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Original Article

Factors affecting abundance and primary productivity of phytoplankton in a wetland ecosystem of Bangladesh

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Abstract
Wetlands are the most productive, economically important and hydrologically variable ecosystems. In this study, the abundance of phytoplankton and its primary productivity were evaluated in Dingapota Haor of Bangladesh. A total of 41 phytoplankton genera belong to Chlorophyceae (15), Bacillariaophyceae (14), Cyanophyceae (8) and Euglenophyceae (4) were recorded whereas Bacillariaophyceae (37.02%) was the most dominant. The highest cell density (22.71×10^4 cell L^{-1}) was recorded in pre-monsoon. Diversity indices were also significantly higher in pre-monsoon. The species diversity, evenness and richness varied from 2.51–3.79, 0.57–0.90 and 4.65–7.50 respectively. Difference in phytoplankton assemblage with an overall average dissimilarity value of 52.56 % was recorded. Cyclotella (3.60%), Bacillaria (3.13%), Volvox (2.95%), Spirulina (2.92%) and Euglena (2.88%) were the five most contributory species to the seasonal variation. Gross Primary Production, Net Primary Production and Community Respiration values ranged from 0.90–2.49, 0.68–1.60 and 0.35–0.89 mgCm^{-3}day^{-1} respectively. Alkalinity and Chl-*a* showed significant positive correlation with GPP, NPP and CR. Pre-monsoon was the most productive phase whereas the monsoon season was the least productive. The current study produced valuable baseline data that will aid in the formulation of wetland conservation and management strategies.

Keywords: diversity indices; environmental parameters; phytoplankton abundance; primary productivity; seasonal fluctuation

1 | INTRODUCTION

Primary production in aquatic ecosystems is largely dependent on phytoplankton, which also has a vital role in the food web (Reynolds 1984). Primary producers in aquatic ecosystems include the phytoplankton, which also play an important role in the diversification of aquatic species and the generation of oxygen through photosynthesis. Distribution and composition of phytoplankton determines the tropic state of an aquatic ecosystem (Reynolds *et al.* 1993; Chen *et al.* 2003; Wu *et al.* 2011). Biotic and abiotic variables contribute to the fluctuating composition of phytoplankton populations (Vanni and Temte 1990; Carrillo *et al.* 1995; Burford and Davis 2011). Growth rate and succession of phytoplankton are changes with the alteration of its metabolic pathways. Temporal and spatial distributions of phytoplankton communities are also regarded as an indicator of water environment (Kruk *et al.* 2010; Reynolds 2012; Visser *et al.* 2016). Therefore, health status of an aquatic ecosystem can be studied by the patterns of phytoplankton community structure and diversity assemblages (Nunes *et al.* 2018; Sabater *et al.* 2008).

Primary productivity by phytoplankton primarily depends on nutrient concentration in aquatic environment. It is possible to evaluate the potential for fish production by assessing primary productivity, the most important factor in fish production. Abiotic and biotic interactions affect primary productivity. The trophic level of a water body is mostly determined by its phyico-chemical properties, such as temperature, transparency, depth, pH, alkalinity, TDS, DO, primary productivity, chlorophyll-*a* etc. Phytoplankton abundance is affected by these factors, which in turn influences fish growth. Researchers have paid a lot of attention to primary productivity of different water bodies in order to estimate the potential for fish production of a water body and, by extension, to build successful fishery management plans.

Haors are natural depression of distinctive hydro-ecological characteristics and essential habitats for the unique and dynamic ecosystems, which have immense productive or ecological values. During the monsoon season, it gets surface runoff from rivers and floodplains and becomes dry in post-monsoon. There are a total of 373 haors (43% of the total land area) in the districts of Sunamganj, Sylhet, Maulvibazar, Habiganj, Brahmanbaria, Netrokona and Kishoreganj (Islam 2010; MPHA 2012; Ahmed 2013). From a geophysical, economic, social, and cultural perspective, Haors in the Netrokona district is crucially important. Dingaputa, in the Mohonganj Upazila (sub district) of the Netrakona district, is the largest inland freshwater haor / wetland environment (~ 8000 ha). This haor is related to the Kongso River, which originates from the Dhonu River and links to the Surma River downstream. Fisheries diversity of Dingapota Haor is very rich that supports many indigenous fish species. Assessment of the productivity state of the investigated haor is might contribute to the effective management of the habitat.

Number of research on the phytoplankton community and its relationship to the physicochemical parameters of the haor ecosystem are available (e.g. Bhuyan *et al.* 2019; Alam *et al.* 2020). However, there is no information on the primary productivity and phytoplankton diversity of Dingapota Haor. The objectives of this paper are to analyse the physicochemical characteristics and their effects on primary production and the phytoplankton population in Dingapota Haor. Therefore, it might help Haor basin biodiversity and conservation efforts by providing information on the composition and abundance of phytoplankton and the production condition of the Dingapota Haor.

2 | METHODOLOGY

2.1 Study area and duration

The current research was conducted in Dingapota Haor at Mohongonj upazila (sub-district) of Netrokona district, Bangladesh. Three sites (Karchapur, 24°77′72″N 91°05′10″E; Mollikpur, 24°80′23″N 91°03′57″E; Khurshimul, 24°88′66″N 91°01′99″E) were monitored for water quality and phytoplankton for a year from July 2020 to June 2021 (Figure 1). The monthly samples were divided into three distinct seasons: a) Monsoon season, which ran from July to October; b) Post-monsoon, which ran from November to February; and c) Pre-monsoon, which ran from March to June.

