Original Article

LIMNOLOGY FRESHWATER BIOLOGY

Decoding the Influence of Water Quality and Seasonal Shifts on Phytoplankton Communities in Eastern Indian Freshwater Waterbodies

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ABSTRACT. This study presents a comparative analysis of phytoplankton dynamics and ecological status across two freshwater ponds in Birbhum, West Bengal, India, for the two years (from April 2020 to March 2022). The two study sites included a fish cultivation pond (S1) and an agricultural waste pond used for irrigation (S2). Phytoplankton productivity and environmental parameters, including chlorophyll-a content, temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), gross primary productivity (GPP), net primary productivity (NPP), and nutrient levels (nitrate, phosphate, ammonia, silicate, and chloride) were monitored. Both sites were exposed to similar temperature ranges (12˚C to 38˚C), but S2 was more alkaline than S1. Chlorophyll-a content ranged from 1.84 to 5.78 mg/L in S1 and 1.22 to 3.68 mg/L in S2. Nutrient concentrations peaked during post-monsoon period, supporting enhanced phytoplankton growth, and were minimum in summer for both sites. Principal component analysis revealed that nitrate, phosphate, and silicate were primary influencers for S1, while pH, nitrate, phosphate, ammonia, and chloride were influential for S2. GPP and NPP emerged as common factor in both ponds. Correlation analysis indicated that chlorophyll-a in S1 was positively associated with nitrate, phosphate, silicate, and GPP-NPP, whereas, in S2, it correlated positively with pH, nitrate, phosphate, ammonia, and chloride. The post-monsoon season exhibited the highest phytoplankton diversity, dominated by chlorophycean species in S1 and Euglenophyceae in S2, the latter likely due to elevated ammonia levels.

Keywords: Phytoplankton dynamics, physicochemical parameters, nutrient variation, correlation coefficient, PCA

For citation: Garai S., Mondal A., Dey I., Bose R., Pal R. Decoding the Influence of Water Quality and Seasonal Shifts on Phytoplankton Communities in Eastern Indian Freshwater Waterbodies // Limnology and Freshwater Biology. 2025. - № 3. - P. 284-297. DOI: 10.31951/2658-3518-2025-A-3-284

1. Introduction

Phytoplankton growth and productivity controlled by environmental parameters indicated the ecological status of ponds and wetlands used for various purposes (Singha Roy et al., 2018, Dey et al., 2021). They are the chief primary producers and efficient bio-indicators for water quality assessment (Brraich and Kaur, 2015). In an aquatic ecosystem, the base of the food chain is maintained by phytoplankton population (Tas and Gonulal, 2007). Seasonal variation of productivity and diversity of phytoplankton are influenced by different physical, chemical and biological parametersand therefore play a significant role in fish growth and diversity in a particular ecosystem (Angelini and Petrere, 2000; Saifulla et al., 2016). Kaparapu and Gwddada (2015) reported temperature, total phosphorus and nitrate to play major roles in phytoplankton dynamics of reservouirs throughout the year. Bose et al. (2016) investigated phytoplankton diversity from different ecological niches of West Bengal, like freshwater lotic & lentic ponds, oligotrophic and eutrophic water bodies, shallow and deep lakes, and recorded more than 70 microplanktonic taxa belonging to 11 families of Cyanobacteria and 11 families of Chlorophyta. After a thorough study on Santragachi Lake of West Bengal, Barinova et al. (2012) revealed that phytoplankton density became high with increasing temperature and nutrients, where Chlorophycean species dominated over Euglenozoa species during the post-monsoon but minimum during the monsoon period. Bhavya et al. (2016) recorded ammonia as a preferred substrate

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Received: February 12, 2025; ***Accepted:*** April 24, 2025; ***Available online:*** June 11, 2025

for phytoplankton growth both in estuary and coastal waters. Nag and Gupta (2014) analysed physicochemical parameters of some waste ponds in and around Santiniketan of Birbhum district and reported huge variation in physicochemical parameters due to anthropogenic activities. Several authors (Ghosh et al., 2012; Saifulla et al., 2016; Singha Roy et al., 2018) reported positive relation of phytoplankton density with temperature and nutrients. Choudhury and Pal (2010) also reported growth of phytoplankton to be positive with dissolved oxygen, salinity and pH and negative with nitrate, silicate, and BOD in the marine environment.

Seasonal variation of phytoplankton production was reported by several authors. Choudhury and Pal (2011, 2012) concluded that the growth of blue-green and green algal populations were maximum during warmer conditions of summer and monsoon months and diatom population dominated in autumn and winter in estuary water. They found that the total phytoplankton density was highest in winter and lowest during monsoon seasons due to dilution of phytoplankton cells by rainwater. After investigation on a lentic water body in Howrah district Ghosh and Keshri (2011) reported highest phytoplankton diversity and distribution during pre-monsoon and lowest in monsoon. After a thorough study from coastal waters, Vajravelu et al. (2018) reported maximum phytoplankton population density during pre-monsoon and minimum during monsoon. After a thorough study from freshwater ponds of the Hooghly district, Halder et al. (2019) reported that dissolved oxygen, electrical conductivity, pH, light intensity and inorganic phosphorus have important roles in occurrence of microalgal taxa and dominance of chlorophycean members throughout the year.

This research offers a thorough examination of the dynamics of phytoplankton in two divergent freshwater ecosystems, emphasizing the influence of environmental conditions and nutrient availability on the structure and productivity of the community. This research employs a comparative approach, which enables us to distinguish the ecological responses and phytoplankton dynamics of a fish cultivation pond (Site S1) and an agricultural runoff pond (Site S2) that are located in the same region, in contrast to previous studies that have primarily concentrated on individual water bodies only. From this background knowledge, it has been found that a very few studies have done till now about the fresh water phytoplankton diversity in relation to nutrient parameters from Birbhum district with laterite soils of eastern India. Thus, an initiative has been taken to determine the phytoplankton productivity in relation to Chlorophyll-a content with several environmental parameters of two different fresh water ecosystems of Birbhum district in West Bengal- one is used for fish cultivation (S1) and another one for agricultural purposes (S2) surrounded by agricultural field.

2. Material and methods

2.1. Study area

Surface water samples were collected from two physiologically different freshwater ponds located in Birbhum district, West Bengal, India (Fig. 1). Study Site 1 (S1) is the Gangasagar pond in Bolpur, primarily used for freshwater fish cultivation (Latitude: $23^0$39’8” N to $23^0$39’12” N; Longitude: $87^0$41’59”E to $87^0$42’3”E; Total Area: 15,625 m^2). This pond retains a stable water level year-round, with an average depth of 1.5 ± 0.5 meters, supported by seasonal rainfall and groundwater inputs. The surrounding area is sparsely vegetated, mostly with grasses and aquatic plants, which contribute to habitat structure and nutrient cycling. The pond is subject to occasional organic matter input from fish feed and local vegetation, impacting water chemistry. Study Site 2 (S2) is an agricultural runoff pond (Latitude: 23º40’12” N to 23º40’16” N; Longitude: 87º42’48” E to 87º42’52” E; Total Area: 14,640 m^2), with an average depth of 1.3 ± 0.5 meters. This pond receives nutrient-rich agricultural runoff from nearby cropland, especially following the monsoon season, which elevates levels of nitrate, phosphate, and other nutrients. Surrounding this pond are fields of rice, mustard, and other seasonal crops that contribute varying levels of sediment and agrochemical residue.

Both sites experience a subtropical monsoon climate, with significant temperature variation (12˚C - 38˚C annually) and distinct wet (June to September) and dry seasons. Rainfall predominantly during the monsoon season affects water quality and nutrient input, influencing phytoplankton dynamics. Additionally, differences in the primary use of these ponds—fish cultivation for S1 and agricultural runoff collection for S2—result in distinct water quality profiles, ecological processes, and seasonal productivity patterns.

2.2. Phytoplankton sampling and identification

Phytoplankton samples were collected from both ponds every 15 days over a two-year period (April 2020 - March 2022), capturing seasonal variations across Summer, Monsoon, Post-monsoon, and Winter. To ensure consistent sampling conditions, all water samples were collected between 8:00 and 10:00 AM, a timeframe chosen to reflect typical diurnal activity levels of phytoplankton and minimize fluctuations due to photosynthetic variation.

Sampling was conducted at the surface layer (0.5 meters depth) to capture the phytoplankton communities that thrive in the photic zone. Using a 20-liter water sampler, 100 litre of water was collected at each site by retrieving five 20-liter subsamples (20 L × 5 = 100 L total). These subsamples were then pooled and filtered through a 20 μm mesh phytoplankton net to concentrate the phytoplankton biomass, ensuring a representative collection of the community structure at each site. Sampling was performed in triplicate to increase data reliability.

