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Spatial and temporal environmental effect of lower Meghna River & its estuary on phytoplankton, Bangladesh

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Abstract
The spatial and temporal effects of environmental variables on phytoplankton abundance and distribution of the lower Meghna River Estuary was studied at Sandwip, Hatiya, Bhola, Barisal and Chandpur during monsoon and post-monsoon. A total of 28 phytoplankton genera were identified of which 22 genera occurred during monsoon and 16 genera occurred during post-monsoon season. During the annual cycle *Nitzschia* was common genera at all five sites however *Coscinodiscus*, *Biddulphia*, *Nitzschia*, *Thalassiothrix* and *Triceratium* were dominant genera in the study area. During the study water was slightly acidic in nature with very low salinity in major part of the estuary. Salinity, H^-CO_3, pH, secchi depth, TSS, water temperature and silt were responsible for the variations in phytoplankton community structure but the effect was not significant ($p>0.05$). During the monsoon season CCA analysis shows, Euglena and *Zygnema* showed a positive relation with salinity while *Clostridium, Fragilaria and Scenedesmus* showed close affinity to water temperature, secchi depth, TSS and pH. Again *Navicula*, *Stauroneis*, *Pediastrum*, *Rhizosolenia*, *Ankistrodesmus* etc. genera exhibited strong affinity to H^-CO_3. On the contrary during the post-monsoon season CCA analysis shows, *Nitzschia*, *Sphaerogoum* and *Melosira* revealed strong relation with H^-CO_3 with the exception of pH, TSS, secchi depth. The dendogram of the phytoplankton genera, based on phytoplankton abundance pattern with different seasonal parameters showed Sandwip, Hatiya, Bhola and Barisal formed cluster. The phytoplankton diversity (H') did not show much variation (1.18±0.22 and 0.87±0.40 for the monsoon and post-monsoon seasons respectively) temporally. The highest phytoplankton diversity (H') was recorded at Sandwip (1.517) during the monsoon and the lowest value was recorded at Sandwip (0.35) during the post-monsoon. Again, the evenness (J') of phytoplankton showed less variation with seasonal environmental changes (0.80±0.23 and 0.58±0.18 monsoon and post-monsoon). The maximum evenness value was found at Bhola (0.99) during monsoon and it was minimum at Chandpur (0.36) during the post-monsoon season.

Keywords: Phytoplankton, Occurrence, Distribution, Biodiversity, Physico-Chemical Parameters, Meghna River and its Estuary

1. Introduction
The Meghna (joint flow of the Surma- Kushiyara) meets its major tributary, the Padma (major flow of the Ganges-Padma and the Jamuna-Brahmaputra river) in Chandpur district and ends in the Bay of Bengal near Bhola district via four principal mouths, named Tetulia (Ilsha), Shahbazpur, Hatiya, and Bamni. After the Padma joins to the Meghna, it is referred to as the Lower Meghna (http://en.banglapedia.org/index.php?title=Meghna_River). The river Meghna forms the largest estuary (about 30km) that fall into the Bay of Bengal. Estuaries are the meeting place of freshwater from rivers and saltwater from the sea; are characterized by large fluctuations in environmental conditions [1]. Phytoplankton is the primary producers [2] that support fishery as nutrition in food web [3]. More preciously, phytoplankton, the important producers of the estuary. Almost all the aquatic fauna directly or indirectly feed on phytoplankton (for their food) at the early stage of their life cycle. They are the best index of the biological productivity and the nature of aquatic habitat [4]. The productivity of the water body largely depends on the amount of phytoplankton in particular [5]. The boosted productivity improves consumer abundance and attracts higher trophic level animals that help to create biological hotspots in an ecosystem [6, 7]. Distribution, abundance and diversity of phytoplankton indicate the nutrient status, more specifically the heath condition of the aquatic system [8, 9, 10, 11].

Moreover, higher amount of nutrients can yield eutrophication [12] with its associated problems, such as harmful algal blooms worsening of water quality [13].

The estuary is mostly turbid with reduced light penetration. It is very imperative to study the occurrence and distribution of phytoplankton in the estuary in relation to physic-chemical factors. Some recent studies on phytoplankton community associated with physico-chemical parameters of rivers as well as estuaries were studied worldwide such as the Chandrabhaga River, India [14]; Greater Zab River, Iraq [15]; River Haraz, Iran [16]; Imo River, Nigeria [17]; Yamuna River, India [18]; Ganga River and its tributaries, India [19]; River Thames, UK [20]; Sutlej River, India [21]; Kenti River, Republic of Karelia [22], Jhelum River, India [23] and head water stream of Garhwal Himalayas, India [24]. In Bangladesh, few research were conducted on distribution and abundance of freshwater, lake and coastal phytoplankton [3, 25, 26, 27, 28, 29, 30]. But there is no or less information on the distribution, density and diversity of the phytoplankton of the lower Meghna River Estuary. The main objective of the present research is to understand the spatial and temporal environmental variables (physico-chemical parameters) effect on phytoplankton of the lower Meghna River and its estuary during monsoon and post-monsoon season. This study will also provide information of phytoplankton occurrence and distribution as well as diversity status in the area.

2. Materials and Methods

2.1 Study Area

The present study was conducted at Chandpur (23°13.768'N, 90°38.58'E), Barisal (22°41.962'N, 90°22.524'E), Bhola (22°37.153'N, 90°44.562'E), Hatiya (22°24.459'N, 91°07.013'E) and Sandwip (22°29.319'N, 91°25.668'E) during monsoon and post-monsoon season. The total length of the investigated 5 selected sites was about 172 miles (Fig. 1).