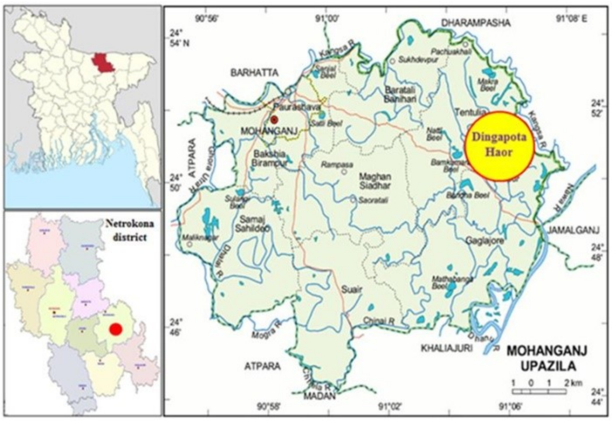

FIGURE 1 Map of the Dingapota Haor in Mohanganj Upazila of Netrokona district (modified from Banglapedia map).

2.2 Measurement of environmental variables

Different physicochemical and biological parameters are considered important regulator for water quality of wetlands. Phytoplankton communities are sensitive to changes in their environment and therefore their total biomass and species composition are used as indicators of water quality (Brettum and Andersen 2005). Monthly readings were taken of the following parameters: temperature, turbidity, depth, dissolved oxygen, pH, NO_3-N, PO_4-P, alkalinity and total dissolved solids (TDS). Water quality parameters were measured from 10:00 am to 12:00 pm, every month. Black-labelled bottles were used to collect 500 ml of surface water from each study site. Using a multi-parameter water quality meter (model HANNA, HI 98194, pH/EC/DO multi-parameter, Romania), the temperature (°C), pH, DO and TDS of the water were measured. The water depth was determined using a standard scale. The transparency of water (in centimetres) was measured using a Secchi disc. With the help of a spectrophotometer (model DR-1900, Germany) alkalinity, NO_3-N and PO_4-P were measured.

2.3 Study of phytoplankton

For the purpose of qualitative and quantitative phytoplankton analysis, three locations of Dingapota Haor were sampled. Twenty litres of water were taken from various depths and places using a tube sampler. The water samples were then filtered via plankton net with a 30 m mesh size. Concentrated into 50 ml is the phytoplankton population found in 10 litres of water. Next, 10% buffered formalin was used to store the concentrated samples in plastic bottles for later analysis. Phytoplankton were studied qualitatively and quantitatively by placing 1 ml of concentrated plankton sample onto Sedgwick-Rafter cells (S-R cell) using a dropper. After putting the sample in the counting chamber, the air bubbles were pushed out with a cover slip, a few minutes to keep in the chamber to allow the plankton to settle. Counts of plankton were taken using a compound microscope (model Optica, Italy) on an S-R counting cell (Michael 1984). The amount of plankton in a sample of 10 randomly selected squares of the cell was estimated using the following formula (Rahman 1992).

N = A × 1000 × c / V × F × L. Where, N = number of plankton cells per litre; A = total number of plankton counted; C = volume of final concentrate of samples in ml; V = volume of a field in cubic millimetre; F = number of the fields counted; L = volume of original water in litre;

The colonial as well as filamentous algae were considered a single unit. The amount of plankton was quantified as cells per litre of water (Needham and Needham 1962; Prescott 1964; APHA 1992; Bellinger 1992).

2.4 Determination of productivity status

According to Gaarder and Gran (1927), the status of primary productivity was measured by using light and dark bottles. The water samples were analysed by Winkler's method. Community Respiration (CR), Net Primary Production (NPP) and Gross Primary Production (GPP) were calculated using the following formula. NPP (mg L^{-1}) = Final DO in light bottle – Initial DO in light bottle; CR (mg L^{-1}) = initial DO in dark bottle – final DO in dark bottle; GPP (mg L^{-1}) = CR (O_2 consumed by respiration) + NPP (net O_2 production).

2.5 Measurement of chlorophyll-*a* (µg L^{-1})

The water samples, totalling 100 ml, were filtered through Whatman GF/C glass fibre filter paper with a pore size of 47 µm. The filter papers were then crushed with a glass rod and stored in PVC vials containing 10 ml of acetone. The vials were kept in a refrigerator for about 14 hours. On the next day, in a centrifuge machine (model Fisher scientific, 5207R, Germany), the samples were centrifuge for 15 minutes at 3500 RPM. Following collection of the supernatant in a 4 ml cuvette, chlorophyll-a concentration was determined at 664 and 750 nm using the following formula (Boyed 1982) and a spectrophotometer (model DR-1900, Germany).

Chlorophyll-*a* (µg L^{-1}) = 119 (A664 – A750) V × 100 / L × S. Where A664 = absorbance at 664 nm; A750 = absorbance at 750 nm; V = the volume of acetone extract in ml; L = the length of light path in the spectrophotometer in cm; S = the volume of ml of filtered sample.

