E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2021; 9(3): 37-44
© 2021 IJFAS
www.fisheriesjournal.com
Received: 19-03-2021
Accepted: 21-04-2021

Afia Zinat
Mphil research fellow, Department of Fisheries, University of Rajshahi, Rajshahi, Bangladesh

Md. Abu Sayed Jewel
Professor, Department of Fisheries, University of Rajshahi, Bangladesh

Bithy Khatun
Department of Fisheries, University of Rajshahi, Rajshahi, Bangladesh

Md. Khayrul Hasan Nayan
Department of Fisheries, University of Rajshahi, Rajshahi, Bangladesh

Saleha Jasmine
Department of Fisheries, University of Rajshahi, Rajshahi, Bangladesh

Corresponding Author:
Md. Abu Sayed Jewel
Professor, Department of Fisheries, University of Rajshahi, Bangladesh

Seasonal variations of phytoplankton community structure in Pasur River estuary of Bangladesh

Afia Zinat, Md. Abu Sayed Jewel, Bithy Khatun, Md. Khayrul Hasan Nayan and Saleha Jasmine

Abstract
In the present study, phytoplankton community structure in relation to hydrological parameters were studied based on three seasons over a period of 12 months from March 2020 to February 2021 in the Pasur river estuary, Bangladesh. Water quality parameters namely water temperature, DO, pH, alkalinity, TDS and Salinity were determined between 23.05 to 32 °C, 4.93 to 8.78 mg/L, 7.12 to 7.99, 109 to 175 mg/L and 6.20 to 14.68 ppt respectively. Concentrations of nutrients viz. nitrate (0.05 to 1.02 mg/L) and phosphate (0.03 to 0.85 mg/L) also fluctuated seasonally. A total 68 species of phytoplankton belonging to 42 genera were identified with 40 belong to the class Bacillariophyceae, 12 to Dinophyceae, 8 to Cyanophyceae, 6 to Chlorophyceae and 2 to Euglenophyceae. Relatively higher total cell density of phytoplankton was observed during post-monsoon season (48.204×10^3 cells/L) and lower during monsoon season (37.301×10^3 cells/L). The percentage composition of phytoplankton was recorded as Diatoms > Dinoflagellates > Blue greens > Greens > Euglenoids respectively. Generally, diatoms formed the dominant group in term of total species and cell numbers during the study period. Species diversity, richness and evenness index ranged from 1.45 to 3.80, 0.25 to 0.98 and 0.48 to 0.96 with highest values were recorded during post-monsoon coinciding with the stable hydrographical conditions with a higher concentration of nutrients in the water columns.

Keywords: phytoplankton, seasonal variation, water quality parameters, Pasur river estuary

Introduction
The southeastern and southwestern coast of this country is mostly covered by a complex estuarine ecosystem with strong interactions of biotic and abiotic factors. Pasur River estuary (PRE) is the largest and most important estuary, supporting the Sundarbans mangrove ecosystem. The Sundarbans, the largest single tract of halophytic mangrove forest in the world which is important from both ecological and economic perspectives. It is the transition zone between freshwater flow from the Ganges and saline water from the Bay of Bengal [1]. The entire mangrove ecosystem has been intersected by an elaborate network of rivers, channels and creeks which occupies 30% of the total Sundarbans mangrove biome. These river systems carry a huge freshwater flow from upstream and fall into the Bay of Bengal through the Sundarbans Reserve Forest [2, 3]. Mangroves in the estuarine ecosystem play important roles in biodiversity and energy flow and in maintaining functioning food chains, with phytoplankton playing a vital role as a primary producer.
Phytoplankton form the base of marine and freshwater food webs and are key players in the global carbon cycle. They initiate the marine food chain by serving as food to primary consumers such as zooplankton, shellfish, and finfish. They are the best index of the biological productivity and the nature of aquatic habitat. The productivity of the water body largely depends on the amount of phytoplankton in particular. The boosted productivity improves consumer abundance and attracts higher trophic level animals that help to create biological hotspots in an ecosystem. Mangrove estuarine areas may export large amounts of organic material and nutrients to coastal marine environments which significantly affects the biological productivity of the estuary. Waters with nutrient content, both nitrate and phosphate are needed for plankton growth. Phytoplankton are also strongly influenced by longitudinal and temporal changes of the estuarine ecological parameters such as temperature, Dissolved Oxygen (DO), salinity, pH etc. Distribution, abundance and diversity of phytoplankton indicate the nutrient status, more specifically the heath condition of the aquatic system.

Several studies have been available on phytoplankton community associated with physico-chemical parameters of rivers as well as estuarine region of Bangladesh. But there is very little information on the seasonality, abundance and diversity of the phytoplankton of the Pasur River estuary. However, the present study was conducted to understand the seasonal variation of phytoplankton population in relation to the water chemistry of Pasur River estuary. Thus it can provide information about composition and abundance of phytoplankton in the Pasur River estuary which will have positive impact on coastal biodiversity and conservation of estuarine fisheries in the estuarine region of Sundarbans.