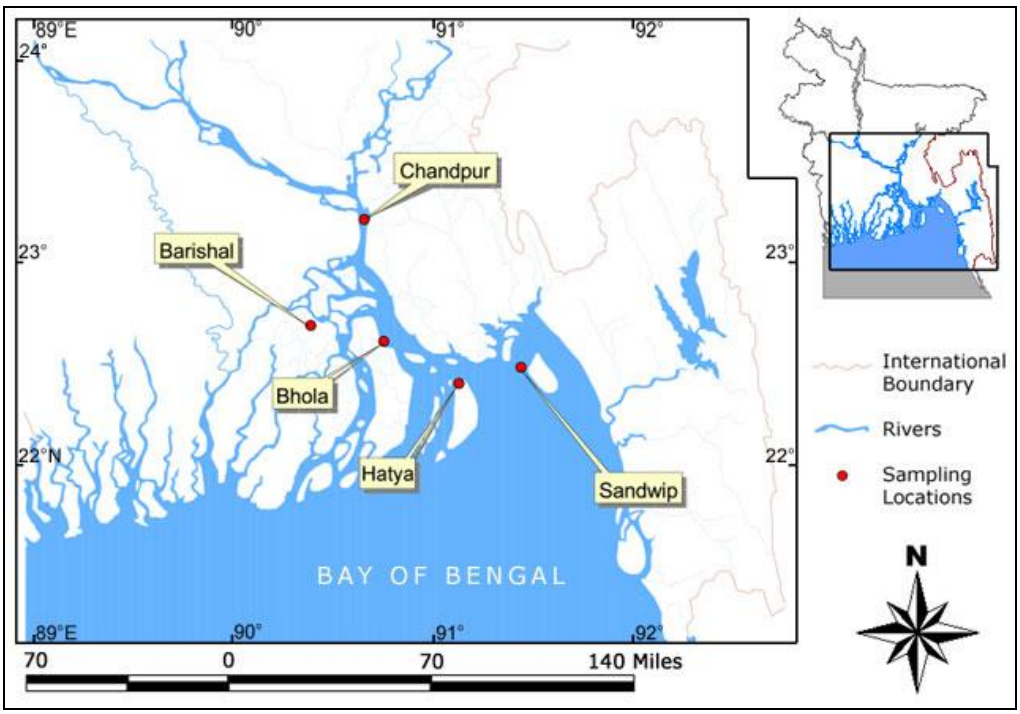

Fig 1: Sampling sites in the Meghna River

2.2 Water Sample Collection and Preservation

The water samples were collected for physico-chemical parameters study from on board passenger ships of Bangladesh Inland Water Transport Authority (BIWTA) at each sites during monsoon and post-monsoon seasons. In situ air and water temperature was determined using a Graduated Centigrade Thermometer; water pH was determined using pH paper strips (color pH ast ®, pH, indicator, strips, Cat.9582. Made in Germany); turbidity was determined using a white secchi disc of 30 cm diameter [31]; water salinity was determined using a hand held refractometer (ATAGO, S/Mill, salinity. 0-100 ‰, Japan.). Dissolved Oxygen (DO) concentration was determined by the Winkler Method (H. O. PUB. No. 607. 1955); Total Suspended Solids (TSS) and Total Organic Matter (TOM) were determined (following [32]. BOD was determined by light and dark bottle method [33]. Alkalinity, $H^{-}CO_3$ and CO_2 were determined following [34].

2.3 Phytoplankton

Phytoplankton samples were collected from surface water of each sites during monsoon and post monsoon seasons. One liter of sample was collected by a Kemmerer water sampler; collected samples were kept in plastic containers, 40 ml of buffered formalin (known as neutral formalin) were added per litter sample, immediately after collection. The container was labelled and transferred to laboratory for study. In the laboratory the samples were transferred to measuring cylinders, the opening was plugged and left over night. The phytoplankton settled, water from the upper layer was removed and the samples were concentrated to 10 ml, and the concentrated samples were kept in marked vials for microscopic examination. The concentrated samples vials were shaken to mix phytoplankton uniformly before microscopic examination. Each time 1 ml of sample was taken into a Sedgewick Rafter Counting cell (S-R cell), cover slip was placed with great care not to incorporate any air bubble. Then it was placed under microscope for

identification and counting. Identification was done following Mizuno [35]; Yamazi [36, 37]; Davis [38]; APHA [34]; Easter [39]; James [40]; Newell and Newell [41, 42]; Islam and Aziz [43]; Islam and Aziz [44]; Haque [45]; Rahman [46]; Chowdhury [47]; Islam [48]; Sarode and Kamat [49]; Subrahmanyan [50]; Hendey [51]; Russel-Hunter [52]; Wickstead [4]; Suess [53]; Islam [54]. Thus each sample was studied and the records were kept in a note book and results were tabulated.

2.4 Statistical Analysis

One Way Analysis of Variance (ANOVA) (Post-hoc LSD test) was done to show the influence of environmental physico-chemical variables in the distribution of phytoplankton (SPSS v.22). Canonical Corresponding Analysis (CCA) was performed to display the ecological relationship between physico-chemical parameters and phytoplankton community during monsoon and post-monsoon seasons (PAST v.3.1). Cluster analysis (Dendogram) was performed to show the similarity among the sites in terms of phytoplankton occurrence using PRIMER (v.6). The phytoplankton diversity was determined following PRIMER (v.6).

3. Results and Discussion

Estuarine environment are exposed to diverse changes in physico-chemical variables due to incessant mixing of fresh water with marine water [55]. Water quality of an ecosystem has great impact on the occurrence of aquatic organisms, so it is very important to estimate [56]. In the present study, surface water was recorded mostly acidic in nature with low salinity in major part of the estuary (during monsoon and post-monsoon). Water temperature, salinity, H^-CO_3, pH, secchi depth and TSS were responsible for the variations in phytoplankton community structure but the effects were found less significant ($p>0.05$).

In the present study, highest water temperature (31ºC) was recorded at Sandwip and the minimum (28ºC) was at Hatiya during monsoon. In post-monsoon, maximum (23ºC) was recorded at Sandwip while the minimum (21ºC) was at Bhola and Chandpur (Table 1). Surface water temperature was (2-3ºC) lower than that of the air temperature. This observation has similarity with the works of Mahmood and Khan [57]; Elias [58], Mahmood [59]; Zafar [60]; Iqbal [61]; Noori [62]; Martin *et al*. [63] and George *et al*. [55] and Aken [64]. Water temperature, the most important characteristics of an aquatic system, is known as the "master biotic factor" which effect on aquatic organism composition in their environment [65].

Water pH is commonly known as the controlling factor because many aquatic properties, processes and reactions are pH dependent. In estuaries pH shows buffering property [66]. Most estuarine organisms prefer conditions with pH values ranging from about 6.5 to 8.5 [67]. Briola *et al*. [68] reported pH 6.9 to 8 for phytoplankton growth. In the resent study pH was slightly acidic in both season and was recorded 6.4 to 7 (Table 1).

Dissolved oxygen (DO) is important ecological variable that decides environmental health of water bodies and support well-balanced aquatic living organisms [55, 69]. In the present study, the concentration of DO ranged (1.9-5.5 ml/L). During monsoon, the highest DO was recorded (2.8 ml/L) at Chandpur and the lowest was 1.5ml/L at Sandwip. During post-monsoon, maximum DO was recorded (5.5 ml/L) at Chandpur and Barisal and the minimum was 3.7 ml/L at Sandwip. (Table 1). Between the seasons DO concentration was more during post-monsoon than the monsoon. Highest DO concentration was reported during post-monsoon period because of supreme occurrence of the phytoplankton density [70]. DO raised to its peak value with the progression of winter and it might be due to high rate of photosynthesis by phytoplankton that forms the most important source of DO [71]. Maximum value of DO in post-monsoon and minimum in monsoon were recorded in some rivers of the Central Himalayas including the Chan-drabhaga River [14]; Haraz River in Iran [72]; the Tons River [73]; several rivers of Gangetic plain, India [74] and head water stream of Garhwal Himalayas [24].