2.6 Diversity indices

The Shannon-Weiner index, Margalef's richness index and Pielou's evenness index were calculated using the following formula:

Shannon diversity index: $H = -\sum i \frac{n_i}{N} \ln \frac{n_i}{N}$ (Shannon and Weiner 1949); where, H = diversity index, n_i = the relative abundance (S / N), S = the number of individuals for each species, N = total number of individuals.

Species richness (S): $D = \frac{S-1}{ln ln\, N}$ (Margalef 1968); where, D = Margarlef's richness index, S = Number of different species in the sample, N = Total number of individual species in the sample.

Evenness index (J): $e = \frac{H}{L_n S}$ [L_n = the natural logarithm] (Pielou 1966); where, H is Shannon-Weiner's diversity index and S is the number of different species in the sample.

2.7 Data analysis

One-way analysis of variance (ANOVA) was performed at the 5% level of significance on seasonal changes in water quality variables using Statistical Package for the Social Sciences (SPSS, version 20.0). To study relationship between the different physico-chemical and biological variables, Pearson correlation was performed.

3 | RESULTS

3.1 Seasonal variation of environmental variables

During the study period seasonal variation was observed in water quality parameters (Figure 2). A one-way ANOVA revealed significant seasonal differences in all water quality parameters. Water temperature was the highest during pre-monsoon season (29.89 ± 0.65°C) and the lowest during post-monsoon season (21.31 ± 2.86°C). Transparency was ranged between 39.59 ± 4.91 cm (pre-monsoon) to 24.66 ± 0.82 cm (monsoon). Water depth was the highest during monsoon (5.96 ± 1.73 m) and the lowest during pre-monsoon (1.66 ± 0.89 m). pH was ranged between 7.00 ± 0.95 (post-monsoon) to 6.38±0.53 (pre-monsoon) and DO between 6.63±0.83 mg/l (post-monsoon) to 4.56 ± 0.49 mg/l (pre-monsoon). NO_3-N and PO_4-P were the highest during pre-monsoon (0.33 ± 0.12 and 1.34 ± 0.11 mg L^{-1}) and the lowest during monsoon (0.13 ± 0.01 and 1.16 ± 0.02 mg L^{-1}). Total alkalinity was 126.89 ± 7.47 L^{-1} during pre-monsoon and 103.38 ± 4.44 L^{-1} during monsoon. TDS was also the highest during pre-monsoon (135.73 ± 5.5 L^{-1}) and the lowest during monsoon. Chlorophyll-*a* was also the highest during pre-monsoon (5.86 ± 0.64 µg L^{-1}) and the lowest during monsoon (2.50 ± 1.02 µg L^{-1}).

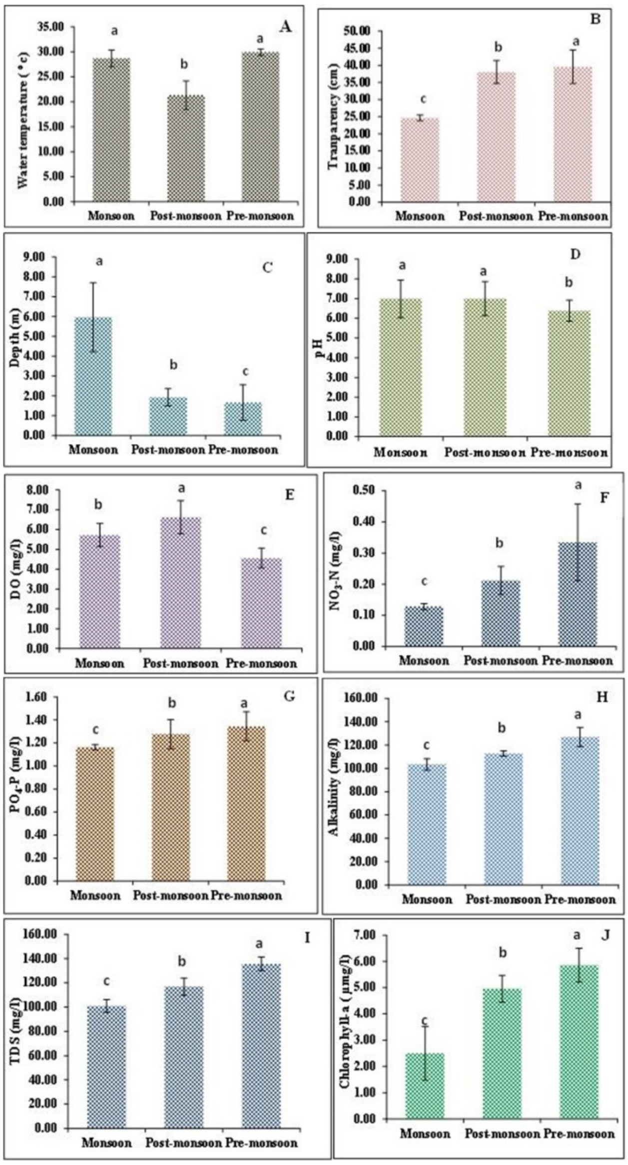

FIGURE 2 Bar chart for each of the ten environmental variables (A – J) from the studied haor during July 2020 - June 2021. A, water temperature; B, water transparency; C, water depth, D, pH; E, dissolved oxygen; F, nitrte; G, phosphate; H, alkalinity; I, total dissolved solid and J, chlorophyll-*a*. Bars that have no letter in common significantly differ from each other.