Materials and Methods

Study area and duration

The present study was conducted over a period of 12 months from March 2020 to February 2021 in the Pasur river estuary which is in the middle part of the Sundarbans, Bangladesh. Four sampling stations were selected for this study. Environmental variables and phytoplankton sample were collected seasonally namely in pre-monsoon (March to June), monsoon (July to October) and the post-monsoon (November to February) from four sampling station, namely Mongla ferry ghat (S1) ($22^0$28.272' N; 89^0 36.028' E), Karamjal (S2) (22^0 25.550' N; 89^0 35.579' E), Joymoni (S3) (22^0 21.038' N; 89^0 37.800' E) and Harbaria (S4) (22^0 18.000' N; 89^0 36.536' E) (Fig. 1).

Measurement of water quality parameters

Samples were collected from each station during the three seasons. Surface water (500 mL) was collected in black colour-coded bottles from each study location. The measurement of water quality parameters was performed on the bank of river between 9.00 AM and 12.00 PM to determine the state of the aquatic environment.

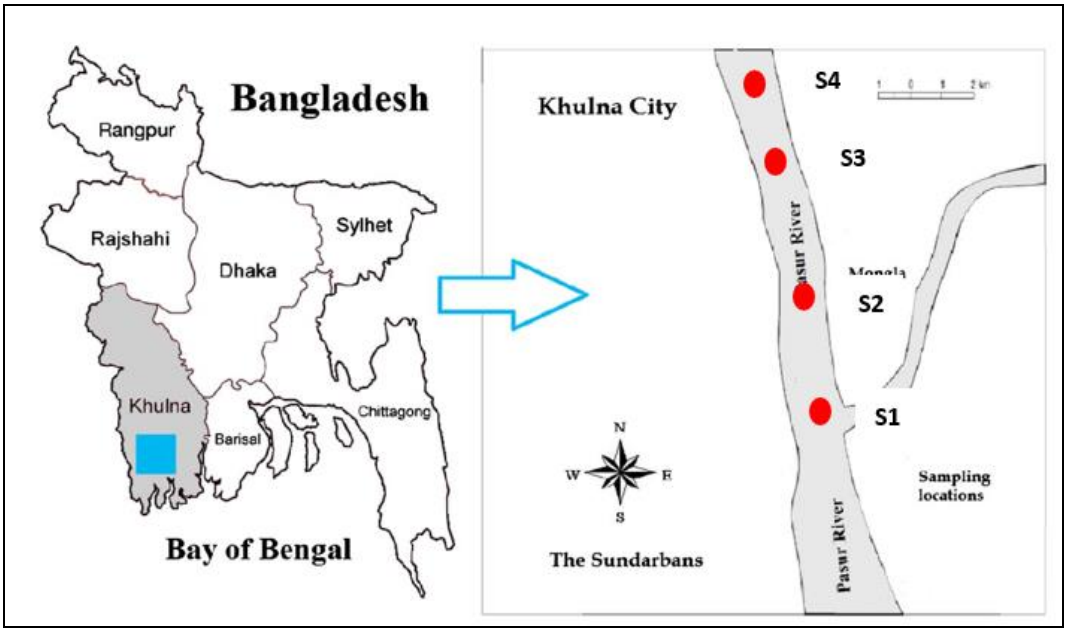

Fig 1: Map showing the study area and sampling points (●) in the Pasur river estuary, Sundarbans, Bangladesh

Water temperature was measured by Celsius thermometer and pH was measured with an electronic pH meter (Jenway 3020, UK). A HACK kit box (Model DR-2010, USA) was used to evaluate the dissolved oxygen (DO) and alkalinity of the collected samples. Salinity was measured by Refractometer and TDS was measured by an Adwa AD31 waterproof TDS tester. Nitrate-nitrogen (NO_3-N) and Phosphate-phosphorus (PO_4-P) were measured using HACK Kit (DR-2020, USA) with high range chemicals (Nitra Ver. 5 Nitrate Reagent Powder Pillows for 25 ml sample for NO_3-N and Phos. Ver. 3 Phosphate Reagent Powder Pillows for 25 mL sample for PO_4-P analysis).

Phytoplankton sampling and identification

Phytoplankton samples were collected from surface water of each sampling station during pre-monsoon, monsoon, and post-monsoon seasons. 100 L of sample water was collected and filtered through a fine meshed (25 µm) plankton net by using a 10 L volume container. Then filtered samples were collected to a sample bottle and immediately preserved by adding 10% alcohol in the sample for further study. The bottle was labeled and transferred to the laboratory for microscopic examination. Before microscopic examination the concentrated sample vials were shaken to mix phytoplankton uniformly. Each time 1 ml of sample was taken by a dropper and then put on the Sedge-wick Rafter Counting cell (S-R cell). Then coverslip was placed with great care so that any air bubble could not arise. Finally, the S-R counting cell was placed under a light microscope for phytoplankton qualitative and quantitative study. Phytoplankton identification was performed according to the literature [4, 5, 6] The quantitative cell density of phytoplankton was expressed as cells/L of water by using the following formula [7]:

$$N = \frac{A \times 1000 \times C}{V \times F \times L}$$

Where,
N = Number of phytoplankton cells per liter of original water
A = Total number of phytoplankton counted
C = Volume of final concentration of the sample in ml
V = Volume of a field
F = Number of the field counted and
L = Volume of original water in liter.

Species diversity, richness and evenness index calculation
For the measurement of species diversity, many indices are available [8, 9]. Among these frequently used indices, of Shannon–Weaver Index (1949) [10] was chosen for the present study.