Salinity is the pointer of freshwater intrusion in the near shore coastal water as well as extrusion of tidal water in estuary [55]. Salinity acts as a limiting parameter that enormously influences the dispersal of plankton community [75]. During monsoon, only (1‰) salinity was recorded at Sandwip, while at all other sites it was almost zero. During post-monsoon maximum salinity was (15‰) at Sandwip and minimum was (8‰) at Hatiya (Table 1) whereas in other sites it was almost zero. Murugan and Ayyakkannu [76] mentioned salinity to be an important controlling factor in determining the species composition and succession in estuary.

Maximum secchi depth (55 cm) was found at Chandpur and the lowermost (4 cm) was recorded at Sandwip during monsoon. Whereas, the highest secchi depth (65 cm) was found at Bhola and the minimum (35 cm) was documented at Sandwip during post-monsoon (Table 1). Ezra [77], Venkateswarlu *et al*. [78] and Haruna *et al*. [79] mentioned that transparency increases the occurrence of phytoplankton.

The Biological Oxygen Demand (BOD) was recorded more during monsoon (17ml/L to 38ml/L) than that of post-monsoon (0ml/L to 13ml/L) at all sites during the present study. During the study CO_2, Alkalinity, H^-CO_3 concentration of investigation sites were comparatively more during monsoon than post-monsoon season.

Table 1: Physical parameters of surface water at five study sites during monsoon (M) and post-monsoon (PM).

Parameters/ Sites	Sandwip		Hatiya		Bhola		Barisal		Chandpur	
	M	PM	M	PM	M	PM	M	PM	M	PM
Air temperature (ºC)	33	28	27.2	29	25.5	23	32	28	26	25
Water Temperature (ºC)	31	23	28	22.5	28.5	21	29	22	29	21
Secchi Depth (cm)	4	35	7	45	12	65	12	37	55	60
TSS (mg/L)	10.83	1.29	7.69	1.34	3.66	1.307	5.445	1.33	0.3175	1.33
TOM (mg/L)	0.86	0.64	0.80	0.61	0.78	0.54	0.79	0.59	0.48	0.56
pH	6.4	7	6.4	7	6.8	6.5	7	6.6	7	6.5
DO (ml/L)	1.9	3.7	2	3.9	2.5	5.2	2.7	5.5	2.8	5.5
BOD (ml/L)	17	0	21	2	38	13	35	6	34	7
CO_2 (ml/L)	0.40	0.34	0.40	0.4	0.60	0.5	0.99	0.3	0.99	0.3
Alkalinity (mg/L)	2.1	1.05	1.5	1	1.8	1.05	0.7	1.1	1.00	0.95

H^-CO_3 (mg/L)	0.000244	0.000244	0.0004	0.0002	0.0004	0.0004	0.0002	0.0003	0.0001	0.0004
Salinity (‰)	1	15	0	10	0	0	0	0	0	0

Phytoplankton

Estuarine phytoplankton populations commonly contribute in primary production and interact between trophic levels [80]. Phytoplankton composition varies with season and this can be attributed to variation in nutrient access, light and temperature [81]. They have great importance in the food webs as primary producer and can be useful indicators of water quality [82]. Geographical areas and variety of habitat types, freshwater influence are known to have massive effects on phytoplankton density, productivity and community structure [83]. Salinity variation induce short term phytoplankton blooms. Sequential changes of the phytoplankton community are influenced by short term tidal variability, zooplankton grazing and exchange between sediment and water column [84]. The species density, diversity, relative abundance and distribution of phytoplankton are a manifestation of the ecological health of a particular water body [85].

Marine tropical areas are known to be less dynamic than in temperate waters in terms of phytoplankton populations with smaller temporal variation in net phytoplankton growth [86]. In the present study, the abundance and distribution of phytoplankton was observed in the lower Meghna River and its Estuary. A total of 28 phytoplankton genera were identified during monsoon and post-monsoon season of which 22 genera occurred during monsoon and 16 genera occurred during post-monsoon season (Table 2). Islam and Aziz [43] listed 29 genera and 76 species of phytoplankton from Northeastern part of the Bay of Bengal. Rahman [87] identified 25 species of phytoplankton under 22 genera from the Naf river-estuary. Salam [88] studied the benthic algae and plankton of the Karnafuli river-estuary and recorded 111 species under 57 genera of which Chlorophyta was the dominant group (48.46%) followed by the Bacellariophyta (35.24%). Islam and Aziz [89] identified 42 species of phytoplankton from the Karnafuli river-estuary belonging to different classes. Islam and Aziz [44] further reported 20 species of marine diatoms from the Bay of Bengal, Bangladesh. Islam [55] worked in the Mathamuhuri River Estuary and recorded 91 species comprising 44 genera. Zafar [90] reported 44 genera of phytoplankton from the Matamuhuti river estuary. In the present study maximum 301120 cells/L and 7096 cells/L of phytoplankton were recorded at Chandpur site during both the seasons (monsoon and post-monsoon). Whereas the lowest 360 cells/L and 180 cells/L phytoplankton occurred at Sandwip during monsoon and post-monsoon respectively.

Table 2: Phytoplankton occurred (cells/L) at five study sites during monsoon (M) and post-monsoon (PM).

Sl. no	Name of phytoplankton Genera	Name of study sites and Season									
		Sandwip		Hatiya		Bhola		Barisal		Chandpur	
		M	PM	M	PM	M	PM	M	PM	M	PM
1	*Actinelius*	-	-	-	-	-	-	-	-	20	-
2	*Anabaena*	120	-	90	-	-	-	-	-	-	660
3	*Ankistrodesmus*	-	-	-	-	-	-	-	-	147	-
4	*Bacillaria*	-	-	-	-	-	-	-	-	53	-
5	*Chrysosphaerella*	-	-	-	-	-	-	-	-	-	60
6	*Clostratum*	60	-	-	-	150	-	150	-	-	-
7	*Coscinodiscus*	60	160	330	540	210	650	210	750	250	1440
8	*Desmidium*	-	-	-	-	-	-	-	-	107	-
9	*Euglena*	30	20	130	90	-	-	-	-	10	-
10	*Fragilaria*	-	-	-	-	-	-	-	-	33	620
11	*Keratella*	-	-	-	-	-	-	-	-	3	40
12	*Leptocylindrus*	-	-	-	230	-	-	-	-	-	-
13	*Melosira*	-	-	-	-	-	9270		730	4853	197640
14	*Micrasterias*	-	-	-	-	-	-	-	-	100	-
15	*Navicula*	-	-	-	-	-	-	-	-	37	-
16	*Nitzschia*	-	-	-	-	-	-	-	-	17	220
17	*Nostoc*	-	-	40	-	-	-	-	-	1110	17940
18	*Pediastrum*	-	-	-	-	-	-	-	-	7	-
19	*Pleurosigma*	-	-	-	60	-	110	-	-	-	-
20	*Rhizosolenia*	-	-	-	-	-	-	-	-	53	-
21	*Scenedesmus*	-	-	-	-	-	80	-	-	173	280
22	*Sphaerogoum*	-	-	-	-	-	-	-	-	-	100
23	*Spirogyra*	-	-	-	-	-	720	-	3880	-	82120
24	*Stauroneis*	-	-	-	40	-	-	-	-	13	-
25	*Striatella*	-	-	-	-	-	-	-	-	70	-
26	*Symbella*	-	-	-	-	150	-	40	-	-	-
27	*Thalassiosira*	-	-	-	320	-	2100	-	-	-	-
28	*Zygnema*	90	-	-	-	-	-	-	-	40	-
	Total	**360**	**180**	**590**	**1280**	**510**	**12930**	**400**	**5360**	**7096**	**301120**

Between the seasons more phytoplankton occurred (cells/L) during post-monsoon than that of monsoon season. Again between the sites, occurrence and distribution of phytoplankton were the most at Chandpur during the both seasons. During the annual cycle *Coscinodiscus* was common at all sites and season.