3.2 Phytoplankton composition, total abundance, diversity and phytoplankton assemblage

A total of 41 taxa representing four taxonomic divisions: Chlorophyceae (15), Bacillariaophyceae (14), Cyanophyceae (8) and Euglenophyceae (4) were recorded (Table 1). For the period of pre-monsoon season, the number of taxa was highest (41) and it was lowest during the monsoon season (23). Among the four taxonomic groups Bacillariophyceae (37.02%) was the most dominant, whereas the lowest contribution was recorded for Euglenophyceae (9.21%) (Figure 3). Pre-monsoon had the highest density (22.71 × 10^4 cell L^{-1}), and monsoon had the lowest density (5.38 × 10^4 cell L^{-1}) (Table 2). Shannon's diversity index (H′) ranged from 2.51 (monsoon) to 3.79 (pre-monsoon). In addition, evenness and richness were highest during the pre-monsoon (0.90 and 7.50) and lowest during the monsoon (0.57 and 4.50), respectively (Table 2).

Phytoplankton assemblage was significantly different among the seasonal groups which is represent by the analysis of similarity (ANOSIM) whereas global R were 0.057, 0.583 and 0.941 and the *p* value were 0.316, 0.029 and 0.031 respectively (Table 3). According to SIMPER analysis, the average dissimilarity between monsoon and post-monsoon, monsoon and pre-monsoon and post-monsoon and pre-monsoon was 44.94, 58.24, and 51.58% respectively. According to ANOSIM, there is a statistically significant difference in species assemblage across the seasons (p = 0.001, R = 0.577). With a dissimilarity of 52.56% on average, SIMPER analysis identified *Cyclotella* (3.60%), *Bacillaria* (3.13%), *Volvox* (2.95%), *Spirulina* (2.92%) and *Euglena* (2.88%) as the top five contributory phytoplankton species responsible for this seasonal variations.

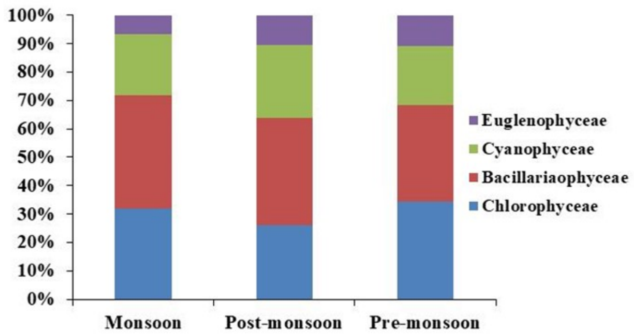

FIGURE 3 Seasonal percentage of phytoplankton groups in the Dingapota Haor during the study period (July 2020 – June 2021).

3.3 Primary productivity

The gross primary production (GPP) of the study haor differed from season to season, and this was maximum (2.49 ± 0.03 mgC m^{-3} day^{-1}) in pre-monsoon and minimum (0.90 ± 0.02 mgC m^{-3} day^{-1}) in monsoon (Figure 4). In contrast, the net primary production (NPP) was maximum (1.78 ± 0.10 mgC m^{-3} day^{-1}) in pre-monsoon and minimum (0.68 ±0.01 mgC m^{-3} day^{-1}) in monsoon at Dingapota Haor. The community respiration (CR) was maximum (0.89 ± 0.04 mgC m^{-3} day^{-1}) in pre-monsoon and minimum (0.35±0.02 mgC m^{-3} day^{-1}) in monsoon season.

TABLE 1 List of phytoplankton diversity from the Dingapota Haor during July 2020 - June 2021.

Genera	Monsoon	Post-monsoon	Pre-monsoon
Chlorophyceae			
Actinastrum	–	–	+
Ankistrodesmus	–	+	+
Chlorella	–	+	+
Closterium	–	–	+
Coleochaete	+	+	+
Cosmarium	+	+	+
Melosira	–	–	+
Microspora	+	+	+
Pediastrum	–	+	+
Spirogyra	+	+	+
Spirulina	+	+	+
Spirulina major	+	+	+
Scenedesmus	–	+	+
Ulothrix	+	+	+
Volvox	+	+	+
Bacillariaophyceae			
Eunotia sp.	+	+	+
Asterionella	–	–	+
Bacillaria	+	+	+
Chaetoceros	–	+	+
Cyclotella	+	+	+
Fragilaria	+	+	+
Gyrosigma	–	+	+
Navicula	+	+	+
Navicula radiosa	+	+	+
Nitzschia	+	+	+
Pinnularia	+	+	+
Surirella	+	+	+
Rhizosolenia	–	+	+
Synedra	+	+	+
Cyanophyceae			
Anabaena	+	+	+
Anabaena spiroides	+	+	+
Apanizomenon	–	+	+
Chroococcus	+	+	+
Microcystis	–	+	+
Microcystis pseudofilamentosa	+	+	+
Oscillatoria	+	+	+
Oscillatoria acuminate	+	–	+
Euglenophyceae			
Euglena	+	+	+
Phacus	+	+	+
Phacus curvicauda	+	+	+
Trachelomonas	–	–	+

3.4 Interaction of water quality and productivity status

Pearson's correlation performed among physicochemical and biological parameters of the Dingapota Haor is shown in Table 4. Transparency showed a negative correlation with depth ($p < 0.001$). Alkalinity, chlorophyll-*a*, diversity indices and GPP showed highly significant positive correlation with transparency ($p < 0.001$). pH showed significant negative correlation with chlorophyll-*a* ($p < 0.05$). DO was negatively correlated with CR ($p < 0.05$). NO_3-N had a highly positive relation with PO_4-P ($p < 0.001$) whereas alkalinity showed highly positive correlation with TDS, GPP, NPP and CR ($p < 0.05$). Chlorophyll-*a* was positively correlated with GPP, NPP, and CR ($p < 0.05$) and negatively correlated with water depth and pH ($p < 0.05$).