Shannon-Weaver diversity index,
$H' = \sum Pi \times \log (Pi)$
Where,
H' = Shannon-Weaver diversity index
Pi = n/N
n = Number of individuals of a species
N = Total numbers of individuals

Margalef's richness index
Species richness index (d) was calculated according to Margalef (1951) [11]

$d=(S-1)/ \text{Log } N$
Where
d = Margarlef's richness index,
S = Number of different species in the sample,
N = Total number of individual species in the sample.

Pielou's evenness index,
Species evenness index (d) was calculated according to Pielou (1969) [12]

$J'=H'/ H'_{(max)}$

Where,
J' = Evenness index
H' = Shannon-Weaver diversity index
$H'_{(max)}$ = The theoretical maximum value for H' if all species in the sample were equally abundant.
$H'_{(max)} = \ln S$

Statistical data analysis
The data were analyzed using statistical tools available in the MS Excel 2013. All the analyses involved were performed in triplicates and the results were expressed as mean (n=3) ± standard deviation (SD). Species diversity was performed using Paleontological Statistics software version 3.

Result
Water quality
Water quality parameters namely temperature; dissolved oxygen; pH; alkalinity; TDS; salinity; nitrate and phosphate are the indicator of the environmental conditions. Seasonal variations of these parameters with their mean values and standard deviation of Pasur river estuary is presented in Table 1.

Table 1: Seasonal mean value of water quality parameters of Pasur river estuary

Water quality	Pre-monsoon	Monsoon	Post-monsoon
Temperature (°C)	31.48±0.31 (31.04-32.00)	27.37± 0.41 (26.78-27.95)	23.48±0.33 (23.05-24.02)
Dissolved oxygen (mg/L)	5.08± 0.11 (4.93-5.25)	6.67± 0.14 (6.48-6.88)	8.58±0.14 (8.37-8.78)
pH	7.46±0.15 (7.24-7.69)	7.35±0.15 (7.12-7.56)	7.80±0.12 (7.57-7.99)
Alkalinity (mg/L)	128.37±13.53 (109.00-145.00)	141.65±14.92 (120.28-160.00)	154.92±16.32 (131.55-175.00)
TDS (ppt)	16.42±0.41 (15.74-16.93)	7.42±0.18 (7.15-7.70)	10.59±0.48 (10.01-11.33)
Salinity (ppt)	14.24±0.35 (13.65-14.68)	6.44±0.15 (6.20-6.68)	9.18±0.41 (8.68-9.82)
NO_3 (mg/L)	0.50±0.10 (0.35-0.64)	0.17±0.08 (0.05-0.31)	0.84±0.11 (0.68-1.02)
PO_4 (mg/L)	0.43±0.09 (0.31-0.57)	0.16±0.08 (0.03-0.29)	0.72±0.08 (0.60-0.85)

Temperature: Seasonal fluctuation of mean water temperature was observed in Pasur river estuary during the study period. Water temperature ranged from 23.05 to 32 °C. Highest temperature was recorded at station four during pre-monsoon and the lowest temperature was recorded at station one during post-monsoon season respectively (Fig. 2).

Dissolved oxygen: Dissolved Oxygen (DO) concentration fluctuated spatially and temporally. DO ranged from 4.93 to 8.78 mg/L in Pasur river estuary. The lowest DO value of 4.93 mg/L found at station four in pre-monsoon caused by high water temperature. In contrast, the highest DO value of 8.78 mg/L found at station one in post-monsoon due to low water temperature. Average value of 6.67 mg/L was found in rainy monsoon which is higher than pre-monsoon (5.08 mg/L) and lower than post-monsoon (8.58 mg/L) due to reducing water temperature (Fig. 2).

pH: In Pasur river estuary pH value ranged from 7.12 to 7.99 of which lowest value was recorded during monsoon at station four and highest value was recorded during post-monsoon at station one (Fig. 2). The highest mean pH value (7.80±0.12) was observed in post-monsoon and the lowest value (7.35±0.15) was observed in rainy monsoon (Table 1).

Alkalinity: Alkalinity is an important parameter of water that maintain the suitable pH range for fishes and other aquatic lives. In Pasur river estuary alkalinity found to vary from 109 mg/L to 175 mg/L. Average value of alkalinity (128.37 mg/L) was found in pre-monsoon which is lower than both monsoon (141.65 mg/L) and post-monsoon (154.92 mg/L) season respectively (Table 1).