Multivariate Analysis

Canonical Correspondence Analysis (CCA)

The RDA triplot used to describe the preferred abiotic environmental factors for the characterizing and dominant phytoplankton genera both in monsoon and post-monsoon seasons and also indicated the influence of parameters (Fig. 2 & 3).

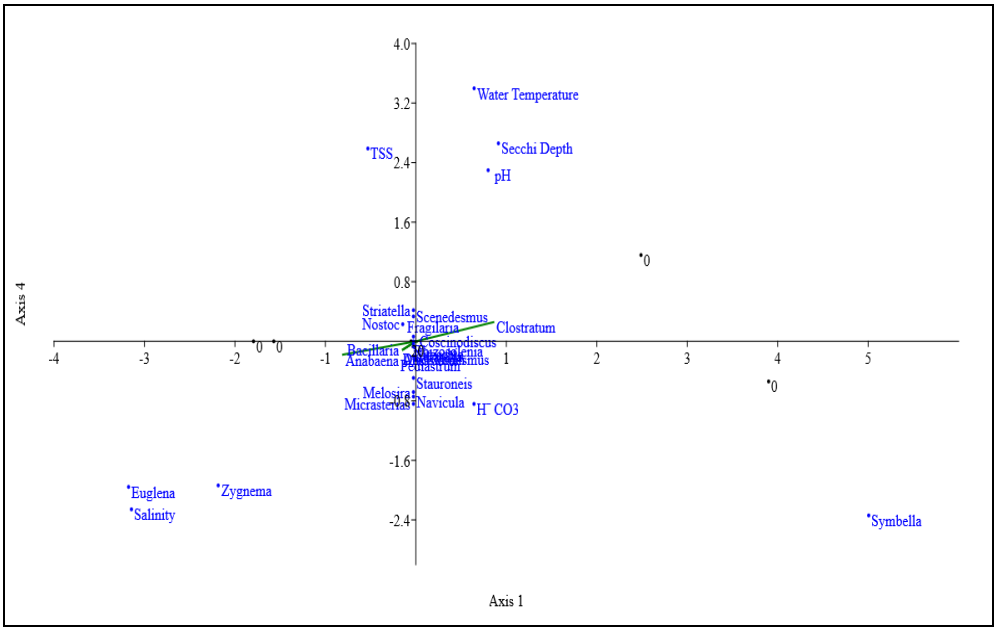

Fig 2: The redundancy analysis triplot displaying the ecological relationship between physico-chemical parameters and phytoplankton during monsoon season

During the monsoon season, when a low-salinity environment existed in major part of the estuary, *Euglena* and *Zygnema* showed a positive relation with salinity while *Clostratum*, *Fragilaria* and *Scenedesmus* showed close affinity to water temperature, secchi depth, TSS and pH. *Navicula*, *Stauroneis*, *Pediastrum*, *Rhizosolenia*, *Ankistrodesmus* etc. genera exhibited strong affinity to $H^{-}CO_3$ but had no proper trend with salinity (Fig. 2).

During the post-monsoon season, *Stauroneis*, *Spirogyra*, *Pleurosigma* and *Sphaerogoum* genera showed neither positive nor negative affinity to salinity (Fig. 3). *Nitzschia*, *Sphaerogoum* and *Melosira* exhibited strong relation with $H^{-}CO_3$ but pH, TSS, secchi depth did not influenced the phytoplankton distribution during post-monsoon (Fig. 3).

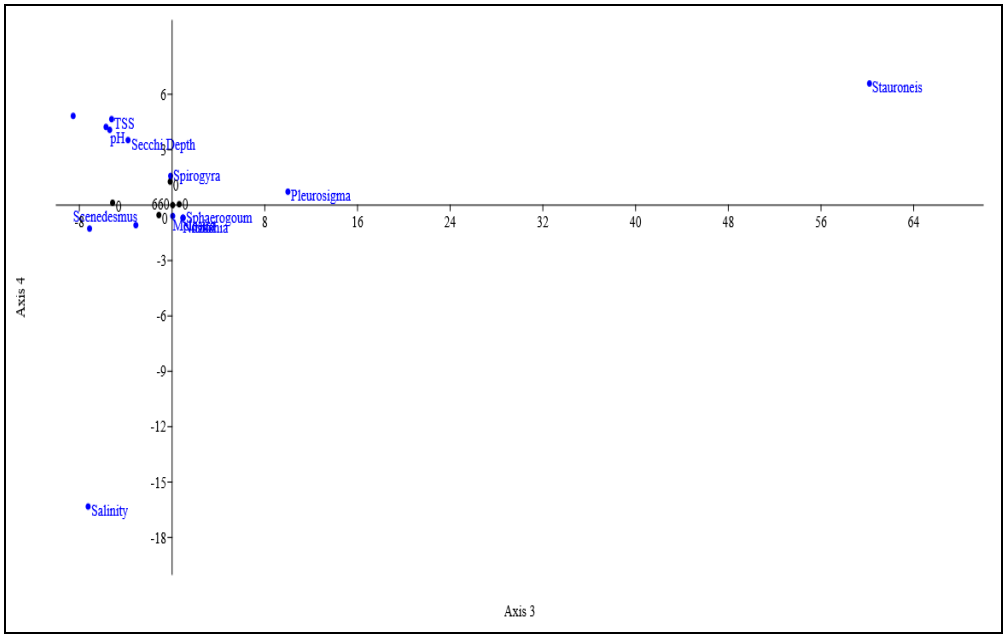

Fig 3: The RDA triplot showing inter-relation between physico-chemical parameters and phytoplankton during post-monsoon season.

Hence, a detailed study on the interrelation among the phytoplankton and environmental factors was performed for each season, and the triplot in the RDA was supportive in both visualizing all the data points plotted in the coordinate system and identifying the interrelationship among phytoplankton and environmental factors.

Cluster Analysis

Cluster Analyses (CA) was done using square root and Bray Curtis Similarity to find the similarity among the sites in terms of phytoplankton occurrence and distribution. The dendogram of the study sites, based on the phytoplankton genera abundance pattern along with different seasons, focus widely similarity understanding about the sites of the study area. In the present study it was observed that during the monsoon and post-monsoon, Hatiya and Sandwip as well as Barisal and Bhola formed cluster (group) that indicates they were almost similar in terms of phytoplankton composition. Chandpur formed a single cluster (Fig. 4a & 4b) that indicate the occurrence and distribution of phytoplankton were unique comparing other sites.