The retained phytoplankton biomass was gently rinsed off the net and combined into a single sample for each site and sampling time. Samples were immediately centrifuged to further concentrate the biomass, then preserved with 4% neutralized formaldehyde to maintain cellular integrity for subsequent analysis.

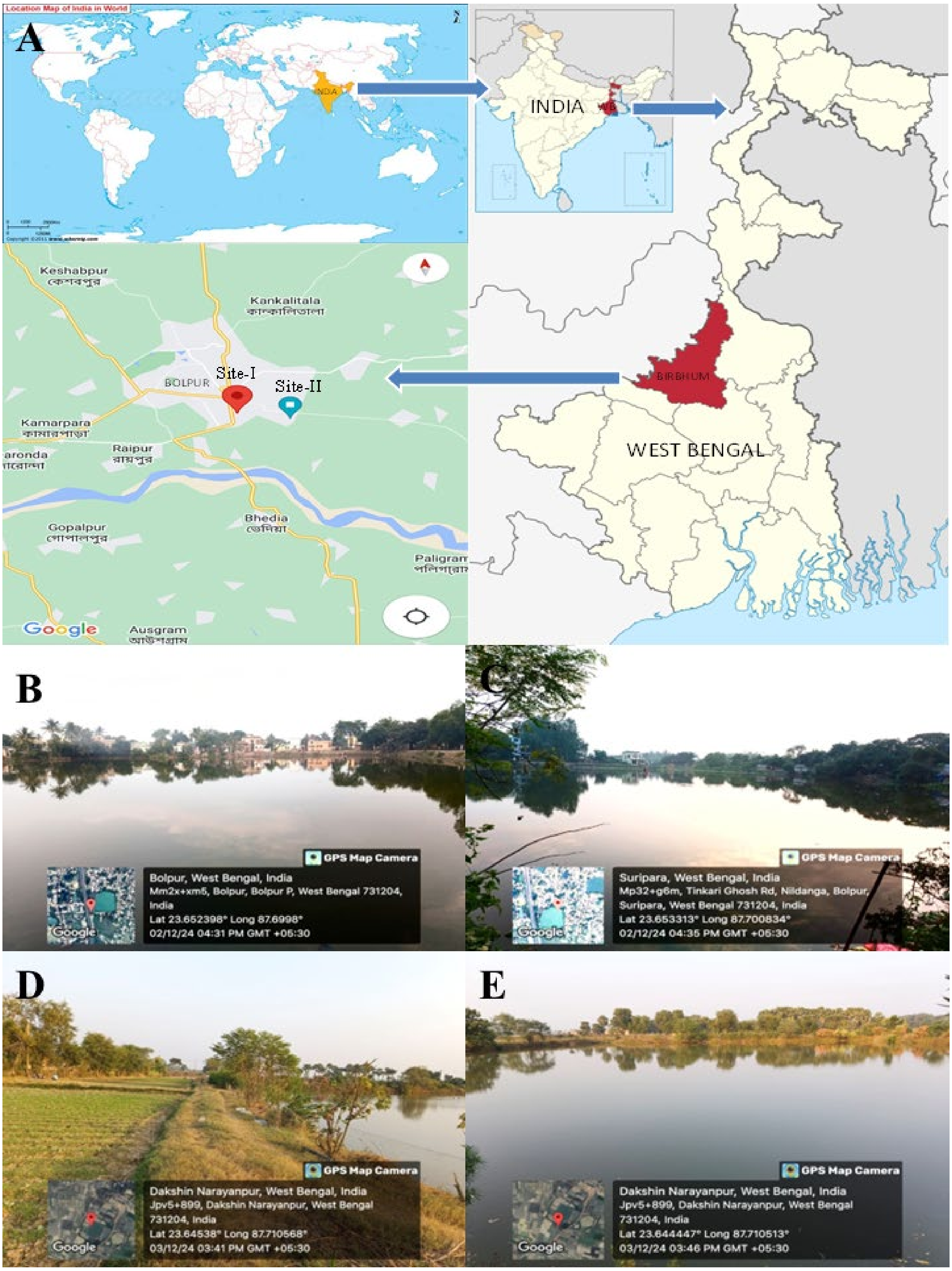


Fig.1. A-Location of study sites B,C Site 1 (S1) and D,E Site 2 (S2).

For microscopic examination, a 200 μl aliquot of the concentrated sample was placed on a glass slide, covered with a cover slip, and examined under a compound microscope (Carl Zeiss Axiostar) at magnifications of 10X, 40X, and 100X. Phytoplankton were identified by morphology and other distinctive features, following standard taxonomic references (Phlipose, 1967; Prescott, 1961; Prescott, 1982; Desikachary, 1989; Komárek and Anagnostidis, 2005; Das and Adhikary, 2014), and cross-verified using Algaebase (Guiry and Guiry, 2002) for confirmation.

2.3. Physico-chemical parameter analysis

Water samples were collected from both sites and immediately filtered through a 20 μm phytoplankton net to remove large particulates and debris. The filtered water samples were then transferred to PVC amber bottles to minimize light exposure and prevent any photochemical changes. Samples were insulated in ice buckets and promptly transported to the laboratory to minimize alterations in water quality parameters.

Upon arrival, several key physicochemical parameters were measured following standard procedures outlined by APHA (2000). Water temperature was recorded in situ using a calibrated glass mercury thermometer (Labworld, -10°C to 110°C) at the sampling depth (0.5 meters), while pH was measured on-site with an Ionix digital pH meter, ensuring immediate and accurate readings.

Dissolved Oxygen (DO) was measured using Winkler's iodometric titration method, known for its accuracy in assessing oxygen concentration directly in the field. Biochemical Oxygen Demand (BOD) was determined by incubating the samples at 20°C for 5 days, following the APHA standard protocol, to assess the organic load in each pond.

In the laboratory, nutrient concentrations (nitrate, nitrite, phosphate, ammonia, silicate, and chloride) were analyzed using spectrophotometric methods. These nutrient levels provided insights into the eutrophic conditions of the ponds and were crucial for understanding phytoplankton growth patterns and seasonal dynamics.

Gross Primary Productivity (GPP) and Net Primary Productivity (NPP) were measured using the light and dark bottle method, which involves incubating samples for 3 hours under natural light conditions to estimate photosynthetic rates. Samples for GPP and NPP were incubated at pond temperature and light levels, simulating natural conditions for accurate productivity measurements.

Chlorophyll-a content, an indicator of phytoplankton biomass and productivity, was determined by the Arnon (1949) method. This involved acetone extraction, followed by spectrophotometric analysis at specified wavelengths to estimate chlorophyll concentration in each sample.

2.4. Correlation coefficient and PCA analysis

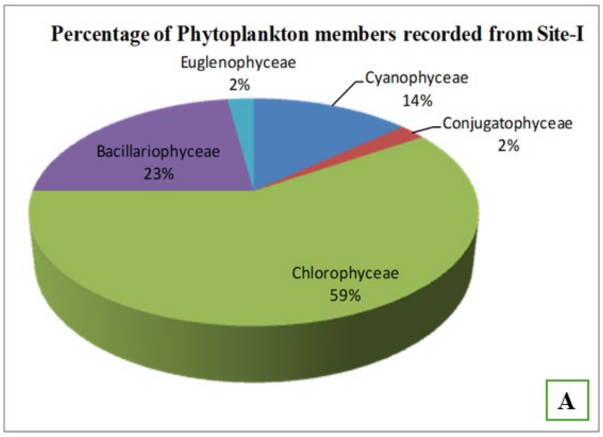
To investigate the relationship between phytoplankton community dynamics and environmental parameters, statistical analyses were performed on the collected data. Pearson and Spearman correlation analyses were used to examine associations between various physico-chemical factors (e.g., nitrate, phosphate, ammonia, silicate, chloride, pH, dissolved oxygen) and phytoplankton abundance and diversity metrics, such as chlorophyll-a concentration. Pearson correlation was applied for parameters with normal distributions, while Spearman correlation was used for parameters with non-normal distributions to capture a broader range of relationships. Principal Component Analysis (PCA) was conducted to reduce the dimensionality of environmental variables and identify the key factors contributing to seasonal changes in phytoplankton communities. This analysis highlighted the primary variables influencing productivity and diversity, differentiating key nutrients and other conditions between the two ponds. Additionally, stepwise regression models were applied to determine the influence of environmental variables on gross and net primary productivity (GPP and NPP) and chlorophyll-a content across seasons. These regression models helped quantify the relative impact of each physico-chemical factor on phytoplankton growth patterns and productivity.

Statistical analyses were conducted using GraphPad Prism (version10.10) with significance levels set at $p < 0.05$. This comprehensive approach allowed for a detailed understanding of how seasonal shifts and nutrient availability drive phytoplankton community dynamics in these freshwater ponds.