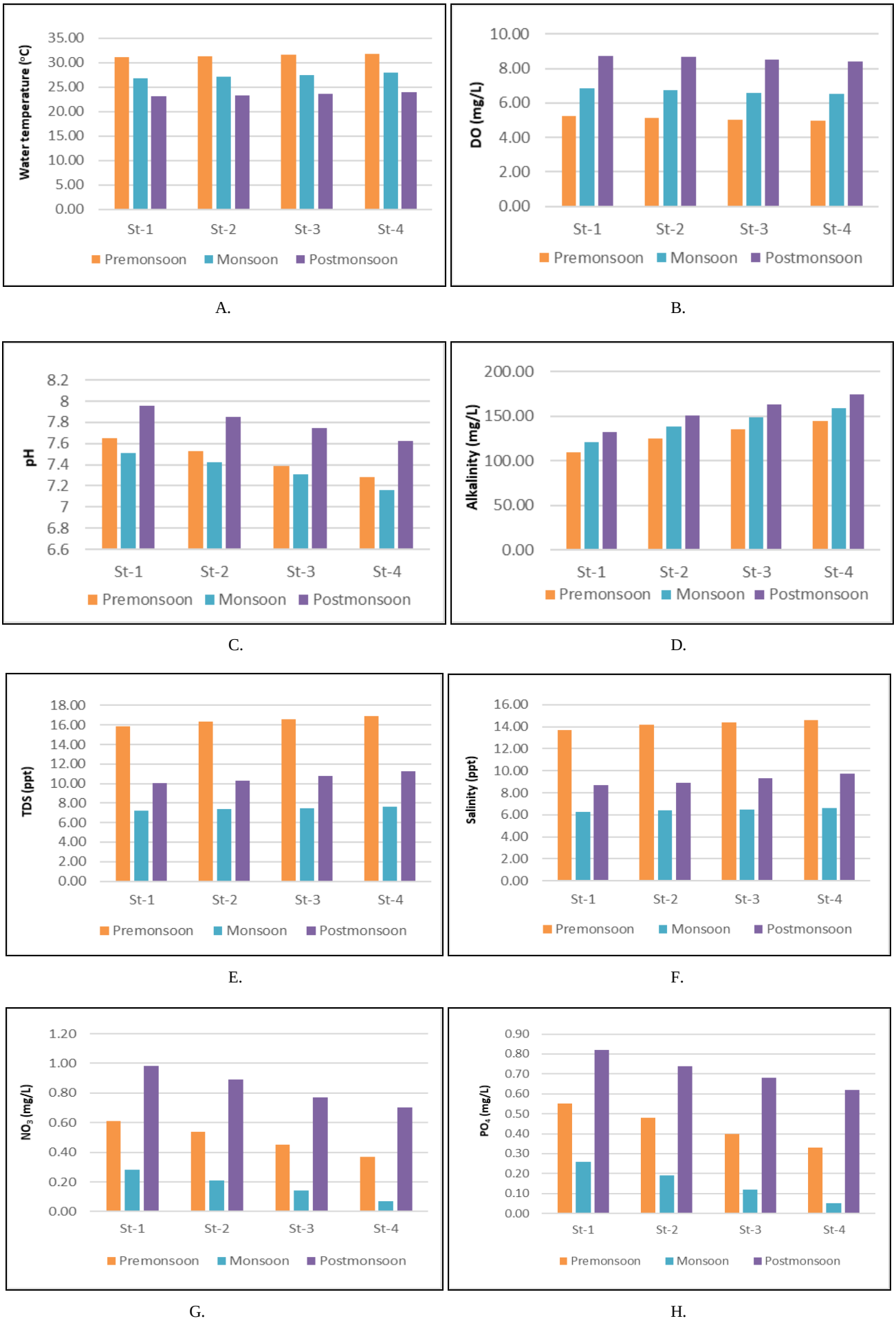

Fig 2: Seasonal variations of mean water quality parameters (a) temperature, (b) DO, (c) pH, (d) alkalinity, (e) TDS, (f) Salinity, (g) NO_3 and (h) PO_4 at four stations of Pasur River estuary.

TDS: TDS concentration in the PRE during the study period ranged between 7.15 and 16.93 ppt with the highest mean value of 16.42 ppt recorded in pre-monsoon and the lowest mean value of 7.42 ppt recorded in monsoon. Salt particle constitutes the major portion of the TDS concentration so TDS was found higher in pre-monsoon as salinity was also higher during this time (Table 1).

Salinity: During study period salinity fluctuated seasonally. The highest value of 14.68 ppt was recorded during pre-monsoon at station four and lowest value of 6.20 ppt was recorded during monsoon at station one (Fig. 2). The highest mean value of salinity (14.24±0.35 ppt) and lowest value of (6.44±0.15 ppt) was found during pre-monsoon and monsoon season respectively. Seasonal variation of salinity may have resulted from saline water intrusion in the Pasur river estuary from Bay of Bengal due to tidal effects and degree of freshwater discharge from the upstream.

NO_3: A seasonal trend of lower NO_3- values in monsoon and higher values in pre-monsoon and post-monsoon were observed in Pasur river estuary during the study period. NO_3 value was found to vary from 0.05 to 1.02 mg/L of which lowest value was recorded from station four and highest value was recorded from station one during monsoon and post-monsoon season (Fig. 2). Average value of NO_3 (0.17±0.08) was found in rainy monsoon which is lower than both pre-monsoon (0.50±0.10) and post-monsoon (0.84±0.11) season respectively.

PO_4: Phosphate concentrations were found lower than 1 mg/L at all stations in Pasur river estuary during the study period. The minimum value of PO_4 (0.03 mg/L) was observed at station four during monsoon and maximum value (0.85 mg/L) was observed at station one during post-monsoon season (Fig. 2). Average value of PO_4 (0.72±0.08) was found in post-monsoon which is higher than both pre-monsoon (0.43±0.09) and monsoon (0.16±0.08) season respectively (Table 1).