TABLE 2 Total species, total abundance and diversity indices of phytoplankton community of Dingapota Haor.

Parameters	Monsoon	Post-monsoon	Pre-monsoon	*p*-value
Total species (N)	23.50 ± 3.79^{c}	34.00 ± 0.82^{b}	41.00 ± 0.00^{a}	<0.001
Total abundance (×10^{4} cells L^{-1})	5.38 ± 0.31^{b}	8.91 ± 0.43^{b}	22.71 ± 9.07^{a}	0.003
Shannon diversity (H')	2.51 ± 0.32^{c}	3.37 ± 0.14^{b}	3.79 ± 0.03^{a}	<0.001
Pielou's species evenness (J')	0.57 ± 0.10^{b}	0.84 ± 0.06^{a}	0.90 ± 0.06^{a}	<0.001
Margalef species richness (d)	4.65 ± 0.93^{c}	6.32 ± 0.15^{b}	7.50 ± 0.60^{a}	0.001

The presence of different superscript letters for mean values in the same row indicates significant ($p < 0.05$) differences.

TABLE 3 ANOSIM and SIMPER analysis of phytoplankton assemblage.

Groups	ANOSIM R	ANOSIM *p*	Dissimilarity index from SIMPER: Ave. diss. (%)	Dissimilarity index from SIMPER: Typical species	% contribution
Monsoon vs. Post-monsoon	0.057	0.316	44.94		
Monsoon vs. pre-monsoon	0.583	0.029	58.24	*Melosira*	3.35
				Trachelomonas	3.31
				Chaetoceros	3.12
				Gyrosigma	2.58
				Chroococcus	2.46
Post-monsoon vs. Pre-monsoon	0.941	0.031	51.58	*Cosmarium*	3.62
				Navicula	3.41
				Volvox	3.53
				Cyclotella	2.78
				Chaetoceros	2.72
overall (pooled)	0.577	0.001	52.56	*Cyclotella*	3.60
				Bacillaria	3.13
				Volvox	2.95
				Spirulina	2.92
				Euglena	2.88

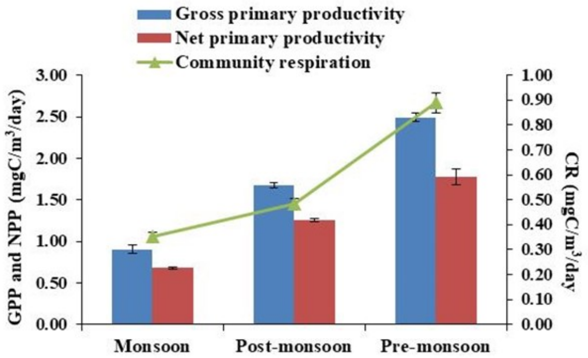

FIGURE 4 Primary productivity of Dingapota Haor, represented as chlorophyll-*a*.

4 | DISCUSSION

Primary productivity in a body of water is typically driven by phyico-chemical and other environmental factors (Hossain *et al.* 2013). The hydrobiological status of Dingapota Haor in relation to the phytoplankton was studied in this research work. Season, location, sample frequency and the temperature of effluents entering the stream have all been shown to have significant effects on water temperature variations (Ahipathy and Puttaiah 2006), which supports our current findings.

Rahman *et al.* (2015) reported similar range of water temperature in three lakes in Jahangiragar University, Bangladesh. Related results were also stated by Bhuiyan *et al.* (2019) and Haque *et al.* (2020) in Tanguar Haor ecosystem of Sunamganj district and in Atrai River of Bangladesh. In the present investigation a gradual increase in water temperature from post-monsoon to pre-monsoon has been observed due to the seasonal variations of sunshine and rain. Monsoonal runoff from the terrestrial land was found to reduce the transparency of water during monsoon season in the present investigation. Study conducted by Haque *et al.* (2021) also described that the occurrence of higher turbidity during the monsoon period in their study period. A satisfactory transparency value for the water of in the investigated haor happened because of the presence of less colloidal matter. Productive water bodies should have a maximum transparency of 40 cm (Rahman 1992). The Water depth was ranges between 5.96 ± 1.73 m in Monsoon to 1.66±0.89m during pre-monsoon. Haque *et al.* (2020) shown that monsoon has the greatest depth and pre-monsoon has the least Mainly heavy rainfall during monsoon season caused higher depth and lower depth in pre-monsoon season because of less rainfall and high evaporation rate**.**