3. Results

3.1. Phytoplankton Diversity and Composition

A total of 47 phytoplankton species were identified in Site 1 (S1), a fish cultivation pond, whereas Site 2 (S2), an agricultural waste pond, exhibited a lower diversity with 24 species (Table 1). The percentage composition of different phytoplankton groups across the two sites is illustrated in Figures 2a and 2b. In S1, Chlorophyceae emerged as the dominant group, constituting 59% of the phytoplankton population, followed by Bacillariophyceae (23%) and Cyanophyceae (14%). Minor contributions came from Conjugatophyceae (2%) and Euglenophyceae (2%). Contrastingly, S2 exhibited a higher representation of Euglenophyceae (33%), making it the second most dominant group after Chlorophyceae (42%). Cyanophyceae (17%) and Bacillariophyceae (8%) were present in smaller proportions, with Conjugatophyceae being virtually



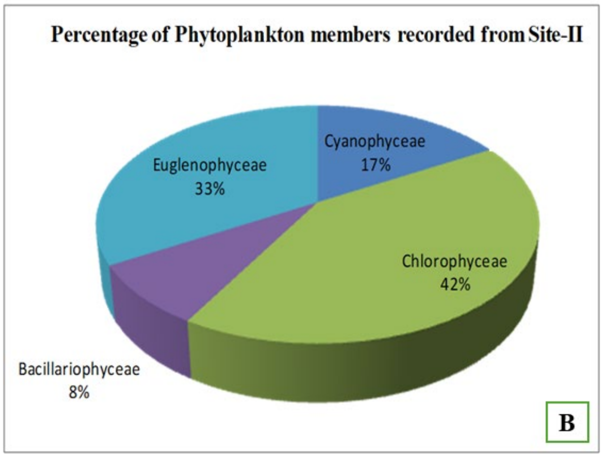


Fig.2. Abundance of different phytoplankton groups in 2a. Site-1, 2b. Site-2.

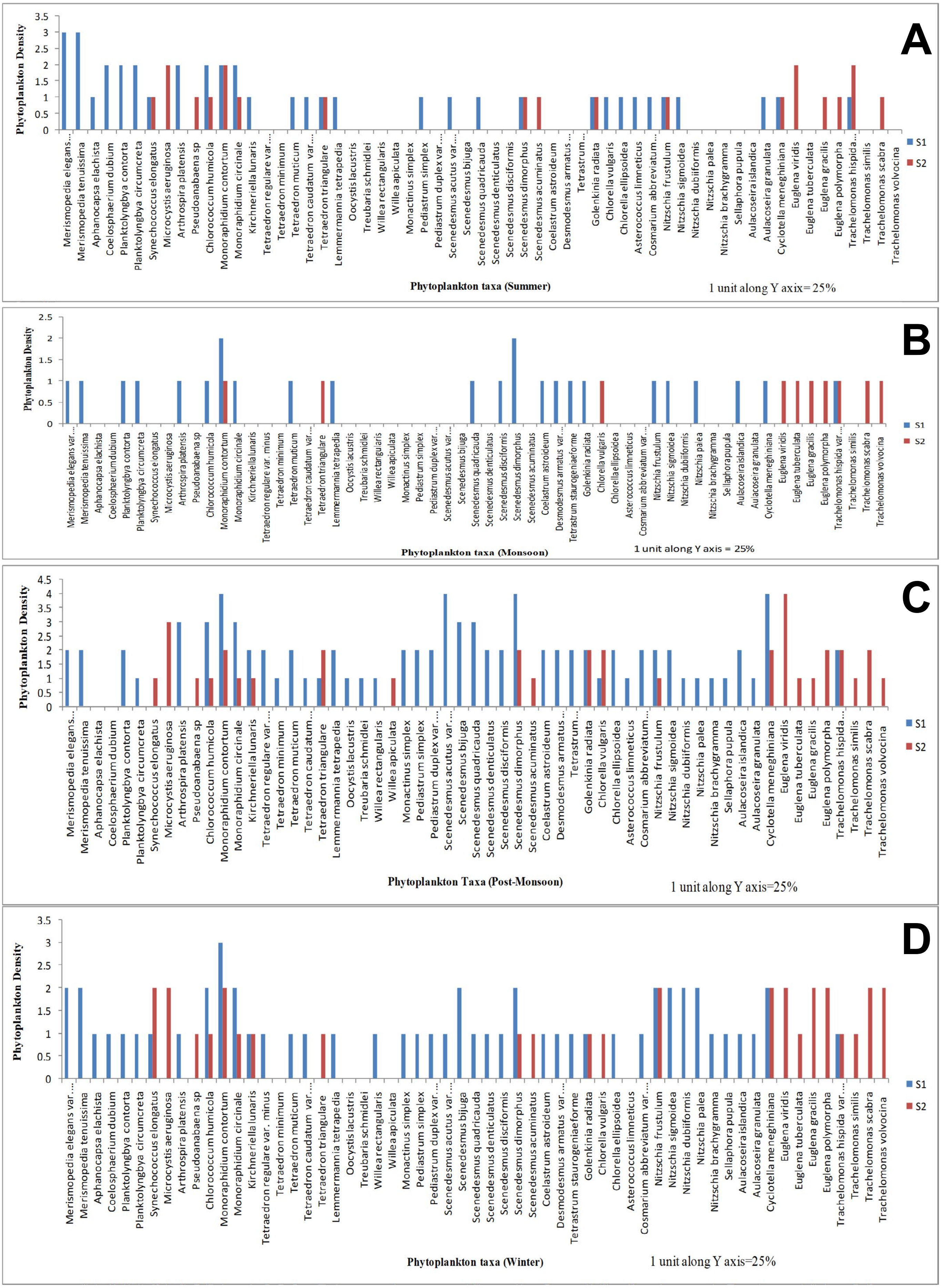


Fig.3. Seasonal variation of phytoplankton taxa in S1 and S2. A. Summer B. Monsoon C. Post-monsoon and Winter.

Table 1. Phytoplankton taxa present in Site 1 and Site 2 in different season.

Systematic Position	**Name of the Species**	**Site-1**				**Site-2**			
		Sum	**Mon**	**Post-Mon**	**Win**	**Sum**	**Mon**	**Post-Mon**	**Win**
Class-Cyanophyceae									
Order-Synechococcales	*Merismopedia elegans var. major*	3	1	2	2	0	0	0	0
	Merismopedia tenuissima	3	1	2	2	0	0	0	0
	Aphanocapsa elachista	1	0	0	1	0	0	0	0
	Coelosphaerium dubium	2	0	0	1	0	0	0	0
	Planktolyngbya contorta	2	1	2	1	0	0	0	0
	Planktolyngbya circumcreta	2	1	1	1	0	0	0	0
	Synechococcus elongatus	1	0	0	1	1	0	1	2
Order-Chroococcales	*Microcystis aeruginosa*	0	0	0	0	2	0	3	2
Order-Oscillatoriales	*Arthrospira platensis*	2	1	3	1	0	0	0	0
	Pseudoanabaena sp	0	0	0	0	1	0	1	1
Class-Chlorophyceae									
Order-Chlorococcales	*Chlorococcum humicola*	2	1	3	2	1	0	1	1
	Monoraphidium contortum	2	2	4	3	2	1	2	2
	Monoraphidium circinale	2	1	3	2	1	0	1	1
	Kirchneriella lunaris	1	0	2	1	0	0	1	1
	Tetraedron regulare var. minus	0	0	2	1	0	0	0	0
	Tetraedron minimum	0	0	1	0	0	0	0	0
	Tetraedron muticum	1	1	2	1	0	0	0	0
	Tetraedron caudatum var. longispinum	1	0	1	1	0	0	0	0
	Tetraedron triangulare	1	0	1	0	1	1	2	1
	Lemmermannia tetrapedia	1	1	2	1	0	0	0	0
	Oocystis lacustris	0	0	1	0	0	0	0	0
	Treubaria schmidlei	0	0	1	0	0	0	0	0
	Willea rectangularis	0	0	1	1	0	0	0	0
	Willea apiculata	0	0	0	0	0	0	1	0
Order-Sphaeropleales	*Monactinus simplex*	0	0	2	1	0	0	0	0
	Pediastrum simplex	1	0	2	1	0	0	0	0
	Pediastrum duplex var. genuinum	0	0	2	1	0	0	0	0
	Scenedesmus acutus var. globosus	1	0	4	1	0	0	0	0
	Scenedesmus bijuga	0	0	3	2	0	0	0	0
	Scenedesmus quadricauda	1	1	3	1	0	0	0	0
	Scenedesmus denticulatus	0	0	2	1	0	0	0	0
	Scenedesmus disciformis	0	1	2	1	0	0	0	0
	Scenedesmus dimorphus	1	2	4	2	1	0	2	1
	Scenedesmus acuminatus	0	0	0	0	1	0	1	1
	Coelastrum astroideum	0	1	2	1	0	0	0	0
	Desmodesmus armatus var. bicaudatus	0	1	2	1	0	0	0	0
	Tetrastrum staurogeniaeforme	0	1	2	1	0	0	0	0
	Golenkinia radiata	1	1	2	1	1	0	2	1
Order-Chlorellales	*Chlorella vulgaris*	1	0	1	0	0	1	2	1
	Chlorella ellipsoidea	1	0	2	1	0	0	0	0
Order-Chlamydomonadales	*Asterococcus limneticus*	1	0	1	0	0	0	0	0
Order-Desmidiales	*Cosmarium abbreviatum var. planctonicum*	1	0	2	1	0	0	0	0