Seasonal Variation of Phytoplankton

The distribution and abundance of phytoplankton in coastal mangrove waters generally varied remarkably due to the seasonal environmental fluctuations. In Pasur river estuary phytoplankton community consisted mainly five groups namely Bacillariophyceae, Dinophyceae, Cyanophyceae, Chlorophyceae and Euglenophyceae. A total 68 species of phytoplankton belonging to 42 genera were identified with 40 belong to the class Bacillariophyceae, 12 to Dinophyceae, 8 to Cyanophyceae, 6 to Chlorophyceae and 2 to Euglenophyceae as shown in (Table 2). Among these 5 groups of phytoplankton Bacillariophyceae (47.653 $\times 10^3$ cells/L) was the most abundant and Euglenophyceae (4.151$\times 10^3$ cells/L) was the least abundant group during the study period.

Table 2: List of phytoplankton recorded from Pasur river estuary during study period.

Bacillariophyceae (Diatoms)	*Thalassiosira decipens*
Amphiprora alata	*T. ecentrica*
A. ovalis	*T. oestrupii*
A. veneta	*T. rotula*
Bacillaria paxillifera	**Dinophyceae (Dinoflagellates)**
Chaetoceros affiis	*Ceratium extensum*
C. debile	*C. furca*
C. pendulus	*C. fusus*
C. socialis	*Cladopyxis hemibrachiata*
Coscinodiscus centralis	*Dinophysis sp.*
C. excentricus	*Gonyaulax sp.*
C. granii	*Gymnodinum sp.*
C. lineatus	*Noctiluca sp.*
C. marginatus	*Protoperidinium claudicans*
C. spiniferus	*P. leonis*
Cyclotella comta	*P. punctulatum*
C. striata	*P. biconicum*
C. stylorum	**Cyanophyceae (Blue green algae)**
Cylindrotheca fusiformis	*Anabaena sp.*
Cymbella sp.	*Anacystis aeruginosa*
Ditylum brightwell	*Aphanizomenon sp.*
Lioloma delicatula	*Gomphosphaeria sp.*
Navicula brekkaensis	*Microcystis protocystis*
N. meninscus	*Nostoc pruniforme*
Nitzschia acicularis	*Oscillatoria sp.*
N. lorenziana	*Spirulina platens*
N. sigma	**Chlorophyceae (Green algae)**
Odontella mobiliensis	*Ankistrodesmus falcatus*
O. sinensis	*Eudorina elegans*
Pleurosigma angulatum	*Oocystis pusilla*
P. directum	*Pediastrum duplex*
P. estuarii	*P. simplex*
Rhyzosolenia setigera	*Uronema sp.*
R. alata	**Euglenophyceae**
Skeletonema costatum	*Euglena sp.*
Synedra ulna	*Phacus sp.*
Thalassionema nitzschioides	

In the present study, the diatoms formed the dominant group in term of total species and cell number followed by dinoflagellates, blue greens, greens and euglenoids. Percentage composition of each group of phytoplankton was in the following order: Diatoms > Dino flagellates > Blue greens > Greens > Euglenoids (Fig. 3)

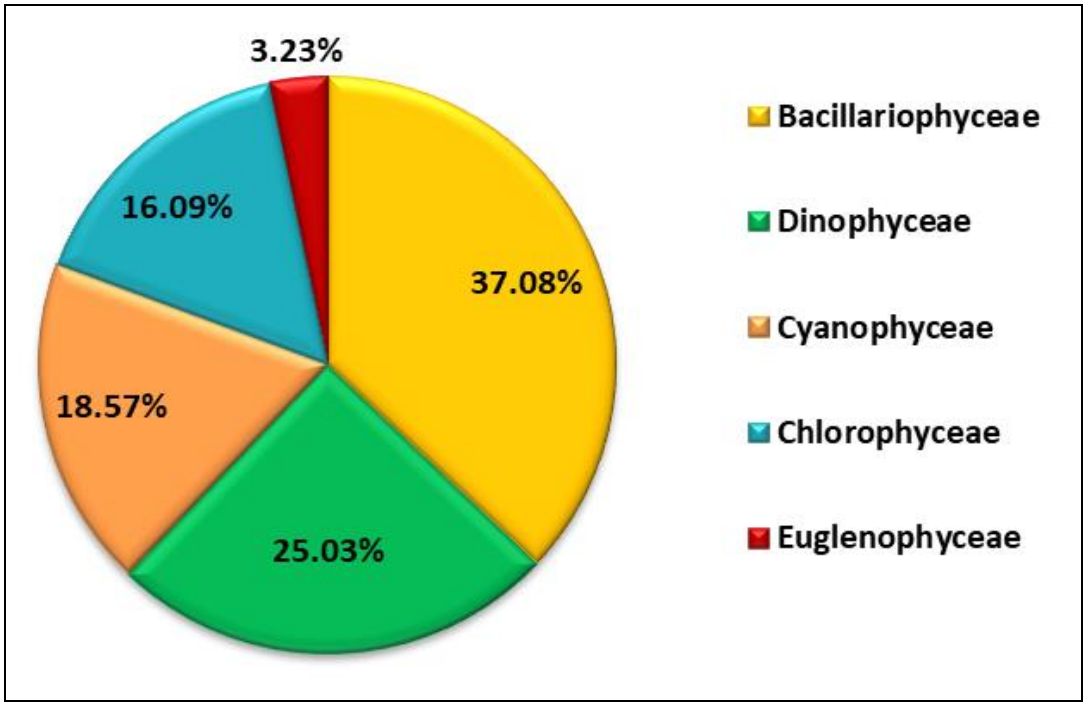

Fig 3: Percentage composition of different groups of phytoplankton

Seasonal variation of phytoplankton production (Cells/L) during the study period is shown in Figure- 4. Variations in the phytoplankton cell density ranged from 37.301 × 10^3 to 48.204 × 10^3 cells/L with the highest and lowest value was recorded during post-monsoon and monsoon season respectively (Fig. 4).