Islam *et al.* (2017) found that the mean pH of the Karimganj Haor was 7.30; our data shows that the highest pH was recorded during the post-monsoon and the lowest pH was recorded during the pre-monsoon. The fluctuation might be due to distillery effluents, rise in temperature and decrease in water level for evaporation, soil properties etc. in the studied haor. The pre-monsoon period observed the highest plankton population and the monsoon period found the lowest. The DO levels fluctuated from 6.63±0.74 mg L^{-1} during the post-monsoon period to 4.56±0.56 mg L^{-1} in the pre-monsoon season. The high concentration of dissolved oxygen during winter was possibly due to the low temperature, low rainfall. Samples taken from Hakaluki Haor showed an average DO content of 5.03 mg L^{-1} (Akter *et al.* 2017), while those taken from Karimganj Haor showed values of 6.40 to 6.90 mg L^{-1} (Khan *et al.* 2007). Nutrient concentrations such as nitrate-N (NO_3-N) at various sites in Chalan Beel fluctuated from 0.01 to 0.33 mg L^{-1}, correlating with those measured by Halder *et al.* (1992) in Kaptai Lake, Bangladesh. The present study found that the NO_3-N content of the water was highest prior to the monsoon season, coinciding with the peak density of phytoplankton.

The varied concentration of PO_4-P in the present investigation might be due to soil properties, decomposition of aquatic materials and utilisation by algae, absence of inflow in summer, rainfall, etc. Kaptai Lake had an average PO_4-P content of 0.367 mg L^{-1}, with readings ranging from 0.32 to 0.41 mg L^{-1}. During the dry season, Khan *et al.* (1996) found significantly higher levels of PO_4-P in the lake water compared to the wet season. Chowdhury *et al.* (2008) discovered that April has the highest total alkalinity and September has the lowest. The mean alkalinity of the Korotoa River water (122.05 mg L^{-1}) was similar to the current study (Ahatun *et al.* 2020).

Therefore, according to the previous study, Dingapota Haor has an optimal and productive alkalinity level. In pre-monsoon season, the haor had a TDS concentration of 135.73 ± 5.50 mg L^{-1}, while it was 100.97 ± 5.16 mg L^{-1} through monsoon season. TDS concentrations in Hakaluki Haor were found to be similar to those found in the present investigation, fluctuating 80.75 to 184.0 mg L^{-1} with a mean concentration of 132.38 mg L^{-1} (Akter *et al.* 2017). Chlorophyll-*a* was also the highest during pre-monsoon (5.86 ± 0.64 µg L^{-1}) and the lowest during monsoon (2.50 ± 1.02 µg L^{-1}). Sultana and Khondker (2009) and Islam *et al.* (2012) stated the lowest biomass of phytoplankton (chlorophyll-*a*) in September. The total number of phytoplankton recorded in this study was consistent with Rangpur Beel (Ehsan *et al.* 1996). Among the four taxonomical groups Bacillariophyceae (37.02%) was the most dominant that could be due to the fact that they can tolerate the widely changing hydrographical conditions. Other researchers have made comparable statements (Maheshara Lake in Gorakhpur of India, Shukla *et al.* 2013; Turag River of Bangladesh, Khatun and Alam 2019). The pre-monsoon season had the highest total phytoplankton density, while the monsoon season had the lowest. It might be due to good adaptability in the fluctuation of physical or chemical variability namely optimum water temperature and higher nutrient concentration prevailed during that period. Islam (2021) found the highest concentration of phytoplankton during pre-monsoon in Halda River, Bangladesh. The highest phytoplankton density was observed in summer in some Indian lakes (Bhaskar *et al.* 2009).

The maximum diversity score was 3.79 in pre-monsoon, 3.37 in post-monsoon and 2.51 in monsoon seasons. These Shannon-Weiner diversity index values may be considered quite low which may be due to heavy rain during monsoon. The maximum value of diversity indices in pre-monsoon season may be due to the high phytoplankton species composition in this season. The other reasons for higher diversity indices during pre-monsoon season may be the desirable environmental conditions with a higher concentration of nutrients in the water column of the studied Haor. Khatun *et al.* (2019) also found more or less similar result in Turag River, Bangladesh. Gross primary productivity, net primary productivity and community respiration were lowest during monsoon season and the highest in pre-monsoon. Highest rate of productivity during pre-monsoon was due to bright sunlight, higher temperature and increased alkalinity in pre-monsoon season accelerated the primary productivity. Lower rate of primary production during monsoon season is the result of limitation of sunshine period and low light energy due to interruption of clouds. Subsequently, the dilution effect of rain on phytoplankton density and as well as the increased in turbidity from nearby area are prime causes of lowering the primary productivity in monsoon season in the investigated haor. Related findings have been noted by several other researchers (Sreenivasan 1964; Singh 1998; Umavati *et al.* 2007; Baruah *et al.* 2009; Patil and Chavan 2010; Sarma and Dutta 2012).

5| CONCLUSIONS

The Dingapota Haor is exposed to seasonal fluctuation in phytoplankton abundance and primary productivity depending upon the seasonal flooding and nutrient availability. Water quality parameters in Dingapota Haor are varied and substantially different among the seasons. Within the current state of water quality this is congenial for primary producer and fish production. Four taxonomical divisions — Chlorophyceae (15), Bacillariaophyceae (14), Cyanophyceae (8) and Euglenophyceae (4) were dominant. Pre-monsoon phytoplankton taxa peaked at 41, dropped to 23 during the monsoon and then progressively increased in the post-monsoon season (34). Bacillariophyceae (37.02%) dominated the four taxonomical categories, while Euglenophyceae (9.21%) was the least. The pre-monsoon period had the highest chlorophyll-*a* concentration, whereas the monsoon period had the lowest concentration. Pre-monsoon values of phytoplankton density were found to be the highest, whereas monsoon values were found to be the lowest. Seasonal variation was also observed in diversity indices whereas pre-monsoon was the most diversified and taxonomically rich season. Primary productivity values GPP and NPP were higher in pre monsoon whereas the lower GPP and NPP were recorded in monsoon. Alkalinity and chlorophyll-*a* values may be considered the most important governing factors for primary productivity of phytoplankton in Dingapota Haor.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

EK supervision and manuscript, MN fieldwork, research design and manuscript preparation; NNN, review and editing; AB manuscript review; YM manuscript review.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request to the corresponding author.