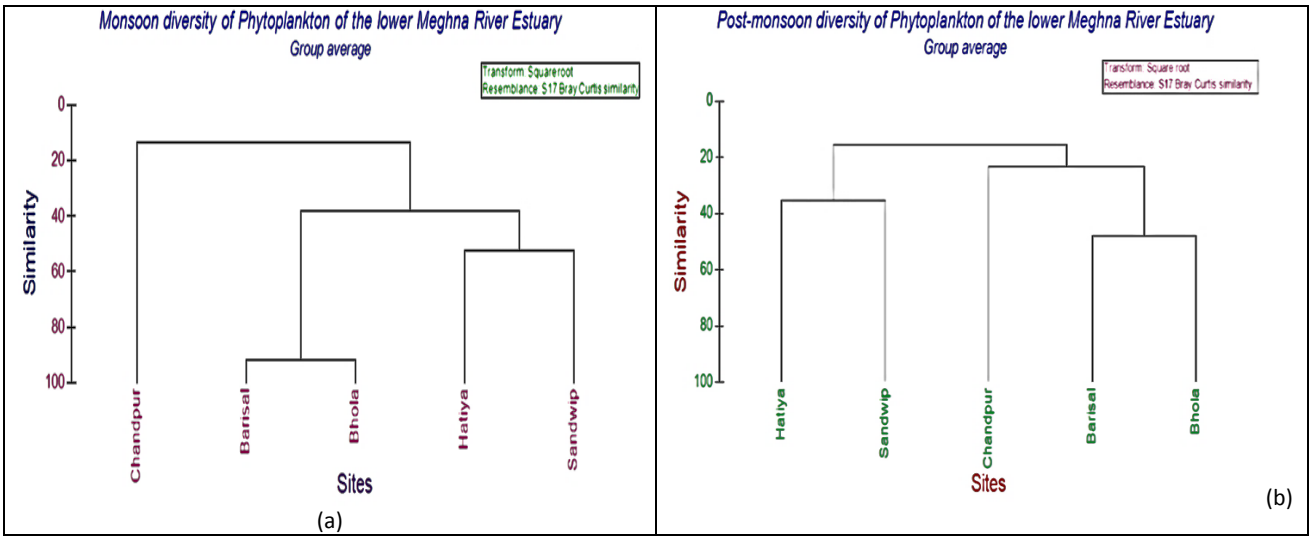

Fig 4: Bray-Curtis similarity-based hierarchical clustering of phytoplankton genera during the (a) monsoon and (b) post-monsoon periods at 5 different sites.

Diversity Index

Commonly, species diversity is a function of species richness and evenness with which the individuals are dispersed in these species [91]. Phytoplankton diversity (H') and evenness (J') varied both spatially and temporally (Fig. 5a & 5b). The phytoplankton diversity (H') did not show much variation (1.18±0.22 and 0.87±0.40 for the monsoon and post-monsoon seasons respectively) temporally. The highest phytoplankton diversity (H') was recorded at Sandwip (1.517) during the monsoon season. The lowest value of diversity (H') was recorded at Sandwip (0.35) during the post-monsoon season (Fig. 5a). Again, evenness (J') of phytoplankton showed less variation with the seasons (0.80± 0.23 and 0.58± 0.18 monsoon and post-monsoon seasons) (Fig. 5b). The maximum evenness value was found at Bhola (0.99) during the monsoon season. The minimum evenness value was observed at Chandpur (0.36) during the post-monsoon season (Fig. 5b).

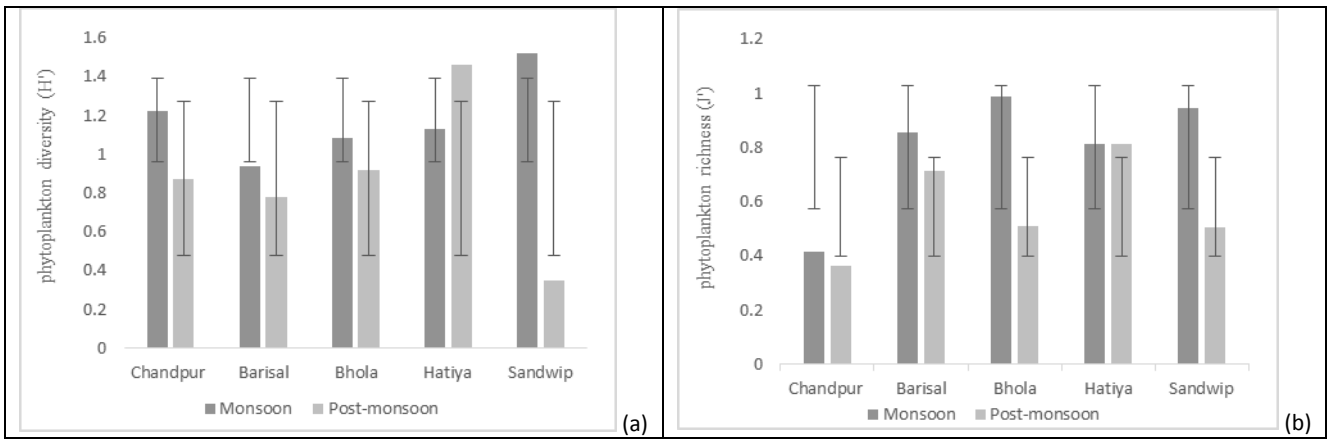

Fig 5: Diversity indices phytoplankton (a) diversity and (b) evenness, along two seasons. The vertical line on the bar diagram indicates the standard deviation.

4. Conclusion

Present study was conducted in the lower Meghna River and its Estuary at Sandwip, Hatiya, Bhola, Barisal and Chandpur during monsoon and post-monsoon season. A total of 28 phytoplankton genera were identified during monsoon and post-monsoon season of which 22 genera occurred during monsoon and 16 genera occurred during post-monsoon season. Phytoplankton abundance was more during post-monsoon than monsoon in the study sites. During the annual cycle *Nitzschia* was common genera at all five sites however *Coscinodiscus, Biddulphia, Nitzschia, Thalassiothrix and Triceratium* were dominant in the study area. During the study water was slightly acidic in nature with very low salinity in major part of the estuary. Salinity, $H^{-}CO_3$, pH,