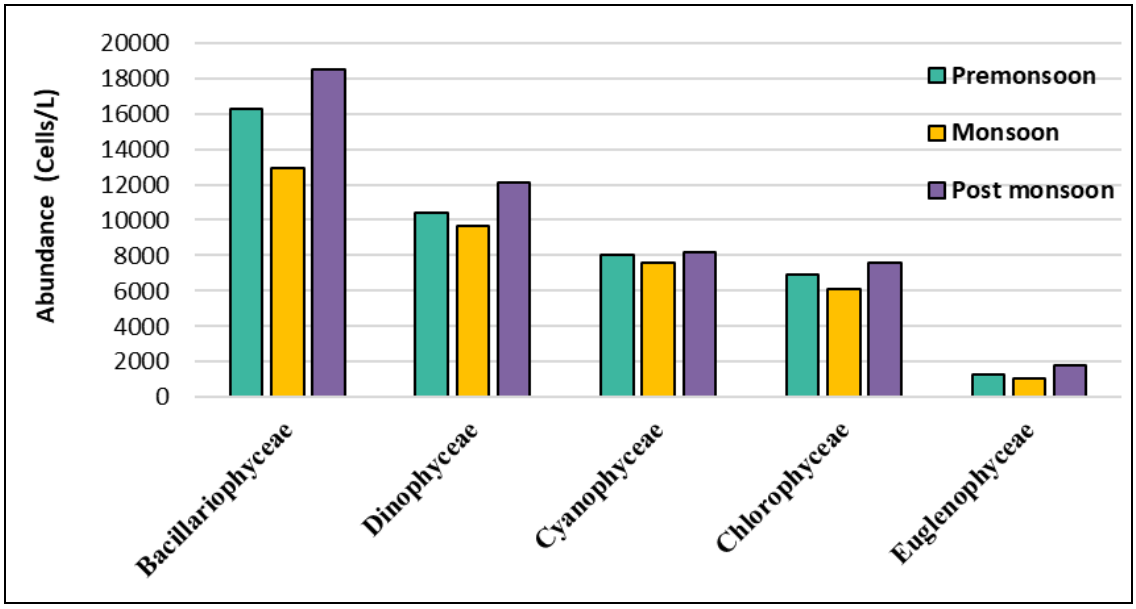

Fig 4: Seasonal variations of phytoplankton abundance (Cells/L) during study period

Bacillariophyceae dominated the phytoplankton group as 40 species were recorded during the period of study. The highest abundance (18.48 × 10^3 Cells/L) were observed during post-monsoon and lowest (12.895 × 10^3 Cells/L) were observed during monsoon season (Fig. 4). The dominant species in the Bacillariophyceae group includes *Chaetoceros socialis, Coscinodiscus excentricus, Cyclotella striata, Navicula brekkaensis, Nitzschia lorenziana, Skeletonema costatum, Thalassionema nitzschioides* and *Thalassiosira oestrupii*.

Dinophyceae ranked second position among all phytoplankton in terms of both abundance and species number. This group dominated by mainly *Ceratium sp., Gymnodinum sp.* and *Protoperidinium sp.* The highest cell density (12.084 × 10^3 Cells/L) of Dinophycea was recored in post-monsoon season and lowest (9.674 × 10^3 Cells/L) in monsoon season (Figure-4).

The cell density of phytoplankton belonging to Cyanophyceae group appeared to be higher (8.210 × 10^3 Cells/L) and lower

(7.582 × 10^3 Cells/L) during post-monsoon and monsoon season respectively (Fig. 4). *Anabaena sp., Nostoc pruniforme* and *Oscillatoria sp.* were found as most abundant species during the study period.

Among Chlorophyceae, *Ankistrodesmus falcatus, Oocystis pusilla* and *Uronema sp.* were mainly dominating species in the Pasur River estuary. The cell density of Chlorophytes usually varies from 6.105 × 10^3 to 7.620 × 10^3 Cells/L with lowest and highest density observed during monsoon and post-monsoon season respectively (Fig. 4).

In terms of both abundance and species number Euglenophyceae ranked the last position among all phytoplankton group. Only two species were recorded under this group with cell density ranged from 1.045 × 10^3 to 1.810 × 10^3 Cells/L. The highest cell density was observed during post-monsoon and lowest density observed during monsoon season (Fig. 4).

Phytoplankton diversity indices are widely used as an indicator of water quality. Temporal diversity indices were analyzed considering three distinct seasons namely pre-monsoon, monsoon and post-monsoon. Species diversity, richness and evenness index values showed seasonal variation.

Table 3: Phytoplankton diversity indices in the Pasur river estuary during study period.