REFERENCES

Ahatun S, Islam MS, Kabir MH, Rehnuma M, Hoq ME (2020) Water quality and fish diversity in Korotoa River of Bogura, Bangladesh. Bangladesh Journal of Fisheries 32(1): 61–72.

Ahipathi MV, Puttaiah ET (2006) Ecological characteristics of Vrishabhavathi River in Bangalore (India). Environmental Geology 49: 1217–1222.

Ahmed A (2013) Bangladesh: environmental and climate change assessment. International Fund for Agricultural Development, Rome, Italy.

Akter S, Saha SK, Kabir MH, Mamun SA, Islam MS (2017) Fluctuations in water quality at Hakaluki Haor of Bangladesh. Bangladesh Journal of Environmental Science 32: 35–40.

Alam MR, Eliyana MNA, Touhiduzzaman MS, Hossain MN (2020) Diversity and seasonal variation of plankton community in Ramsagar Lake, Bangladesh. Discovery Agriculture 6(16): 199–209.

APHA (1992) Standard methods for the examinations of water and waste water. American Public Health Association, 1015 Eighteenth Street, New York, Washington D.C. 874 pp.

Baruah PP, Kakati B (2009) Studies on phytoplankton community in a highland temple pond of Assam, India. Indian Journal of Environment and Ecoplanning 16(1): 17–24.

Bellinger EG (1992) A key to common algae: freshwater, estuarine and some coastal species. The Institute of Water and Environment Management, London, UK.

Bhaskar CV, Mansour SAG, Nagendrappa G (2009) Phytoplankton studies in relation to physico-chemical environment of some lakes around Tumkur City, Karnataka, India. Nature Environment and Pollution Technology 8(3): 533–538.

Bhuiyan MAH, Islam SAMS, Kowsar A, Islam MR, Kakoli SA, ... Khondker M (2019) Phytoplankon in relation to water quality of Tanguar Haor ecosystem, Bangladesh: I Rauar station. Dhaka University .Journal of Biological Science 28(2): 131–138.

Brettum P, Andersen T (2005) The use of phytoplankton as indicators of water quality. NIVA-report SNO 4818-2004: 197 pp.

Burford MA, Davis TW (2011) Physical and chemical processes promoting dominance of the toxic cyanobacterium *Cylindrospermopsis raciborskii*. Chinese Journal of Oceanology and Limnology 29: 883–891.

Carrillo P, Reche I, Sanchez-Castillo P, Cruz-Pizarro L (1995) Direct and indirect effects of grazing on the phytoplankton seasonal succession in an oligotrophic lake. Journal of Plankton Research 17: 1363–1379.

Chen Y, Qin B, Teubner K, Dokulil MT(2003) Long-term dynamics of phytoplankton assemblages: *Microcystis* domination in Lake Taihu, a large shallow lake in China. Journal of Plankton Research 25: 445–453.

Ehshan MA, Hossain MS, Mazid MA, Mollah, MFA, Rahman S, Rezzaque A (1996) Limnology of Chanda beel. Bangladesh Journal of Fisheries Research 1(1): 31–34.

Gardner T, Gran HH (1927) Investigation of the production of plankton in the Oslo Fiord. Rapports et Et Proc-Verb. Consortium Internal Explore Science Mer Mediterranean 42: 1–48

Haldar GC, Mazid MA, Ahmed KK (1992) Limnology and primary production of Kaptai Lake, Bangladesh. In: De Silva SS (Ed) Reservoir fisheries of Asia. Proceedings of the 2nd Asian reservoir fisheries workshop held in Hangzhou, People's Republic of China, 15–19 October, 1990. IDRC, Ottawa. ON, Canada. IDRC- 291e. pp. 2–11.

Haque MA, Jewel AS, Akhi MM, Atique U, Paul AK, ... Alam MM (2021) Seasonal dynamics of phytoplankton community and functional groups in a tropical river, Environ Monitoring and Assessment 193: 704.

Haque MR, Salam MA, Roy KC, Jewel AS, Samad MA (2020) Spatio-temporal variation of some physico-chemical parameters and abundance of planktonic community in the Atrai River, Dinajpur, Bangladesh . International Journal of Biosciences 17(2): 238–248.

Hossain MI, Alam MM, Alam M, Kamal BMM, Galib SM (2013) Investigation of phytoplankton and physico-chemical parameters in nursery, growout and broodstock ponds. Journal of Scientific Research 5(3): 553–569.

Islam MA (2010) Adaptive crop agriculture including innovative practices in Haor basin. Centre for Natural Resource Studies (CNRS), Bangladesh. Proceedings of the South Asia Regional Consultations on Strengthening Climate Resilience through a Climate Smart Disaster Risk Management Approach. Faridabad, Delhi NCR, India, 14 – 16 June, 2010.

