution, which was also reported in another study on nearby river Matla of Sundarbans (Nandy and Mandal, 2020). A similar scenario was also reported in a study on Gulf of Gabes, Tunisia (Drira et al., 2017). On the other hand, the coexistence of lowest TDS and highest zooplankton diversity in monsoon can be explained by the fact that more transparent water results in increased zooplankton diversity (Neves et al., 2003).

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Monsoon season is characterized by high rainfall that increases water volume of any water body. This scenario was reflected in the present study also and as a result the mean value of TDS, EC, dissolved oxygen and salinity was found to reach its lowest value during monsoon. On the contrary, Nitrate, phosphate and silicate concentrations reached its peak during monsoon because of flood, domestic sewage input, agricultural runoff from adjacent human habitation and agricultural land. Increased nutrient level in water enhanced phytoplankton's growth, resulting in increased chlorophyll-a concentration. All these conditions were associated with highest number of zooplankton taxa and highest zooplankton density in monsoon. A similar scenario was also reported in river Matla by Nandi and Mandal (2020), where low salinity and high nitrate concentration seemed to elevate zooplankton density.

In all seasons, the four diversity indices were found highest in station 3 with highest TDS, EC, DO, salinity, nitrate, phosphate, silicate, chlorophyll-a and lowest temperature, pH characterized. In our study, the dominance index was found to be highest during post monsoon season in station 2. Indices like Shannon-Weiner Diversity index and Simpson 1_D index were found highest during monsoon season in station 3. Similarly, the Margalef index was also found highest during monsoon in station 2. All these results indicate Monsoon enhanced favourable environment for zooplankton growth. This might also be due to ample growth of sea grass and mangroves during this season (Soundarapandian, 2013). In the correlation matrix, the dominance index showed significant positive correlation with pH and DO (at $p<0.05$). The dominance index showed a significant negative correlation with phosphate ($p<0.01$). The Shannon index showed significant negative correlation with pH, DO (at $p<0.01$) and negative correlation with nitrate and phosphate concentration (at $p<0.01$). The Margalef reflected significant negative correlation with pH, DO and significant positive correlation with nitrate and phosphate ($p<.01$).

Conclusion

Bidyadhari is one of the most essential rivers of Sundarban estuarine system, with a major impact on the socio-economics of the residents of its both banks. The present study provides insight into the physiochemical parameters of Bidyadhari river, which is affected by periodic tidal inflow and regular river discharge that makes the region dynamic in terms of environmental parameters. This dynamism further increases some folds due to human interventions. In this study, salinity and nutrient load were the major factors that reflect the ecological conditions of Bidyadhari river. The spatio-temporal dynamics of zooplankton are considered as a potential bio-indicator of an aquatic environment. The seasonal and spatial alteration of environmental parameters seems to regulate the overall zooplankton diversity and abundance of particular zooplankton, which can be taken as an early indication of water pollution and thereby help in formulation of preventive measures. In our study, there was an indication of organic pollution and eutrophication of Bidyadhari river. The rise or depletion of certain zooplankton taxa or drastic change in the overall zooplankton community indicates the change in hydrological parameters which is not only caused due to seasonal changes but also by human intervention. So, measuring the degree to which Bidyadhari river is affected by human interaction on a regular interval is important. This is crucial regarding the socio-economic conditions of Sundarbans, which is chiefly dependent on fishery industry that supports the livelihood of a vast number of people of Sundarban Biosphere Reserve.

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Conflict of Interest

All the authors declare that there is no conflict of interest.

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