Diversity Indices	Pre-monsoon	Monsoon	Post-monsoon	Seasonal mean
Shannon-Weaver diversity index (H')	3.10	1.45	3.80	2.78
Margalef's richness index (d)	0.81	0.25	0.98	0.68
Pielou's evenness index (J')	0.83	0.48	0.96	0.76

The Shannon diversity index (H) describes the species diversity in a community. During the study period, species diversity ranged from 1.45 to 3.80 with higher value recorded at post-monsoon season and lower value in monsoon season (Table 3). Margalef Species Richness Index (d) measures both common and rare species. Species diversity increases when richness increases. Richness values were found in the range of 0.25 to 0.98 with seasonal mean value of 0.68 in Pasur river estuary during the study period. Higher evenness value increases species diversity. The lowest evenness value (0.48) was recorded in monsoon season and the highest value (0.96) was in post-monsoon season (Table 3).

Discussion

In Pasur river estuary environmental parameters showed a distinct pattern of seasonal variation and may be responsible for the marked variation in phytoplankton abundance and distribution. Water temperature is the most important physical factors and found to vary from 23.05 to 32 °C during the study period. The highest water temperature was recorded in pre-monsoon could be attributed to higher solar radiation and the lowest in post-monsoon due to the lowest atmospheric temperature. The present findings of water temperature were more or less similar to the findings of Rahman *et al.* [13] and Masoud *et al.* [14] and there is a positive relation with phytoplankton abundance. An inverse relationship observed between temperature and DO as the solubility of oxygen in water decreases with the increasing water temperature. The minimum DO value (4.93 mg/L) and maximum value (8.78 mg/L) was recorded in pre-monsoon and post-monsoon season during the study period. A similar trend of DO concentration between 5.97 and 8.43 mg/L has been also reported by Shefat *et al.* [15]. A pH range between 6.5 and 9 is considered as suitable for fish and other aquatic life. The pH value ranged from 7.12 to 7.99 with highest value was recorded in post-monsoon and lowest in monsoon which was similar to the findings of Aziz *et al.* [16] and Shefat *et al.* [15]. The observed high pH values during post-monsoon might be due to the influence of seawater inundation and high density of phytoplankton [17, 18]. In Pasur river estuary the highest and lowest value of salinity were recorded during pre-monsoon and monsoon season. The heavy rainfall and the resultant freshwater inflow from the land during the monsoon season, moderately reduced the salinity. A recent study by Shaha & Cho [19] also recorded higher salinity near Chalna during the dry season and found to existing from December to June. Nutrients are considered as one of the most important parameters in the mangrove environment influencing the distribution of phytoplankton. Distribution of nutrients is mainly based on the season, tidal conditions and freshwater flow from land sources. Concentrations of nutrients viz. nitrate and phosphate also varied seasonally. For both nutrients lowest value was recorded during monsoon season which was very close to the findings of Rahaman *et al.* [13] who also found lowest concentration of nutrients in monsoon season.

In Pasur river estuary total phytoplankton cell density was highest during post monsoon season and lowest was recorded in monsoon season. The observed high density during the post-monsoon could be attributed to more stable hydrographical conditions namely low water temperature and higher nutrient concentration prevailed during that period. Vajravelu *et al.* [20] found that nutrient enrichment was responsible for higher phytoplankton abundance in post-monsoon at Parangipettai coastal waters in the South East Coast of India. During monsoon months, phytoplankton abundance was lowest as the water column was remarkably stratified to a large extent due to heavy rainfall, high turbidity caused by run-off, reduced salinity, lower pH and TDS, overcast sky and cool conditions [21, 22, 23].

During the period of study, a total 68 species of phytoplankton were recorded belonging to diverse groups namely Bacillariophyceae, Dinophyceae, Cyanophyceae, Chlorophyceae and Euglenophyceae. Among 5 groups of phytoplankton, Bacillariophyceae was the most dominant and Euglenophyceae was the least dominant group during the study period. Generally, diatoms were found to be dominant in mangrove waters, which could be due to the fact that diatoms can tolerate the widely changing hydrographical conditions [24-26]. At first sampling site (S1) phytoplankton species composition and cell density was comparatively higher than the other three stations, it may be due to higher concentration of nutrients (nitrate and phosphate) present in the water column of that station triggered high concentration of phytoplankton. Percentage composition of each group of phytoplankton was in the following order: Diatoms > Dinoflagellates > Blue greens > Greens > Euglenoids. Similar trend of percentage composition of phytoplankton groups was also reported by [21, 24].

The ranges of diversity indices namely species diversity, richness and evenness were highest in post-monsoon and lowest in monsoon seasons. The maximum value of diversity indices in post-monsoon seaon may be due to the high phytoplankton species composition in this season. The other reasons for higher diversity indices during post-monsoon season may be the desirable environmental conditions with a higher concentration of nutrients in the water column of the study area which support the findings of Dupuis and Hann [27] who also reported that higher nutrient concentration may be responsible for maximum diversity of phytoplankton. On the other hand, unfavorable environmental conditions and high water level may be responsible for minimum value of diversity indices during monsoon season. Flood is considered as a disturbance factor that causes water column instability and reduced water retention time [28]. Thus, a wash-out flood may responsible for species loss and reduced number of plankton communities in a few organisms during monsoon. The Shannon-Weiner diversity index of phytoplankton in the present study is greater than 3, which reflects that the water of this estuary is good for growth and production of of phytoplankton.