Islam MS (2021) Phytoplankton variables dynamics in the Halda River (Bangabandhu Fisheries Heritage), Chittagong, Bangladesh. Aquatic Bioresources & Environment 4(3): 24–37.

Islam MS, Alfasane MA, Khondker M (2012) Planktonic primary productivity of a eutrophic water body of Dhaka metropolis, Bangladesh. Bangladesh Journal of Botany 41(2): 135–142.

Islam MS, Jahan J, Mou MA, Kabir MH, Uddin MJ (2017) Investigation of water quality and fish status of Karimganj Haor area in Kishoreganj. Journal of Environmental Science and Natural Resources 10(2): 19–27.

Khan MAG, Chowdhury SH, Paul JC (1996) Community structure and ecology of microbenthic invertebrate fauna of Lake Kaptai, Bangladesh. Tropical Ecology 37(2): 229–245.

Khatun M, Alam AKM (2019) Phytoplankton assemblage with relation to water quality in Turag River of Bangladesh. Caspian Journal of Environmental Sciences 18(1): 31–45.

Kruk C, Huszar VLM, Peeters ETHM, Bonilla S, Costa L, Lurling M (2010) A morphological classification capturing functional variation in phytoplankton. Freshwater Biology 55: 614–627.

Margalef R (1968) Perspectives in ecological theory. University of Chicago Press, Chicago.

Michael P (1984) Ecological methods for field and laboratory investigations. Tata McGraw-Hill, New Delhi.

MPHA (2012) Master plan of haor area, Ministry of Water Resources, Government of the People's Republic of Bangladesh.

Needham JG, Needham PR (1962) A guide to the study of freshwater biology, fifth edition. Liolden-day, Inc. San Francisco. 106 pp.

Nunes S, Latasa M, Gasol JM, Estrada M (2018) Seasonal and interannual variability of phytoplankton community structure in a Mediterranean coastal site. Marine Ecology Progress Series 592: 57–75

Patil A, Chavan N (2010) Primary productivity studies in some freshwater water bodies of Sangli District, Maharashtra. National Environment and Pollution Technology 9(1): 101–103.

Pielou EC (1966) Species diversity and pattern diversity in the study of ecological succession. Journal of Theoretical Biology 3: 131–144.

Presscott GW (1964) Algae of the Western Great Lakes area. Wm, C. Brown. Co., Inc. Dubyque.

Rahman MA, Sultana S, Salam MA (2015) Comparative analysis of some water quality parameters of three lakes in Jahangirnagar university campus, Savar, Bangladesh. Bangladesh Journal of Zoology 43(2): 239–250.

Rahman MS (1992) Water quality management in aquaculture. BRAC Prokashana, Dhaka, Bangladesh. 84 pp.

Reynolds CS (1984) Phytoplankton periodicity – the interactions of form, function and environmental variability. Freshwater Biology 14: 111–142.

Reynolds CS (2012) Environmental requirements and habitat preferences of phytoplankton: chance and certainty in species selection. Botanica Marina 55(1): 1–17.

Reynolds CS, Padisák J, Sommer U (1993) Intermediate disturbance in the ecology of phytoplankton and the maintenance of species diversity: a synthesis. Hydrobiologia 249(1–3): 183–188.

Sabater S, Artigas J, Durán C, Pardos M, Romaní AM, ... Illa Y (2008) Longitudinal development of chlorophyll and phytoplankton assemblages in a regulated large river (the Ebro River). Science of the Total Environment 404(1): 196–206.

Sarma D, Dutta A (2012) Ecological studies of two riverine wetlands of Goalpara District of Assam, India. National Environment and Pollution Technology 11(2): 297–302.

Shannon CE, Wiener W (1949) The mathematical theory of communication (p. 117). University of Illinois Press, Urbana, IL.

Shukla P, Preeti, Singh A (2013) A seasonal variations of plankton population of Maheshara Lake in Gorakhpur, India. World Journal of Zoology 8(1): 9–16.

Singh HP (1998) Studies on primary production in Gobindsagar reservoir, Himachal Pradesh. Journal of Environmental Biology, Lucknow 19(2): 167–170.

Sreenivassan A (1964) Limnological feature and primary production in a polluted moat at Vellore, Madras state. Environmental Health 6: 237–245.

Sultana M, Khondker M (2009) Assesment of Phytoplankton primary productivity of two urban pond ecosytems of Bangladesh. Dhaka University Journal of Biological Sciences 18(2): 127– 135.

Umavati S, Logankumar K, Subhalaxmi,S, Longaswamy S (2007) Studies on primary productivity of Sulur Pond, Coimbatore, Tamil Nadu. Nature Environment and Pollution Technology 6(3): 491–494.

Vanni MJ, Temte J (1990) Seasonal patterns of grazing and nutrient limitation of phytoplankton in a eutrophic lake. Limnology & Oceanography 35(3): 697–709.

Visser PM, Verspagen JMH, Sandrini G, Stal LJ, Matthijs HCP, Davis TW (2016) How rising CO_2 and global warming may stimulate harmful Cyanobacterial blooms. Harmful Algae 54: 145–159.

Wu N, Schmalz B, Fohrer N (2011) Distribution of phytoplankton in a German lowland river in relation to environmental factors. Journal of Plankton Research 33(5): 807–820.