Systematic Position	Name of the Species	Site-1				Site-2			
		Sum	Mon	Post-Mon	Win	Sum	Mon	Post-Mon	Win
Class-Bacillariophyceae									
Order-Bacillariales	*Nitzschia frustulum*	1	1	2	2	1	0	1	2
	Nitzschia sigmoidea	1	1	2	2	0	0	0	0
	Nitzschia dubiiformis	0	0	1	2	0	0	0	0
	Nitzschia palea	0	1	1	2	0	0	0	0
	Nitzschia brachygramma	0	0	1	1	0	0	0	0
Order-Navicullales	*Sellaphora pupula*	0	0	1	1	0	0	0	0
Order-Aulacoseirales	*Aulacoseira islandica*	0	1	2	1	0	0	0	0
	Aulacoseira granulata	1	0	1	1	0	0	0	0
Order-Thalassiosirales	*Cyclotella meneghiniana*	1	1	4	2	1	0	2	2
Class-Euglenoidea									
Order-Euglenales	*Euglena viridis*	0	0	0	0	2	1	4	2
	Euglena tuberculata	0	0	0	0	0	1	1	1
	Euglena gracilis	0	0	0	0	1	1	1	2
	Euglena polymorpha	0	0	0	0	1	1	2	2
	Trachelomonas hispida var. papillata	1	1	2	1	2	1	2	1
	Trachelomonas similis	0	0	0	0	0	0	1	1
	Trachelomonas scabra	0	0	0	0	1	1	2	2
	Trachelomonas volvocina	0	0	0	0	0	1	1	2

Note: 0→Absent, 1→1-25%, 2→26-50% 3→51-75%, 4→76-100% Occurrence.

absent (Fig. 2, Table 1). The most frequently observed species in S1 included *Merismopedia elegans* var. *major* G.M.Smith, *Monoraphidium contortum* (Thuret) Komárková-Legnerová, *Scenedesmus acutus* var. *globosus* Hortobágyi, *Scenedesmus dimorphus* (Turpin) Kützing, *Desmodesmus armatus* var. *bicaudatus* (Guglielmetti) E.H.Hegewald, *Nitzschia frustulum* (Kützing) Grunow, and *Cyclotella meneghiniana Kützing*. In contrast, S2 was dominated by *Microcystis aeruginosa* (Kützing) Kützing, *Synechococcus elongatus* (Nägeli) Nägeli and *Euglena viridis* (O.F.Müller) Ehrenberg (Table 1).

3.2. Seasonal Variations

Phytoplankton abundance and diversity varied significantly across seasons in both sites. S1 was dominated by *Merismopedia elegans*, *M. tenuissima* and S2 with *Microcystis aeruginosa*, *Monoraphidium contortum*, *Euglena viridis* and *Trachelomonas hispida* during Summer (Fig. 3A). Post-monsoon exhibited the highest species richness and productivity, while summer Monsoon recorded the lowest (Fig. 3B). In S1, the dominant species included *Monoraphidium contortum*, *Scenedesmus acutus* var. *globosus*, *Scenedesmus dimorphus*, *Desmodesmus armatus* var. *bicaudatus*, *Nitzschia frustulum*, and *Cyclotella meneghiniana*. These species thrived in the nutrient-enriched post-monsoon environment, with Chlorophyceae being particularly responsive to increased nitrate and phosphate levels (Table 1). In S2, dominant species included *Microcystis aeruginosa*, *Synechococcus elongatus* and *Euglena viridis*. The dominance of Euglenophyceae in S2, particularly during post-monsoon (Fig. 3C), was likely influenced by elevated ammonia levels from agricultural runoff. This group's resilience to highly alkaline conditions and nutrient enrichment underscores their adaptability to such environments. S1 was influenced by *M. contortum*, many species of *Merismopedia*, *Scenedesmus*, *Nitzschia* and *Cyclotella* and S2 with *S. elongatus*, *M. aeruginosa*, *M. contortum*, *N. frustulum*, *C. meneghiniana* and several species of *Euglena* and *Trachelomonas* during winter (Fig. 3D) due to prolonged nutrient availability.

It was recorded from the results that S2 pond was more alkaline (pH 10.69) than that of S1 (pH 8.16) (Fig. 4A). The seasonal temperature variation was almost similar for both the ponds ranging from 12°C to 38°C (Fig. 4B) but dissolved oxygen content was more in S1(17.23 mg/L) than that of S2 (14.66 mg/L (Fig. 4C). The BOD level was 8.25 to 8.73 in S1 and S2 respectively (Fig. 4D). Maximum GPP value recorded as 1.4 mg/L/h in S1 and0.98mg/L/h in S2 during post-monsoon period (Fig. 4E), NPP level was more (0.8 mg/L/h) inS1 than that of S2 again (0.58 mg/L/h) (Fig. 4F). Maximum chlorophyll content was recorded in post monsoon period but more in S1 as expected (5.78 mg/L) compared to S2 (3.68 mg/L) followed by winter season (Fig. 5A). High growth rate of Euglenophyceae is justified with high amount of nitrate (2.52 mg/L) (Fig. 5B), phosphate (4.56 mg/L) (Fig. 5C) and ammonia (0.664 mg/L) (Fig. 5D) contents of S2 pond indicating eutrophication. Chloride content recorded maximum 162.5 mg/during winter

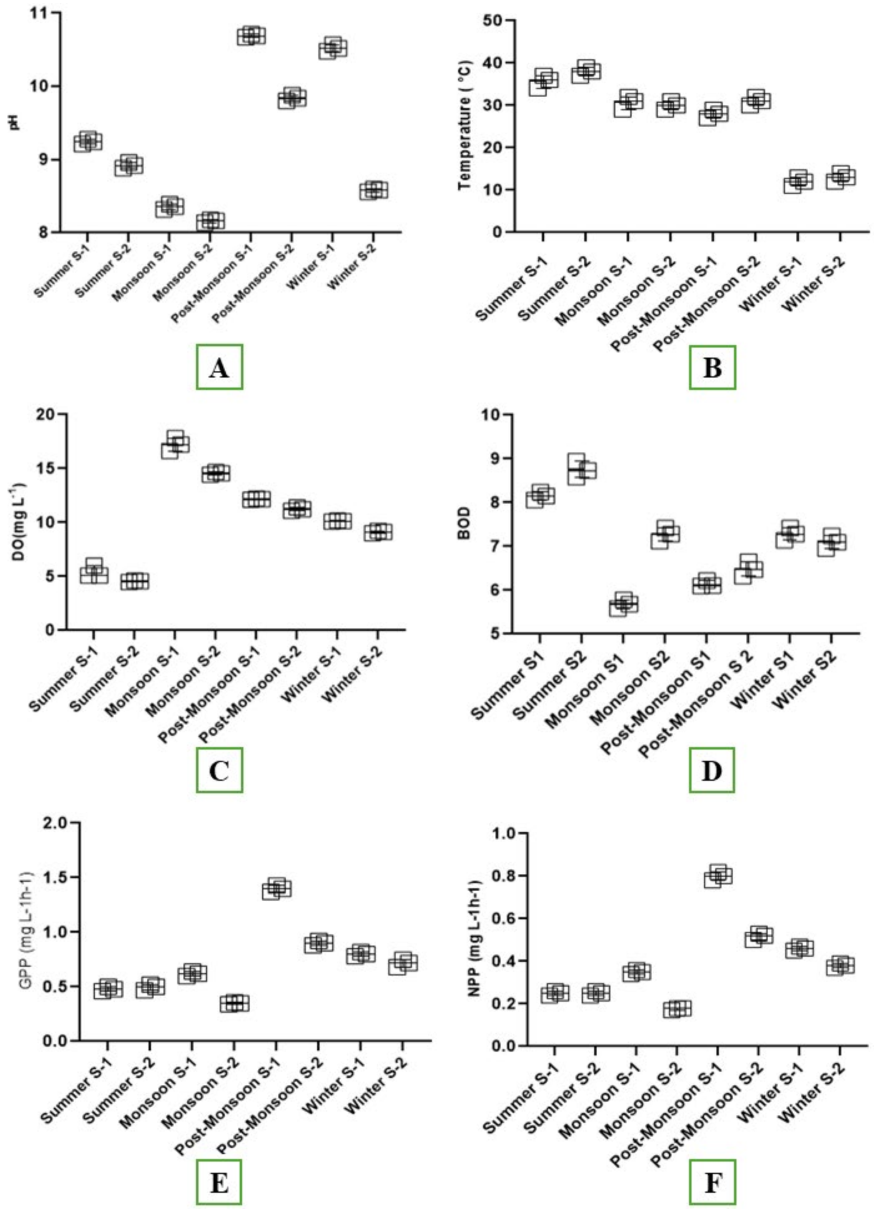


Fig.4. Variations in seasonal mean values with standard error of physicochemical parameters of Site-1(S-1) and Site-2(S-2)- A. pH B. Temperature C. Dissolved oxygen. D. BOD E.GPP, F. NPP.