secchi depth, TSS, water temperature and silt were responsible for the variations in phytoplankton community structure but the effect was not significant ($p>0.05$). During the monsoon season CCA analysis shows, Euglena and *Zygnema* showed a positive relation with salinity while *Clostratum, Fragilaria and Scenedesmus* showed close affinity to water temperature, secchi depth, TSS and pH. Again *Navicula, Stauroneis, Pediastrum, Rhizosolenia, Ankistrodesmus* etc. genera exhibited strong affinity to H^-CO_3. On the other hand during the post-monsoon season CCA analysis shows, *Nitzschia, Sphaerogoum and Melosira* exhibited strong relation with H^-CO_3 but pH, TSS, secchi depth. Cluster Analyses (CA) by root and Bray Curtis Similarity of sites in terms of phytoplankton occurrence showed that during the both season Hatiya and Sandwip as well as Barisal and Bhola formed cluster (group) that indicates they were almost similar in terms of phytoplankton composition. While Chandpur formed a single cluster. The phytoplankton diversity (H') of phytoplankton did not show much variation (1.18±0.22 and 0.87±0.40 for the monsoon and post-monsoon seasons respectively) temporally. The highest phytoplankton diversity (H') was recorded at Sandwip (1.517) during the monsoon season and the lowest value was recorded at same site Sandwip (0.35) during the post-monsoon season. Again, the evenness (J') of phytoplankton showed less variation with seasonal environmental changes (0.80±0.23 and 0.58±0.18 monsoon and post-monsoon seasons). The maximum evenness value was at Bhola (0.99) during monsoon season and it was minimum at Chandpur (0.36) during the post-monsoon season.

Limitation

In the present study the sampling sights covered an area of about 172 km and samples were collected from passenger ship. So it was difficult to take sample at a time from all sites as well as to maintain tidal cycle or tide log. Again as samples were collected from passenger ship on board samples have to collect where the ship anchored for disembarkation of passengers and goods.

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5. References

1. James TY, Litvintseva AP, Vilgalys R, Morgan JAT, Taylor JW, Fisher MC. Rapid expansion of an emerging fungal disease into declining and healthy amphibian populations. PLoS Pathogens. 2009; 5:10-45.
2. Battish SK. Freshwater zooplanktons of India. A preliminary observation on water quality and Oxford and IBH publishing co. Ltd., New Delhi, 1992.
3. Rahman S, Jewel MAS. Cyanobacterial blooms and water quality in two urban fish ponds. University Journal of Zoology, Rajshahi University. 2008; 27:79-84. DOI: http://dx.doi.org/10.3329/ujzru.v27i0.1960
4. Wickstead JH. An Introduction to the study of Tropical Plankton. Hutch inson and Co. Ltd. London, 1965, 160.
5. Davies OA, Abowei JFN, Tawari CC. Phytoplankton Community of Elechi Creek, Niger Delta, Nigeria-A Nutrient-Polluted Tropical Creek, American Journal of Applied Sciences. 2009; 6:1143-1152.
6. Munk P, Hansen BW, Nielsen TK, Thomsen HA. Changes in plankton and fish larvae communities across hydrographic fronts off West Greenland. Plankton Resource. 2003; 25:815-30.
7. Molinero JC, Ibanez F, Souissi S, Bosc E, Nival P. Surface patterns of zooplankton spatial variability detected by high frequency sampling in the NW Mediterranean: role of density fronts. Marine System. 2008; 69:271-82.
8. Farahani F, Korehi H, Mollakarami S, Soghra Skandari S, Zaferani SGG, Shashm ZMC. Phytoplankton Diversity and Nutrients at the Jajerood River in Iran. Pakistan Journal of Biological Sciences. 2006; 9:1787-1790. DOI: 10.3923/pjbs.2006.1787.1790
9. Rahman S, Hossain MB. Present status of culture management and production status in various leased out fish ponds of Rajshahi City corporation. Intl. J Bio Res. 2009; 6:53-60.
10. Bahaar SWN, Bhat GA. Aquatic Biodiversity in the Paddy Fields of Kashmir Valley (J and K) India. Asian Journal of Agricultural Research. 2011; 5:269-276. DOI: 10.3923/ajar.2011.269.276
11. Jalal KCA, Ahmad Azfar BM, Akbar John B, Kamaruzzaman YB. Spatial Variation and Community Composition of Phytoplankton along the Pahang Estuary, Malaysia, Asian Journal of Biological Sciences. 2011; 4:468-476. DOI: 10.3923/ajbs.2011.468.476
12. Newton A, Icely JD, Falcao M, Nobre A, Nunues JP, Ferreira JG *et al*. Evaluation of the eutrophication in the Ria Formosa coastal lagoon, Portugal. Cont. Shelf Res. 2003; 23:1945-1961.
13. Domingues RB, Anselmo TP, Barbosa AB, Sommer U, Galvao HM. Nutrient limitation of phytoplankton growth in the freshwater tidal zone of a turbid, Mediterranean estuary, Estuarine, Coastal and Shelf Science. 2011; 91:282-297. http://dx.doi.org/10.1016/j.ecss.2010.10.033
14. Sharma A, Sharma RC, Anthwal A. Monitoring phyto-plankton diversity in the hill stream Chandrabhaga in Garhwal Himalayas, Life Science Journal. 2007; 4:80-84.
15. Ali AL. Seasonal variation in physico-chemical properties and zooplankton biomass in Greater Zab River – Iraq, Jordan Journal of Biological Sciences. 2010; 3:115-120.
16. Jafari N, Nabavi SM, Akhavan M. Ecological investigation of zooplankton abundance in the river Haraz Northeast Iran: impact of environmental variables, Archives of Biological Sciences. 2011; 63:785-798. DOI:10.2298/ABS1103785J
17. Ogbuagu DH, Ayoade AA. Seasonal dynamics in plankton abundance and diversity of a freshwater body in Etche, Nigeria, Environment and Natural Resources Research. 2012; 2:48-59.
DOI: http://dx.doi.org/10.5539/enrr.v2n2p48
18. Chopra G, Bhatnagar A, Malhotra P. Limnochemical characteristics of river Yamuna in Yamunanagar, Haryana, India, International Journal of Water Resources and Environmental Engineering, 2012; 4:97-104.
19. Negi RK, Joshi PC, Negi T. Seasonal variation and

