SPATIO-TEMPORAL VARIATIONS OF WATER QUALITY AND PHYTOPLANKTON DIVERSITY OF THE DIFFERENT RIVERS FLOWING WITHIN SUNDARBAN MANGROVE WETLAND ECOSYSTEM OF BANGLADESH

Ahmed, A., N. Akter, S. Hasan[1] and M. Ataullah

Ecology and Environment Laboratory, Department of Botany, University of Dhaka, Dhaka-1000;
[1]Ecology and Environment Laboratory, Department of Botany, Jagannath University, Dhaka

Abstract

The water of different rivers passing in the Sundarban Mangrove Forests (SMF) of Bangladesh was analyzed to know the spatio-temporal variations in the water quality and phytoplankton diversity of the river. The pH of the waters of all the rivers examined showed a narrow range of variation (6.60-7.8 in 2015 and 6.3 to 7.5 in 2016) indicating the buffering capacity of different rivers. The values of pH showed a slightly decreasing tendency indicating the acidification of river waters which might be due to increase of global CO_2 concentration in the atmosphere. The temperature of water, conductivity, salinity, DO (ppm), DO (% sat), K, Na, was found to vary from 27.6 to 30.8° C, 8.00 to 32.30 mS/cm, 5.50 to 23.00 ‰, 3.5 to 6.35 ppm, 46.60 to 82.00 %, 125.00 to 630.00 mg/l, 600 to 4300 ppm, respectively in April 2015; and ranged from 28.8 to 31.0° C, 9.48 to 31.60 mS/cm 5.00 to 24.00 ‰, 0.11 to 5.33 ppm, 1.2 to 95.2 % saturation, 110 to 670 ppm, 4683.5 to 13465.10 ppm, respectively in March 2016. The values of Ca, Mg and Fe were 210 to 500 ppm, 320.0 mg/l to 892.0 mg/l and 0.25 to 0.050 mg/l, respectively in 2015. The amount of DO was very low during 2016 especially in the locations 1, 2, 3 which might be due to cloudy condition during sampling time. Principal component analyses (PCA) of different variables of the year 2015 showed that PC-1 had positive loading of water temperature, air temperature, humidity, pH, conductivity, Salinity, Na, K, Fe, Mg, Zn whereas PC-1 of different variables during 2016 showed positive loading of only water temperature and pH. Maximum number of phytoplankton taxa was recorded from Sela river (Tambulbunia) where 34 taxa (with the unknown ones) were recorded followed by Passur river (near Mongla Ferry Ghat). *Coscinodiscus* is found to be the dominant genus. Maximum Shannon-Weaver index of diversity was found in Homra Khal (value was 6.825) and minimum was found in Sela river (where the oil tanker sank and value was 0.0). Only one species of phytoplankton was found in this place. Maximum species richness (d) was observed in Passur river at Mongla ferry ghat with a value of 14.81 whereas, maximum evenness (e) was found in location 16 (Homra khal with a value of 5.437).

Key words: Bangladesh Sundarbans; Water quality; Spatio-temporal variation; Phytoplankton diversity.

INTRODUCTION

Mangroves are the dominant intertidal vegetation in tropical and sub-tropical estuarine systems (Chapman 1976, Duke 1992). It supports essential ecological functions (Shervette *et al.* 2007). The Sundarban mangrove forests (SMF) are the single largest track of the world. It is situated at the southern coastal zone of Bangladesh. The Sundarbans (both Bangladeshi and Indian parts) form the southern part of Gangetic delta between the Hugli river on the west and Meghna river on the east (Nazrul-Islam 2003). In Bangladesh, the western part of Sundarbans is demarcated by the Raimangal river. The area has a number of low lying swampy islands formed by the main distributaries of the Ganges and their anabranches and connection creeks. In the eastern section between the Madhumati (the Baleshwar) and the Meghna, cultivation and clearing extend up to the sea-face. The central portion between the Baleshwar and Raimangal rivers had reserved forest in the past, but at present the areas have decreased in size (Nazrul-Islam 2003).

The health of the wetlands has been influenced by the anthropogenic activities (Claessens *et al*. 2006, Chang 2007) which have resulted in the changes of water temperature (Nelson and Palmer 2007) and biological processes (Baker 2003). The physico-chemical and biological characteristics have been found to determine the status of the aquatic ecosystems. To know the spatio-temporal changes in the water quality is essential to monitor as focused by different authors (Chang 2005, Rajasekar *et al*. 2005,

Crosa *et al*. 2006, Anilakumary 2007, Astel *et al*. 2007, Prabu *et al*. 2008, Ahmed *et al*. 2010). The present study is envisaged to discuss the spatial variations of physico-chemical properties of water and phytoplankton diversity in the different rivers and canals passing through the Bangladesh Sundarbans mangrove wetland ecosystems. The study has also been aimed to characterize the spatial variability of coastal water which can be horizontally or vertically found.