from S1 and 162.5 mg/L during post-monsoon from S2 (Fig. 5E), and silicate contents were almost high in post-monsoon (6.92 mg/L) and lowest (2.065 mg/L) during summer (Fig. 5F).

3.3. Correlation with Environmental Parameters

The environmental parameters monitored across seasons included temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), gross primary productivity (GPP), net primary productivity (NPP), and key nutrients such as nitrate, phosphate, ammonia, silicate, and chloride.

The chlorophyll-a content, an essential indicator of phytoplankton biomass, varied significantly between the two sites (S1 and S2). At Site S1, chlorophyll-a levels ranged from 1.84 to 5.78 mg/L, while at Site S2, values were lower, ranging from 1.22 to 3.68 mg/L. These variations highlight differences in the ecological dynamics and nutrient availability between the sites.

In S1, a strong positive correlation was observed between chlorophyll-a content and nutrients such as nitrate, phosphate, and silicate, indicating that nutrient enrichment plays a critical role in promoting phytoplankton growth. Additionally, chlorophyll-a showed a positive relationship with both gross primary productivity (GPP) and net primary productivity (NPP). This suggests a synergistic effect where higher nutrient concentrations enhance productivity, further stimulating phytoplankton biomass. Notably, during the post-monsoon period, both nutrient levels and chlorophyll-a content peaked, emphasizing the significance of nutrient runoff and seasonal mixing in driving primary productivity.

At Site S2, chlorophyll a demonstrated a positive correlation with pH, nitrate, phosphate, ammonia, and chloride. The strong relationship with pH indicates the influence of alkaline conditions in shaping the phytoplankton community structure. Unlike S1, nutrient levels at S2 were comparatively lower, yet the correlation between chlorophyll-a and ammonia highlights the role of ammonium as a preferred nitrogen source for

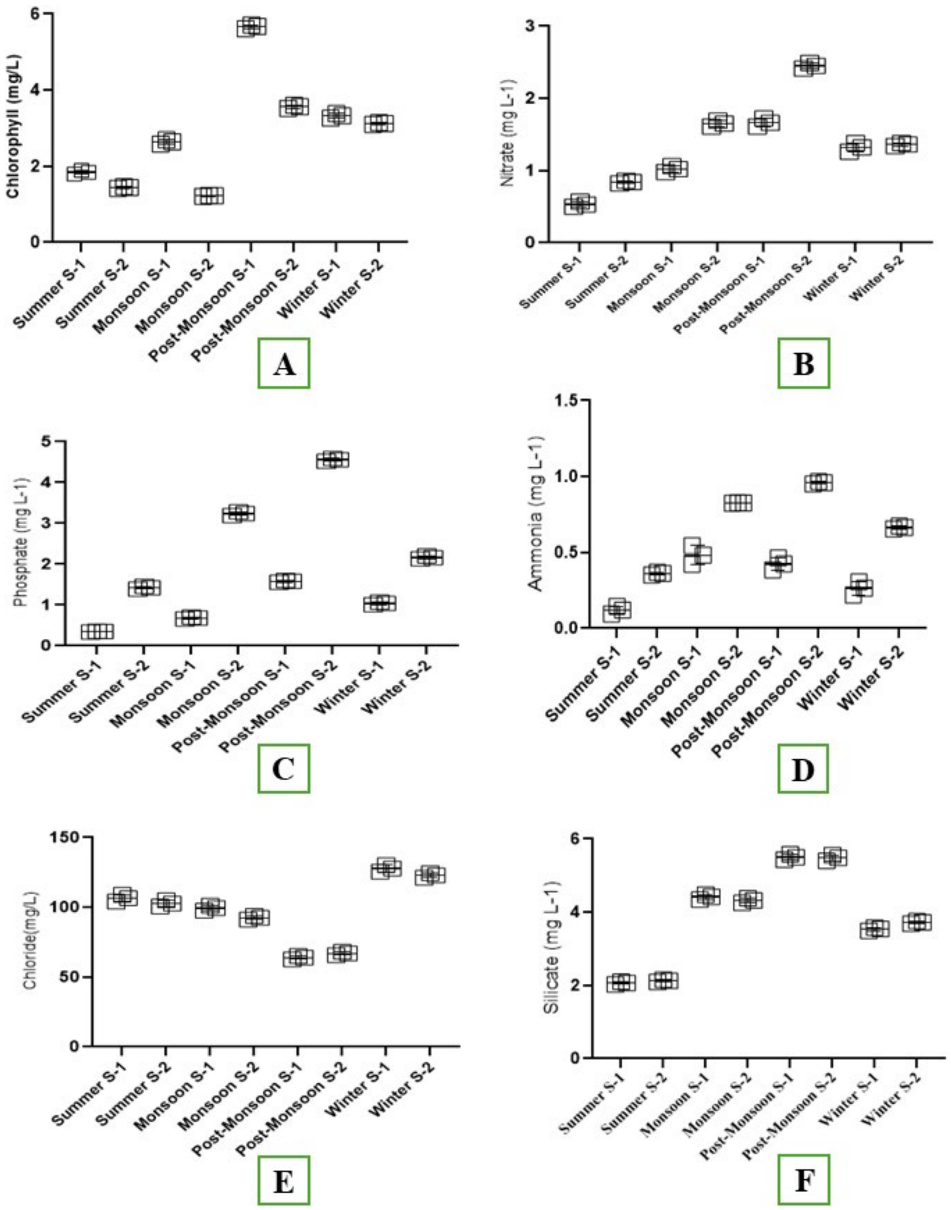


Fig.5. Variations in seasonal mean values with standard error of physico-chemical parameters of Site-1(S-1) and Site-2(S-2)- A. Chlorophyll B. Nitrate C. Phosphate D. Ammonia E. Chloride F. Silicate.

phytoplankton. Seasonal patterns showed a moderate increase in chlorophyll a during the monsoon season, likely driven by nutrient inputs from surrounding areas.

From the Correlation matrix and PCA biplots of S1 and S2 of chlorophyll-a content during different seasons, it was found that PCA of S1 were Nitrate and Silicate (Table 2A, Fig. 6A) and PCA of S2 were pH, phosphate, ammonia and Chloride (Table 2B, Fig. 6B). Among the PCA, GPP and NPP were common for both sites and showed positive relations. Temperature and BOD showed a negative correlation with chlorophyll-a in both the wetlands (Table 2A, 2B and Fig. 6A, 6B).

The graphical representation of environmental parameters across seasons provides a clear insight into the interplay between physical and chemical factors influencing phytoplankton biomass. The pH values (Fig. 4A) exhibited a seasonal trend, with higher alkalinity during the summer and post-monsoon periods, particularly at Site S2, indicating favourable conditions for phytoplankton growth under alkaline environments. Temperature (Fig. 4B) followed a predictable seasonal pattern, peaking during summer and declining in winter. This rise in temperature corresponded with increased metabolic and photosynthetic activity, as reflected by higher gross primary productivity (GPP) and net primary productivity (NPP) during these periods, especially at Site S1.

Dissolved oxygen (DO) levels (Fig. 4C) showed seasonal peaks that aligned with periods of heightened primary productivity. The post-monsoon period, in particular, recorded elevated DO concentrations due to increased photosynthetic activity driven by nutrient enrichment. Conversely, biological oxygen demand (BOD) values (Fig. 4D) were moderately higher at Site S2, indicative of active decomposition processes likely linked to organic matter inputs. These opposing trends in DO and BOD emphasize the dynamic balance between oxygen production and consumption across seasons.