species composition of phytoplankton in Ganga River and its tributary at Garhwal region, Uttarakhand, India, International Journal of Environment, Ecology, Family and Urban Studies. 2012; 2:24-30.
20. Waylett AJ, Hutchins MG, Johnson AC, Bowes MJ, Loewen- thal M. Physic-chemical factors alone cannot simulate phytoplankton behaviour in a lowland river, Journal of Hydrology. 2013; 497:223-333. http://dx.doi.org/10.1016/j.jhydrol.2013.05.027
21. Sharma C, Jindal R, Singh UB, Ahluwalia AS, Thakur RK. Population dynamics and species diversity of plankton in relation to hydrobiological characteristics of river Sutlej, Punjab Ecology, Environment and Conservation. 2013; 19:717-724.
22. Chekryzheva TA. Anthropogenic changes in phytoplankton in lakes of the Kenti River System (Republic of Karelia), Water Resources, 2014; 41:431-438. DOI: 10.1134/S0097807814040046
23. Hafiz BZ, Pandit AK, Shah JA. Phytoplankton community of river Jhelum in Kashmir Himalaya, Journal of Environmental Science and Technology. 2014; 7:326-336.
24. Sharma RC, Singh N, Chauhan C. The influence of physico-chemical parameters on phytoplankton distribution in a head water stream of Garhwal Himalayas: A case study, The Egyptian Journal of Aquatic Research. 2016; 42:11-21. http://dx.doi.org/10.1016/j.ejar.2015.11.004
25. Azadi MA. Limnology of the kaptai reservoir physical-chemical aspects of Bangladesh, Proceeding of 12th annual Bangladesh Science Conference (BSC'87), Bangladesh Association for the Advancement of Science, Dhaka, 1987, 44-45.
26. Affan A, Jewel SA, Haque M, Khan S, Lee JB. Seasonal Cycle of Phytoplankton in Aquaculture Ponds in Bangladesh, Algae, 2005; 20:43-52. doi: https://doi.org/10.4490/algae.2005.20.1.043
27. Alam A, Mustafa MG, Azad MAK. Water and sediment quality and plankton diversity of Posna beel, Tangail, Bangladesh Journal of Fisheries. 2007; 30:177-18.
28. Ahmed MS, Hiller S, Luckas B. Microcystis aeruginosa Bloom and the Occurrence of Microcystins (Heptapeptides Hepatotoxins) From an Aquaculture Pond in Gazipur, Bangladesh, Turkish Journal of Fisheries and Aquatic Sciences. 2008; 8:37-41.
29. Rahman S, Jewel MAS, Hossain MB. Cyanobacterial Abundance and Bloom Dynamics in Two Urban Wastefed Fish Pond of Bangladesh, Journal of Subtropical Agricultural Research Development. 2009; 7:645-652
30. Ahmed S, Arifur Rahman AFM, Belal Hossain M. Phytoplankton Biodiversity in Seasonal Waterlogged Paddy Fields, Bangladesh. Ecologia. 2013; 3:1-8. DOI**:** 10.3923/ecologia.2013.1.8
31. Pipkin BW, Donn SG, Richard EC, Duglas EH. Laboratory exercise in oceanography. W-H. Freeman and company, Sanfrancisco. USA. 1977, 255.
32. Jin-Eong O, Gong WK, Wong CH, Zubir BHD. Productivity of the mangrove ecosystem: A manual of method. Unit Pencetakan Pusat. University Sains. Malaysia. 1985, 117.
33. APHA-AWWA-WPCF. Standard Methods for the examination of water and waste water 13th (edi). American public health association American water works association USA. Water pollution control Federation. 1974, 1099.
34. APHA-AWWA-WPCF. Standard Methods for the examination of water and waste water 14th (edi). American public health association American water works association USA. Water pollution control Federation, 1975, 1193.
35. Mizuno T. Illustrations of the fresh water plankton of Japan. Hoikusha publishing Co., Ltd. Osaka, Japan, 1976, 351. (In Japanese)
36. Yamaji I. Illustrations of the marine plankton of Japan. Hoikusha Publishing Co. Ltd. Osaka, Japan, 1972, 369.
37. Yamaji I. The plankton of Japanese coastal water. Hoikusha publishing co.; Ltd. Osaka. Japan, 1974, 238.
38. Davis CC. The marine freshwater plankton Michigan state University Press. Chiago USA, 1955, 562.
39. Easter EC. Marine plankton diatom of the west coast of North America. University of California press Berkeley, Losangles, USA and Cambridge University press London, England, 1943, 136.
40. James F, Nature adrift. The story of marine plankton. The University press Aberdeen, Great Britain, 1943, 178.
41. Newell GE, Newell RC. Marine Plankton-A practical guide. Hutchinson and Co. Ltd. London, 1973, 282.
42. Newell GE, Newell RC. Marine plankton a practical guide. (5th edi). Hutchinson and Co. (Publishers) Ltd. London. 1979, 244.
43. Islam AKMN, Aziz A. A preliminary study on the zooplankton of the North-eastern Bay of Bengal Bangladesh Joural of Zoology. 1975; 3:125-138.
44. Islam AKMN, Aziz A. Marine Diatoms from the Bay of Bengal, Bangladesh, Bangladesh Journal of Botany. 1980; 9:29-35.
45. Haque SMA. Study on phytoplankton of the Matamuhuri estuary and the fish ponds in the vicinity. M. Sc. Thesis. IMS, CU. 1983, 175.
46. Rahman MM. Texonomic studies of the Ichthyoplankton of the Karnophully River estuary. M. Sc thesis. IMS. CU. Ctg. 1997, 58.
47. Chowdhury MZR. Study on micronutrients and standing crop of phytoplankton in the coastal waters of Cox's Bazar, Chittagong, Bangladesh. M. Sc, Thesis. IMS, University of Chittagong. 1998, 98.
48. Islam ME. Phytoplankton of coastal waters of Bangladesh, A Review. B.Sc. (Hons.). Term paper. 2001, 79.
49. Sarode PT, Kamat ND. Freshwater Diatoms of Maharashtra, Saikripa Prakashana Aurangabad. Maharashtra. India, 1948, 323.
50. Subrahmanyan R. A systematic account of the Marine plankton diatoms of the Madras coast. Bangalor press. Bangalore, India, 1946, 198.
51. Hendey NI. An introductory Account of the smaller algae of the British coastal waters. Pergamon press. 1964, 170.
52. Russel-Hunter WD. Aquatic productivity The Macmillan company New York USA. 1970, 303.
53. Suess MJ. Examination of water for pollution control: A reference hand book. Pergamon Press, 1982, 531.
54. Islam AKMN. Contribution to the study of Marine Algae of Bangladesh, 1982, 253.
55. George B, Kumar JIN, Kumar NR. Study on the influence of hydro-chemical parameters on phytoplankton