References

1. Junk WJ, Shuqing A, Finlayson CM *et al*. Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. Aquatic sciences 2013;75:151-167.
2. Hussain Z, Acharya G. Mangroves of the Sundarbans, IUCN: Bangladesh, Bangkok, Thailand 1994;2:257.
3. Hossain GM, Rahman MS, Khan SA. Species composition, richness, density and distribution of climbers in relation to salinity in Sundarbans mangrove forest of Bangladesh. International Journal of Chemical, Environmental & Biological Sciences 2015;3:78-83.
4. Needham JG, Needham PR. A guide to the study of freshwater biology. Holdenday. Inc San Fransisco. 1962
5. APHA. Standard methods for the examination of water and wastewater. American Public Health Association, 1050 Eighteenth Street, Washington DC 20036, 1992, 874.
6. Bellinger EG. A key to common Algae: Freshwater, estuarine and some coastal species. The Institution of Water and Environmental Management, London 1992, 138.
7. Stirling G, Wilsey B. Empirical relationships between species richness, evenness, and proportional diversity. The American Naturalist 2001;158:286-299.
8. Berger WH, Parker FL. Diversity of planktonic formanifera in deep-Sea Sediments. Science 1970;168:1345-1347.
9. Sanders HL. Marine benthic diversity: A comparative study. Amer. Natural 1968;102:243.
10. Shannon CE, Weaver W. The mathematical theory of communication. University Illinois Press. Illinois 1949, 125.
11. Margalef R. Species diversity in natural comunidales. Publ Inst Biol Ap L 1951;9:5-27.
12. Pielou EC. An Introduction to Mathematical Ecology. John Wiley, New York 1969, 286.
13. Rahaman SMB, Golder J, Rahaman MS, Hasanuzzaman AFM, Huq KA, Begum S *et al*. Spatial and temporal variations in phytoplankton abundance and species diversity in the Sundarbans mangrove forest of Bangladesh. J Mar Sci Res Dev 2013;3:1-9.
14. Masoud MS, Abdel-Halim AM, El Ashmawy AA. Seasonal variation of nutrient salts and heavy metals in mangrove (*Avicennia marina*) environment, Red Sea, Egypt. Environmental Monitoring and Assessment 2019;191(7):425.
15. Shefat SHT, Chowdhury MA, Haque F *et al*. Assessment of physico-chemical properties of the Pasur river estuarine water. Ann. Bangladesh Agric 2020;24:1-16.
16. Aziz A, Rahman M, Ahmed A. Diversity, Distribution and Density of Estuarine phytoplankton in the Sundarban Mangrove Forests. Bangladesh. J. Bot 2012;41:87-95.
17. Das J, Das SN, Sahoo RK. Semidiurnal variation of some physico-chemical parameters in the Mahanadi estuary, east coast of India. Indian J. Mar. Sci 1997;26:323-326.
18. Subramanian B, Mahadevan A. Seasonal and diurnal variations of hydro biological characters of coastal waters of Chennai (Madras) Bay of Bengal. Indian J. Mar. Sci. 1999;28:429-433.
19. Shaha DC, Cho YK. Salt plug formation caused by decreased river discharge in a multi-channel estuary. Scientific Reports 2016;6:271.
20. Vajravelu M, Martin Y, Ayyappan S, Mayakrishnan M. 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 2018;60:114-127.
21. Rajkumar M, Perumal P, Prabu VA, Perumal NV, Rajasekar KT. Phytoplankton diversity in Pichavaram mangrove waters from south-east coast of India. Journal of Environmental Biology 2009;30:489-498.
22. Baliarsingh SK, Sahu BK, Srichandan S, Sahu KC. Seasonal Variation of Phytoplankton Community in Navigable Channel of Gopalpur Port, East Coast of India: A Taxonomic Study. International Journal of Modern Botany 2012;2:40-46.
23. Iqbal MM, Billah MM, Haider MN *et al*. Seasonal distribution of phytoplankton community in a subtropical estuary of the south-eastern coast of Bangladesh. Zoology and Ecology 2017, DOI: 10.1080/21658005.2017.1387728
24. Babu A, Varadharajan D, Vengadesh PN, *et al*. Diversity of Phytoplankton in Different Stations from Muthupettai, South East Coast of India. Journal of Marine Science: Research and Development 2013;3:128.
25. Saifullah ASM, Abu Hena MK, Idris MH, Halimah AR, Johan I. Composition and diversity of phytoplankton from mangrove estuaries in Sarawak, Malaysia. J Biol Sci. 2014;14:361-369.
26. Haque AKMF, Begum N, Islam MS. Seasonal variations in phytoplankton and zooplankton population in relation to some environmental factors at the tidal Sangu river in Chittagong of Bangladesh. J. Sylhet Agril. Univ 2015;2:209-219.
27. Dupuis AP, Hann BJ. Climate change, diapause termination and zooplankton population dynamics: an experimental and modelling approach. Freshwater Biology 2009;54:221-235.
28. Roozen FCJM, Van Geest GJ, Ibelings BW *et al*. Lake age and water level affect the turbidity of floodplain lakes along the lower Rhine. Freshwater Biology 2003;48:519-531.