The productivity parameters, GPP and NPP (Figs. 4E and 4F), exhibited strong correlations with chlorophyll-a levels, underscoring the role of pri-

Table 2A. Correlation coefficient of Chlorophyll-a and different physico-chemical parameter of Site-I.

	Chloro-a	Temperature	pH	Nitrate	Phosphate	Ammonia	Chloride	Silicate	DO	BOD	GPP	NPP
Chloro-a	1	-0.265	0.710	0.928	0.974*	0.546	-0.679	0.847	0.237	-0.487	0.993**	0.997**
Temperature	-0.265	1	-0.568	-0.477	-0.455	-0.055	-0.507	-0.203	-0.075	0.030	-0.214	-0.242
pH	0.710	-0.568	1	0.590	0.738	-0.130	-0.108	0.285	-0.385	0.193	0.709	0.726
Nitrate	0.928	-0.477	0.590	1	0.972*	0.717	-0.505	0.930	0.495	-0.666	0.902	0.905
Phosphate	0.974*	-0.455	0.738	0.972*	1	0.563	-0.528	0.853	0.290	-0.500	0.961*	0.962*
Ammonia	0.546	-0.055	-0.130	0.717	0.563	1	-0.574	0.906	0.934	-0.994**	0.518	0.506
Chloride	-0.679	-0.507	-0.108	-0.505	-0.528	-0.574	1	-0.678	-0.312	0.546	-0.709	-0.684
Silicate	0.847	-0.203	0.285	0.930	0.853	0.906	-0.678	1	0.715	-0.871	0.825	0.819
DO	0.237	-0.075	-0.385	0.495	0.290	0.934	-0.312	0.715	1	-0.953*	0.200	0.189
BOD	-0.487	0.030	0.193	-0.666	-0.500	-0.994**	0.546	-0.871	-0.953*	1	-0.454	-0.447
GPP	0.993**	-0.214	0.709	0.902	0.961*	0.518	-0.709	0.825	0.200	-0.454	1	0.990***
NPP	0.997**	-0.242	0.726	0.905	0.962*	0.506	-0.684	0.819	0.189	-0.447	0.990***	1

Note: * Weak correlation, ** Median correlation, *** strongly correlation, **** Very strong correlation. Correlation is significant at the 0.05 level (2-tailed).

Table 2B. Correlation coefficient of Chlorophyll-a and different physicochemical parameter of Site-II.

	Chloro-a	Temperature	pH	Nitrate	Phosphate	Ammonia	Chloride	Silicate	DO	BOD	GPP	NPP
Chloro-a	1	-0.223	0.700*	0.608*	0.497	0.489	0.797**	0.309	0.039	-0.099**	0.732**	0.927****
Temperature	-0.223	1	0.404	-0.114	-0.033	-0.290	0.017	0.054	-0.428	0.300	-0.243	-0.007
pH	0.700*	0.404	1	0.528	0.483	0.250	0.766**	0.401	-0.261	0.070	0.385	0.832***
Nitrate	0.608*	-0.114	0.528	1	0.987****	0.949****	0.931****	0.936****	0.676*	-0.790***	0.236	0.542
Phosphate	0.497	-0.033	0.483	0.987****	1	0.948****	0.896****	0.977****	0.712**	-0.830***	0.150	0.449
Ammonia	0.489	-0.290	0.250	0.949****	0.948****	1	0.804**	0.906****	0.857***	-0.909****	0.186	0.363
Chloride	0.797**	0.017	0.766**	0.931****	0.896****	0.804**	1	0.802**	0.386	-0.523**	0.443	0.772**
Silicate	0.309	0.054	0.401	0.936****	0.977****	0.906****	0.802**	1	0.738**	-0.865**	-0.015	0.284
DO	0.039	-0.428	-0.261	0.676*	0.711**	0.857***	0.386	0.738**	1	-0.971**	-0.131	-0.125
BOD	-0.099**	0.300	0.070	-0.790***	-0.830***	-0.909****	-0.523**	-0.865**	-0.971**	1	0.157	0.028
GPP	0.732**	-0.243	0.385	0.236	0.150	0.186	0.443	-0.015	-0.131	0.157	1	0.643*
NPP	0.927****	-0.007	0.832***	0.542	0.449	0.363	0.772**	0.284	-0.125	0.02	0.643*	1

Note: * Weak correlation, ** Median correlation, *** strongly correlation, **** Very strong correlation. Correlation is significant at the 0.05 level (2-tailed).

mary productivity in driving phytoplankton biomass. Seasonal peaks in GPP and NPP during the post-monsoon period at Site S1 highlighted the combined effect of nutrient runoff and optimal environmental conditions. In contrast, the comparatively lower productivity observed at Site S2 reflected nutrient limitations, with ammonium playing a critical role in sustaining phytoplankton communities during certain seasons.

Collectively, these graphs illustrate the seasonal and site-specific dynamics of environmental factors, reinforcing the pivotal role of nutrient availability, temperature, and pH in regulating primary productivity and phytoplankton growth. Site S1's nutrient-enriched conditions supported higher productivity and chlorophyll-a content, whereas Site S2 displayed a more nuanced response influenced by pH and specific nutrient parameters.

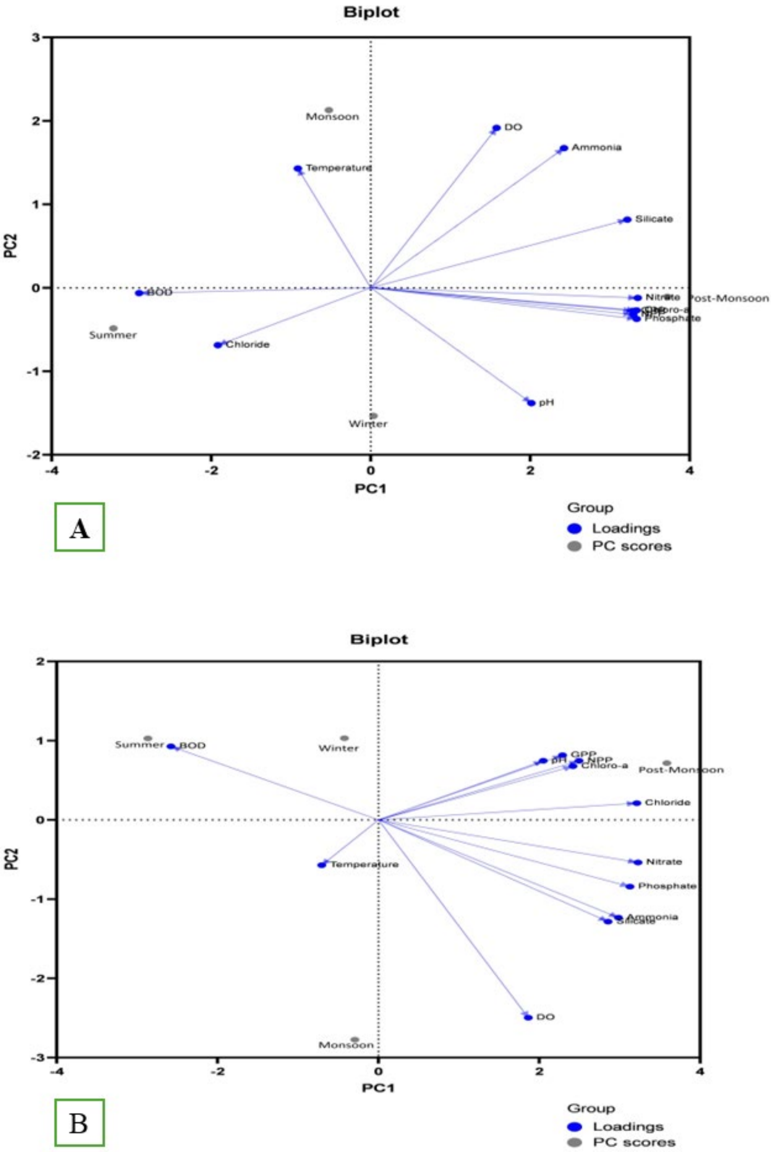


Fig.6. Principal Component Analysis of environmental variables recorded from Site-1 (A) and Site-2 (B).

3.4. Ecological Implications and Status

From the study, it was revealed that the post-monsoon season was ideal for maximum nutrient availability as well as peak phytoplankton production. Site S2, with its higher nutrient content, showed some degree of eutrophication, evident from the occurrence of Euglena and Microcystis species. Correlation and PCA analyses identified nitrate, phosphate, and silicate as the principal components influencing phytoplankton dynamics in Site S1, while pH, nitrate, ammonia, and chloride played dominant roles in Site S2. Among the principal components, GPP, NPP, and chlorophyll-a were common drivers across both sites and displayed strong positive correlations. The PCA analysis provided a comprehensive understanding of the environmental variables shaping phytoplankton dynamics. In Site S1, nitrate, phosphate, and silicate emerged as key contributors to phytoplankton growth, as reflected in the PCA biplots (Fig. 6A). These variables formed a tight cluster aligned with post-monsoon conditions, underscoring their importance in enhancing chlorophyll-a concentration and supporting chlorophycean species. The alignment of temperature and dissolved oxygen (DO) with summer and monsoon seasons further highlighted their seasonal influence, while the lower influence of chloride and BOD during winter suggested reduced nutrient input and productivity in this period.