MATERIAL AND METHODS

Water samples were collected from different rivers flowing within the Sundarban mangrove forests (SMF) of Bangladesh part for analyzing the spatio-temporal variations of physico-chemical features and phytoplankton diversity of rivers. Water samples (500 ml) were collected during 4-8 April in 2015 and 27-31 March in 2016 from twenty one locations. A total of 16 different rivers and canals (Khals) flowing within the forests was selected (Table 1).

Table 1. Sampling locations, Ranges and ecological zones of Sundarban Mangrove Forests (SMF) of Bangladesh part (NC = not collected, R. = river).

Name of the rivers/khals	Coordinate of the locations	Dates, time and tidal conditions		Ranges /Ecological zones (BFD 2010/Nazrul-Islam 2003)
		2015	2016	
Mongla Ferry Ghat Passur R.	22°28′17.9″ -22°27′4.1″ N 89°35′41.5″ -89°35′21″ E	06.04.15 HT 9.33 A.M.	27.03.16 HT 9.00A.M	Out skirt of SMF
Koramjol Passur R.	22º25′28″- 22º25′01″N 89º35′43″- 89º35′38″E	06.04.15 HT 11.04 A.M.	NC	Chandpai Oligo-Mesohaline
Sela R. (starting at Joimony Ghol)	22º21′26″- 22º21′59″N and º ′ ″- 89º38′33″E	06.04.15 HT 1.30 P.M.	27.03.16 HT 2.10 A.M	Chandpai Oligo-Mesohaline
Shela R. (Tanker sinking place)	22º21′42″-20º21′36.3″N 89º40′4.8″- 89º40′8.7″E	06.04.15 LT 2.30 P.M.	27.03.16 LT 5.10 A.M	Chandpai Oligo-Mesohaline
Shela R. Tambulbunia	22º12′31.3″-22º12′33.7″N 89º41′55.1″-89º42′15.9″E	07.04.15 LT 7.00 A.M.	28.03.16 HT 8.30 A.M	Chandpai Oligo-Mesohaline
Pathuria R.	22º12′33.7″-22º10′49.5″N 89º42′16″- 89º44′41.7″E	07.04.15 HT 11.00 A.M	28.03.16 HT 10.30 AM	Chandpai Oligo-Mesohaline
Suputi R./ Dudmukhi R.	22º10′4.7″- 22º03′3.2″N 89º44′37.1″- 89º49′29.5″E	07.04.15 HT 1.30 P.M.	28.03.16 LT 2.35 A.M	Sarankhola Oligo-Mesohaline
Choto Kotka	21º54′27.1″-21º54′6.6″N 89º46′54.5″- 89º46′55.5″E	07.04.15 LT 5.15 P.M.	NC	Sarankhola Oligo-Mesohaline
Kotka Betmar Gang	21º51′33.6″- 21º51′33.3″N 89º46′40.2″- 89º46′48.9″E	08.04.15 HT 8.45 A.M.	29.03.16 HT 9.20 A.M	Sarankhola Oligo-Mesohaline
Harbaria Passur R.	22º20′17.6″-22º19′15″ 89º37′53.4″- 89º37′31″E	09.04.15 LT 11.00 A.M	31.03.16 HT 12.00 AM	Chandpai Oligo-Mesohaline
Khalpatua R. (Burigualini forest office)	22º27′50.5″-22º13′59.2″N 89º19′10.9″- 89º14′23.6″E	10.04.15 LT 7.00 A.M.	NC	Satkhira Polyhaline
Kobatak R. Forest office	22º12′53.1″-22º12′1.7″N 89º14′13.6″-89º18′59.4″E	10.04.15 LT 10.00 A.M	30.03.16 HT 10.15 AM	Satkhira Polyhaline
Khashitana Forest office (Khashitana Khal)	22º12′46.9″- 22º12′38.7″N 89º22′12.1″- 89º22′45.5″E	10.04.15 HT 2.00 P.M.	30.03.16 LT 4.45 P.M	Khulna Mesohaline
Sibsha R. Adachi forest office	22º16′54.9″- 22º17′30.1″N 89º28′38.9″-89º29′22.1″E	10.04.15 HT 4.30 P.M.	NC	Khulna Mesohaline
Kalabogi	22º29′30″- 22º24′4.1″N 89º26′45.7″-89º27′0.4″E	06.04.15 HT 5.30 P.M.	NC	Khulna Mesohaline
Homra Khal	22º79′ N - 89º44′E	NC	29.03.16 HT; 12.00 PM	Sarankhola Mesohaline
Sela R.	22º02′ N - 89º42′E	NC	29.03.16 HT; 4.00 P.M	Sarankhola Mesohaline
Harmal R.	22º04′ N - 89º36′E	NC	29.03.16 HT; 5.00 P.M.	Sarankhola Mesohaline
Chawlabogi	22º45′ N - 89º38′E	NC	29.03.16 HT; 5.30 P.M.	Sarankhola Mesohaline
Patcosta	22º1.5′ N - 89º26′E	NC	30.03.16 LT; 7.45 A.M	Khulna Polyhaline
Ball R. North of Jalia forest office	22º3.4′ N - 89º22′E	NC	30.03.16 LT; 8.30 A.M	Khulna Polyhaline

For the measurement of species diversity, many indices are available (Berger and Parker 1970, Sanders 1968). From the four frequently used indices, one was chosen for the present study. It is of Shannon–Weaver Index (1949) which is as follow:

$$H = -\sum (pi) (\log_2 pi)$$

where, H = index of species diversity derived from the information.
S = number of species and
pi = proportion of total sample belonging to the i-th species.