distribution along Tapi estuarine area of Gulf of Khambhat, India, Egyptian Journal of Aquatic Research. 2012; 38:157-170. http://dx.doi.org/10.1016/j.ejar.2012.12.010
56. Chang H. Spatial analysis of water quality trends in the Han River basin, South Korea, Water Research. 2008; 42:3285-3304. http://dx.doi.org/10.1016/j.watres.2008.04.006
57. Mahmood N, Khan YSA. Preliminary observations on the hydrological conditions of the Bay of Bengal off the coast on Bangladesh Journal of Asiatic Society, Bangladesh (Sc.). 1976; 1:117-122.
58. Elias SM. Zooplankton of the Mathamuhuri estuary with special reference to shrimp and finfish larvae. M. Sc. Thesis (unpublished) Institute of Marine Sciences, University of Chittagong. 1983, 172.
59. Mahmood N. Study on immigration of commercially important penaied Shrimp post larvae in the estuarine area of Chakaria, Cox's Bazar, Bangladesh. Phd. Thesis. Department of Zoology. Rajshahi University. Bangladesh. 1990, 125.
60. Zafar M. Seasonal influence on Zooplankton abundance with emphasis on postlarvae of Macrobrachium rosenbergii in the Kutubdia channel, Bay of Bengal. Proceeding of the workshop on the Coastal Aquacualture and environmental management, 1995, 39-44.
61. Iqbal MH. Study on water quality and some commercially important fishes of the Rezu khal-estuary. M.Sc, Thesis. IMS, University of Chittagong, 1999, 95.
62. Noori MN. An investigation on seasonal variation of micronutrients and standing crop of phytoplankton in neritic waters off the southeast coast of Bangladesh. M. Sc. Thesis. (Unpublished), IMS. Univ. Ctg. 1999, 91.
63. Martin GD, Vijay JG, Laluraj CM, Madhu NV, Joseph T, Nair M *et al*. Fresh water influence on nutrient stoichiometry in a tropical estuary, Southwest coast of India, Applied Ecology and Environmental Research. 2008; 6:57-64.
64. Aken HM. Variability of the water temperature in the western Wadden Sea on tidal to centennial time scales, Journal of Sea Research. 2008; 60:227-234. http://dx.doi.org/10.1016/j.seares.2008.09.001
65. Dehairs F. Marine Physio-Chemistry: Salt, Temperature and Density. In Physicochemistry of Marine Systems. Retrieved from; http://www.vub.ac.be/ANCH/educ/Marine%20Physico%20Chemistry%20Pdf%20version%20Chs%201%20to%207/Chapter%202%20Salt%20Temperature%20and%20Density.pdf 2005.
66. Millero FJ. The pH of estuarine waters, Limnology and Oceanography. 1986; 31:839-847.
67. Nakles D, Ray L. Overview of Bioremediation Research of Texas and Gas Research Institute. Presentation at DOE/PERF Bioremediation Workshop, 2002.
68. Briola M, Guevara M, Menzies D, Oshima H, Sanderson K. The Effects of pH on the Abundance of Phytoplankton for Mariculture. Ketchikan High School. 2010, 20.
69. Chang H. Spatial and temporal variations of water quality in the river and its tributaries, Seoul, Korea, 1993–2002, Water, Air, and Soil Pollution. 2005; 161:267-284. DOI: 10.1007/s11270-005-4286-7
70. Morgan AM, Royer TV, David MB, Gentry LE. Relationships among nutrients, chlorophyll-*a*, and dissolved oxygen in agricultural streams in Illinois, Journal of Environmental Quality. 2006; 35:1110-1117.
71. Sharma RK, Rathore V. Pollution ecology with reference to commercially important fisheries prospects in rural-based water body: The Lake Sarsai Nawar, Etawah (Uttar Pradesh). Pollut. Res. 2000; 19:641-644.
72. Pejman AH, Bidhendi GRN, Karbassi AR, Mehrdadi N, Esmaeili MB. Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. International Journal of Environmental Science & Technology. 2009; 6:467-476. DOI: 10.1007/BF03326086
73. Sharma RC, Arambam R, Sharma R. Surveying macro-invertebrate diversity in Tons River, Doon Valley, India, The Environmentalist, 2009; 29:241-254. DOI: 10.1007/s10669-008-9187-z
74. Rani N, Sinha RK, Prasad K, Kedia DK. Assessment of temporal variation in water quality of some important rivers in middle Gangetic plains, India, Environmental Monitoring and Assessment. 2011; 174:401-415. DOI:10.1007/s10661-010-1465-9
75. Sridhar RT, Thangaradjou S, Senthil K, Kannan L. Water quality and phytoplankton characteristics in the Palk Bay, south- east coast of India, Journal of Environmental Biology. 2006; 27:561-566.
76. Murugan A, Ayyakkannu K. Studies on the ecology of phytoplankton in Cuddalore Uppanar Brak-Wate, Southeast coast of India, Journal of Marine Sciences. 1993; 2:45-58.
77. Ezra AG. A study of Planktonic Algae in Relation to the physicochemical properties of some freshwater ponds in Bauchi. Nigeria, Nigerian Journal of Experimental and Applied Biology. 2000; 1:55-60.
78. Venkateswarlu N, Reddy PM. Plant Biodiversity and Bioindicators in Aquatic. Environment, ENVIRO NEWS, 2000.
79. Haruna AB, Abubakar KA, Ladin BMB. An assessment of physicochemical parameter and productivity status of Lake Geriyo, Yola Adamawa State, Nigerian. Best Journal. 2006; 3:18-23.
80. Roy R, Pratihary A, Mangesh G, Naqvi SWA. Spatial variation of phytoplankton pigments along the south west coast of India. Estuarine, Coastal and Shelf Science. 2006; 69:189-195. http://dx.doi.org/10.1016/j.ecss.2006.04.006
81. Jouenne F, Lefebvre S, Veron B, Lagadeuc Y. Phytoplankton community structure and phytoplankton production in small intertidal estuarine-Bay ecosystem, Marine Biology. 2007; 151:805-825. DOI: 10.1007/s00227-006-0440-z
82. Rey PA, Taylor JC, Laas A, Rensburg L, Vosloo A. Determining the possible application value of diatoms as indicators of general water quality: a comparison with SASS 5. Water SA, 2004; 30:325-332. http://dx.doi.org/10.4314/wsa.v30i3.5080
83. Harnstrom K, Karunasagar I, Godhe A. Phytoplankton species assemblage and their relationship to hydrographic factors-a study on the old port in Mangalore, Coastal Arabian sea, Indian Journal of Marine Sciences. 2009; 38:224-234.
84. Carstensen J, Henriksen P, Heiskanen AS. Summer algal bloom in shallow estuaries: definition, mechanisms and link to eutrophication, Limnology and Oceanography.

2007; 52:370-384.
85. Khattak TM, Bhatti N, Murtaza G. Evaluation of algae from the effluent of Dandot Cement Company, Dandot, Pakistan, Journal of Applied Sciences and Environmental Management. 2005; 9:147-149.
86. Qasim SZ, Bhattathiri PMA, Devassy VP. The influence of salinity on rate of photosynthesis and abundance of some tropical phytoplankton, Marine Biology. 1972; 12:200-206. DOI: 10.1007/BF00346767
87. Rahman M. Phytoplankton of the Naf River-estuary during post-monsoon near Teknaf Coast. M.Sc. Project (Unpublished). Univ. Ctg. 1977, 24.
88. Salam AMA. Algal flora of the karnafully estuary and ecological observations on changes in the growth of some intertidal algae at patenga coast. M. Sc. Thesis; Dept. Mar. Biol, Univ. Ctg, 1977, 149.
89. Islam AKMN, Aziz A. Studies on the phytoplankton of the Karnafully River-estuary. Journal of Bangladesh Academy of Sciences. 1977; 1:141-154.
90. Zafar M. Study on Sergestid Shrimp Acetes in the vicinity of Mathamuhuri river confluence, Bangladesh. PhD. Thesis (Unpublished). IMS. Univ. Ctg. 2000, 223.
91. Margalef R. Information theory in ecology- Gen. Sys. 3:36-71.Transl. R. Acad. Ciene. Artes. Barc. 1957, 1958; 32:373-449.