In contrast, the PCA biplot for Site S2 (Fig. 6B) revealed distinct drivers. Here, pH, nitrate, ammonia, and chloride were the most influential parameters, closely associated with the post-monsoon season. Their strong alignment with GPP, NPP, and chlorophyll-a content illustrated their role in promoting eutrophication events and supporting Euglenophyceae and Cyanophyceae abundance. Temperature and DO showed moderate influences during summer and monsoon seasons, while BOD was prominent during winter, indicating seasonal variations in organic load and decomposition rates.

The principal component analysis (PCA) highlights distinct environmental and nutrient-driven factors influencing phytoplankton dynamics in the two ponds. At Site S1, nitrate, phosphate, and silicate were identified as the primary drivers of phytoplankton diversity and productivity, supporting the dominance of Chlorophyceae and Bacillariophyceae. These groups thrived in the nutrient-enriched conditions typical of a fish cultivation pond, where the interplay between nutrient availability and seasonal variations fostered a robust and responsive phytoplankton community. In contrast, Site S2, heavily influenced by agricultural runoff, demonstrated a more specialized ecological profile. Here, pH, nitrate, phosphate, ammonia, and chloride emerged as critical determinants, reflecting the alkaline and nutrient-specific conditions that favoured the proliferation of Euglenophyceae and Cyanophyceae. The ammonia-rich environment, coupled with elevated chloride levels, provided a competitive edge to these phytoplankton groups, enabling them to adapt and sustain productivity despite lower diversity compared to S1. These findings underscore the ecological dichotomy between the two sites: S1, characterized by a nutrient-responsive and diverse phytoplankton community, and S2, exhibiting a nutrient-adaptive yet less diverse assemblage shaped by its unique environmental stressors. Seasonal nutrient fluctuations further amplified these site-specific dynamics, reinforcing the pivotal role of both natural and anthropogenic influences in governing phytoplankton diversity and ecological health.These findings have significant ecological and practical implications. The study enhances understanding of phytoplankton dynamics in nutrient-rich freshwater ecosystems, offering insights into the ecological models of fish cultivation ponds and agricultural runoff ponds. For instance, the dominance of chlorophycean species in Site S1 highlights the potential for optimizing fish pond management through nutrient modulation. Similarly, the eutrophication observed in Site S2 underscores the need for strategies to manage agricultural runoff to maintain water quality. Moreover, this research suggests the potential for predictive modelling of phytoplankton dynamics based on environmental parameters. Such models could aid in sustainable water resource management, ensuring balanced ecosystem productivity while mitigating adverse effects like eutrophication.

4. Discussion

The phytoplankton population of the particular ecosystem is controlled by various physical, chemical, and biological factors, which ultimately regulate the phytoplankton dynamics of particular ecosystems (Cole and Cloern, 1984). Results indicated a diverse phytoplankton population, primarily composed of members of Cyanobacteria, Chlorophyceae, Euglenophyceae, Bacillariophyceae, and Conjugatophyceae. Members of Chlorophyceae made up the bulk of the population for both the ponds, followed by Bacillariophyceae, Cyanobacteria, Euglenophyceae and Ochlorophyceae for fish pond and Euglenophyta, Cyanobacteria and Bacillariophyta for the Agricultural pond (Table 1 and Fig. 2a, 2b). Similar results of dominance of Euglenophyceae, Chlorophyceae, followed by cyanobacteria, were recorded from East Kolkata Wetland- a Ramsar site by other authors (Singha Roy et al., 2018), wetlands of tropical region (Bose et al., 2016). The dominant genera recorded from the study area included *Merismopedia* from Cyanobacteria, *Scenedesmus* from Chlorophyta, *Nitzschia* from Bacillariophyta, and *Euglena* from Euglenophyta as already published (Garai et al., 2022). In a similar study at different discharge points of the Tannery industry, Dey et al. (2021) reported the role of chemical parameters in phytoplankton productivity and recorded *Phormidium*, *Leptolyngbya, Pseudoanabaena, Amphora* and *Nitzschia* as major taxa.

No significant interseasonal variation was noted among different groups of phytoplankton population. In case of both the sites, almost same groups appeared, except dominance of Euglenophyceae members in post-monsoon and winter in Site-2.

Wassie et al. (2017) reported that *Melosira* and *Microcystis* were dominated in polluted water with high Nitrate and phosphate content polluted water. We also noticed that S2 contained high amount of nitrate, phosphate and dominance of cyanobacteria and *Euglena* signifying eutrophication of the water body. The nutrient concentration and pH play an important role in phytoplankton productivity as evident from correlation matrix and PCA studies. Among different factors, pH, nitrate, phosphate, ammonia, silicate, GPP, and NPP played the most significant role as they are highly positively correlated with chlorophyll productivity. On the other hand from the PCA plot also Nitrate and Silicate in S1 and pH, phosphate, ammonia and chloride in S2 appeared as principal components for phytoplankton dynamics.

Karak et al. (2013) estimated total nitrogen (16.9 g/kg), total carbon (321.4 g/kg) from agricultural fish pond sediment, which was better than the Indian compost standard. Our results showed that the post-monsoon period was most productive for both the ponds, showing high chlorophyll content with maximum level of nutrients like nitrate, phosphate, silicate etc, along with high GPP value as expected. Therefore, the fishpond sediment would be very good compost as well.

Highly significant correlations between chlorophyll content and GPP clearly established that GPP was the estimation of total fixed carbon by phytoplankton population (Choudhury and Pal, 2012). Thus, the overall productivity is totally dependent on phytoplankton photosynthetic activity for both ponds.

This study provides a comprehensive analysis of phytoplankton dynamics in two distinct freshwater ecosystems, highlighting how nutrient availability and environmental conditions shape community structure and productivity. Unlike previous studies that have primarily focused on individual water bodies, our research adopts a comparative approach, allowing us to differentiate the ecological responses and phytoplankton dynamics of a fish cultivation pond (Site S1) and an agricultural runoff pond (Site S2) belonging from the same area.

A key novelty of this study lies in its demonstration of site-specific phytoplankton adaptation to varying nutrient inputs. At Site S1, the dominance of Chlorophyceae and Bacillariophyceae under nutrient-rich post-monsoon conditions aligns with findings from managed aquaculture systems in the region. However, this study reveals a unique interplay between nitrate, phosphate, and silicate, which together foster a more diverse and resilient phytoplankton community. The seasonal influence of temperature and dissolved oxygen further underscores the dynamic nature of fish ponds, distinguishing them from static water bodies like reservoirs or lakes, where nutrient turnover rates may be slower. Conversely, Site S2 exhibited a phytoplankton community composition strongly influenced by agricultural runoff, with Euglenophyceae and Cyanophyceae emerging as dominant groups. This pattern aligns with eutrophic conditions observed in other anthropogenically impacted freshwater bodies, yet this study provides novel insights into the role of ammonia and chloride in shaping these assemblages. Unlike previous reports where nutrient enrichment primarily favored cyanobacterial blooms, our results suggest a co-dominance of Euglenophyceae, indicating a more complex response to agricultural inputs.

Comparative studies from regional lakes and reservoirs have reported different phytoplankton compositions, often dominated by diatoms (Bacillariophyceae) in winter and Cyanophyceae in summer. In contrast, our findings highlight how specific nutrient regimes in managed ponds can sustain diverse communities year-round, emphasizing the importance of localized environmental factors. This distinction underscores the need for tailored water management strategies, as generic models based on large water bodies may not accurately predict phytoplankton dynamics in smaller, human-influenced ecosystems. By integrating PCA and correlation analyses, this study not only identifies key environmental drivers but also provides a framework for predicting phytoplankton shifts in response to nutrient fluctuations. These findings contribute to the broader understanding of freshwater ecology by offering a site-specific perspective on phytoplankton responses, which can be valuable for both aquaculture management and eutrophication mitigation strategies in similar water bodies.

5. Conclusion

From the study, it was revealed that the post-monsoon season was ideal for maximum nutrient availability as well as peak phytoplankton production. Site S2, with its higher nutrient content, showed some degree of eutrophication, evident from the occurrence of *Euglena* and *Microcystis* species. Correlation and PCA analyses identified nitrate, phosphate, and silicate as the principal components influencing phytoplankton dynamics in Site S1, while pH, nitrate, ammonia, and chloride played dominant roles in Site S2. Among the principal components, GPP, NPP, and chlorophyll-a were common drivers across both sites and displayed strong positive correlations. These findings have significant ecological and practical implications. The study enhances understanding of phytoplankton dynamics in nutrient-rich freshwater ecosystems, offering insights into the ecological models of fish cultivation ponds and agricultural runoff ponds. For instance, the dominance of chlorophycean species in Site S1 highlights the potential for optimizing fish pond management through nutrient modulation. Similarly, the eutrophication observed in Site S2 underscores the need for strategies to manage agricultural runoff to maintain water quality. Moreover, this research suggests the potential for predictive modelling of phytoplankton dynamics based on environmental parameters. Such models could aid in sustainable water resource management, ensuring balanced ecosystem productivity while mitigating adverse effects like eutrophication. Future studies should expand to other freshwater ecosystems with varying anthropogenic impacts to validate these findings. Investigating intervention strategies, such as controlled nutrient inputs or bioremediation techniques, could further enhance the applicability of this research in ecological conservation and resource management.

Acknowledgements

The infrastructural facility was supported by CAS Phase VII and DST-FIST Level II, Department of Botany, University of Calcutta.

Authors contribution

Sumanta Garai: Writing – original draft, Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis. Anwesha Mondal: Writing – review & editing, Validation, Methodology, Formal analysis, Data curation. Iman Dey: Methodology, Formal analysis, Rahul Bose: Visualization, Methodology, Ruma Pal: Writing – review & editing, Investigation, Conceptualization, Supervision.

Funding

Author (s) received no financial support for the research, authorship and publication of the article.

Availability of Data and materials

All the data are enclosed within the manuscript. There is no associated data.

Conflict of interest

The authors declared no potential conflicts of interest with respect to the research, authorship and publication of the article.

References

Angelini R., Petrere Jr.M. 2000. A model for the plankton system of the Broa reservoir, Sao Carlos, Brazil. Ecological Modelling 126(2–3): 131–137. DOI: 10.1016/S0304-3800(00)00261-1

APHA. 2000. Standard methods for the examination of water and waste water. 20th Edition, American Public Health Association, Washington, D.C. USA.

Arnon D.I. 1949. Copper Enzymes in Isolated Chloroplasts. Polyphenoloxidase in *Beta Vulgaris*. Plant Physiol 24 (1): 1–15. DOI: 10.1104/pp.24.1.1

Barinova S., Keshri J.P., Ghosh S. et al. 2012. The influence of the monsoon climate on phytoplankton in the Shibpukur pool of Shiva temple in Burdwan, West Bengal, India. Limnological Review 12(2): 47–63.

Bhavya P.S., Kumar S., Gupta G.V.M. et al. 2016. Nitrogen uptake dynamics in a tropical eutrophic estuary (Cochin, India) and adjacent coastal water. Estuaries Coasts 39: 54–67.

Bose R., Nandi C., Roy A.S. et al. 2016. Floristic survey of microplanktonic Cyanobacteria and Chlorophyta from different ecological niches of West Bengal, India. Phytomorphology 66(3–4): 77–93.

Brraich O.S., Kaur R. 2015. Phytoplankton community structure and species diversity of Nangal Wetland, Punjab, India. International Research Journal of Biological Sciences 4(3): 1.

Choudhury A.K., Pal R. 2010. Phytoplankton and nutrient dynamics of shallow coastal stations at Bay of Bengal, Eastern Indian Coast. Aquatic Ecology 44: 55–71. DOI: 10.1007/s10452-009-9252-9

Choudhury A.K., Pal R. 2011. Variation in seasonal phytoplankton assemblages as a response to environmental changes in the surface waters of a hyposaline coastal station along the Bhagirathi-Hooghly estuary. Environmental Monitoring and Assessment 179: 531–553. DOI: 10.1007/s10661-010-1761-4

Choudhury A.K., Pal R. 2012. Understanding the seasonal dynamics of primary productivity in relation to phytoplankton populations from the Bhagirathi-Hooghly estuary, eastern Indian coast. Journal of algal biomass utilization 3(4): 80–88.

Cole B.E., Cloern J.E. 1984. Significance of biomass and light availability to phytoplankton productivity in San Francisco Bay. Marine Ecology Progress Series 17(1): 15–24.

Das S.K., Adhikary S.P. 2014. Freshwater Algae of Eastern India. New Delhi: Astral International Pvt. Ltd.

Desikachary T.V. 1989. Atlas of Diatoms (Marine Diatoms of the Indian Ocean Region). Madras Science Foundation, Madras. VI: 1–13, pls. 622–809.

Dey I., Banerjee S., Bose R. et al. 2021. Spatiotemporal variations in the composition of algal mats in wastewater treatment ponds of tannery industry. Environmental Monitoring and Assessment 193(6): 359. DOI: 10.1007/s10661-021-09144-5

Garai S., Bose R., Pal R. 2022. Seasonal variation in phytoplankton diversity of freshwater wetlands of Birbhum district, West Bengal. Journal of the Botanical Society of Bengal 76(2): 25–42.

Ghosh S., Barinova S., Keshri J.P. 2012. Diversity and seasonal variation of phytoplankton community in Santragachi Lake, West Bengal, India. QScience Connect 3(1): 1–19. DOI: 10.5339/connect.2012.3

Ghosh S., Keshri J.P. 2011. Assessment of phytoplankton diversity and dynamics of a lentic water body of Belur rail station area with reference to pollution status. Environment and Ecology 29(1): 232–234.

Guiry M.D., Guiry G.M. 2002. Algaebase: Worldwide electronic publication, National University of Ireland, Galway. URL: http://www.algaebase.org

Halder P., Debnath M., Ray S. 2019. Occurrence and diversity of microalgae in phytoplankton collected from freshwater community ponds of Hooghly District, West Bengal, India. Plant Science Today 6(1): 8–16. DOI: 10.14719/pst.2019.6.1.426

Kaparapu J., Gwddada M.N.R. 2015. Seasonal dynamics of phytoplankton and its relationship with the environmental factors in Meghadrigedda Reservoir of Visakhapatnam, Andhra Pradesh, India. Journal of Algal Biomass Utilization 6(4): 60–67.

Karak T., Bhattacharyya P., Paul R.K. et al. 2013. Evaluation of composts from agricultural wastes with fish pond sediment as bulking agent to improve compost quality. Clean – Soil Air Water 41(7): 711–723. DOI: 10.1002/CLEN.201200142

Komárek J., Anagnostidis K. 2005. Cyanoprokaryota II. Teil: Oscillatoriales. In: Büdel B., Gardner G., Krienitz L., Schagerl M. (Eds.) Süßwasserflora von Mitteleuropa. Elsevier, München.

Nag A., Gupta (Joshi) H. 2014. Physicochemical analysis of some water ponds in and around Santiniketan, West Bengal, India. International Journal of Environmental Sciences 4(5): 676–682. DOI: 10.6088/ijes.2014040404507

Phlipose M.T. 1967. Chlorococcales. New Delhi: Indian Council of Agricultural Research.

Prescott G.W. 1961. Algae of the Western Great Lakes Area. Dubuque: Brown Composition Publication.

Prescott G.W. 1982. Algae of the Western Great Lakes Area. Otto Koeltz Science Publishers, Germany.

Roy A.S., Gorain P.S., Paul I. et al. 2018. Phytoplankton nutrient dynamics and flow cytometry based population study of a eutrophic wetland habitat in eastern India, a Ramsar site. RSC Advances 8(17): 9530–9545. DOI: 10.1039/C7RA12761H

Saifulla A.S.M., Mustafa Kamal A.H., Rajaee A.M. et al. 2016. Phytoplankton in tropical mangrove estuaries: role and interdependency. Forest Science and Technology 12(2): 104–113. DOI: 10.1080/21580103.2015.1077497

Tas B., Gonulal A. 2007. An ecologic and taxonomic study on phytoplankton of a shallow lake. Journal of Environmental Biology 28(2): 439.

Vajravelu M., Martin Y., Ayappan S. et al. 2018. Seasonal influence of physico-chemical parameters on phytoplankton diversity, community structure and abundance at Parangipettai coastal waters, Bay of Bengal, South East Coast of India. Oceanologia 60(2): 114–127. DOI: 10.1016/j.oceano.2017.08.003

Wassie T.A., Melese A.W. 2017. Impact of physicochemical parameters on phytoplankton compositions and abundances in Selameco manmade reservoir, Debre Tabor, South Gondar, Ethiopia. Applied Water Science 7(4): 1791–1798. DOI: 10.1007/s13201-015-0352-5