Species richness index (d) and Evenness index (e) were also calculated according to following equations.

Species richness index (d) was calculated according to Margalef (1951)

$$d = (S–1)/ \text{Log } N$$

where, d = Species richness index
S = Number of species in a population
N = Total number of individuals in S species.

The equitability or evenness (e) refers to the degree of relative dominance of each species in that area. It was calculated according to Pielou (1969) as:

$$e = Hs / \text{Log } S$$

where, e = Equitability index
Hs = Shannon and Weaver index
S = Number of species in a population

RESULTS AND DISCUSSION

Spatio-temporal variations of water quality

The river water quality study is required for stabilizing base line conditions, setting quality criteria and standards, monitoring of temporal and spatial variations (Ahmed 2004). The present study showed that the temperature of water samples at different sites varied from 27.6 to 30.8° C in April 2015 and 28.8 to 31.0° C in March 2016 (Table 2). Water temperature did not show significant correlation with all variables during second visit. Rahman *et al.* (2013) recorded water temperature between 19.92°C and 31° C.

The pH of a water body affects other chemical reactions such as solubility and metal toxicity (Fakayode 2005). During first visit in April 2015, pH of the water of different rivers showed a narrow range of variation (6.60 - 7.80) with the mean value of 7.21 ± 0.33 showing the buffering capacity of the water of different rivers. The highest pH (7.80) was recorded in Kotka and the lowest in Sela river at Tambulbunia. The mean pH value was 7.15 ± 0.27 in Passur river at Mongla Ferry Ghat (location 1). The mean pH value in location 3 (Sela river where it starts from Passur river at Joymoni Ghol), 4 (at Sela river where an oil carrying tanker was sank in 2015) and 5 (Sela river, Tambulbunia forest office) were 6.90 ± 0.08, 6.92 ± 0.19 and 6.77 ± 0.05, respectively. The pH mean values in location 12 (Kobadak), location 14 (Sibsha), and location 15 (Kalabogi) were 6.60 ± 0.17, 6.83 ± 0.10 and 6.67 ± 0.32, respectively. pH showed positive significant weak correlation with salinity conductivity, Na and Mg and did not show significant correlation with other variables (Table 3).

In March 2016 the pH of water samples at different sites of the rivers was found to vary from 6.30 to 7.50 with a mean value of 6.92 ± 0.30. pH showed negative moderate to weak correlation with Salinity, Conductivity, DO (% Sat), DO (ppm), K, Na, but did not show significant correlation with other

variables. Aziz *et al*. (2012) found the pH of rivers flowing in SMF ranged from 7.2 to 8.0 which indicated that the water of the rivers was slightly to moderately alkaline in nature. Rahman *et al*. (2013) recorded pH between 6.70 and 7.87. The present study showed that pH decreased in the rivers. This is an indication of slight acidification of the rivers' water of the SMF. It may be due to the increase in CO_2 content in air due to global climate change. Change in pH in estuaries is more complicated than in the open ocean due to direct impacts from land run-off and coastal current dynamics. Absorption of atmospheric carbon dioxide (CO_2) resulted in the ocean acidification of the Earth's oceans, i.e. pH decreases (Caldeira and Wickett 2003) (0.1 units over the last century) (Orr *et al.* 2005). The decline in the pH of the water of the ocean surface might be attributed to increase in aqueous carbon dioxide which is resulted from the absorbance of 30-40 % of all CO_2 that are released to atmosphere (Orr *et al.* 2005). Islam (2012) recorded the pH of water in the Meghna estuary ranging from 7.40 to 7.80 where mean value was 7.46. Ahmed *et al.* (2010) recorded pH ranging from 7.80 to 8.20 from the Buragauranga estuary at Rangabali, Patuakhali district. Almost similar pH (6.80-7.90) was found from the water of the Padma river at Mawa ghat, Munshiganj (Ahmed 2004) and from the Manipur river system (Singh *et al.* 2010). pH values were found higher (8.1) than that of the present study in the Padma near north western region of the Bangladesh (Talukdar *et al*. 1994). The standard of pH ranged from 6.50 to 8.50 as per WHO (1995). The pH of the different rivers of SMF during April 2015 and March 2016 were within this limits. This water could be regarded as slightly alkaline and unpolluted (Fakayode 2005).

Table 2. Physico-chemical properties of the water of different rivers and khals (canals) flowing within the Sundarban mangrove forests (- = not studied, Temp. = Temperature, Humid. = Humidity, R. = river).

Locations and names of the rivers / khals	Water temp. (ºC)		Air Temp. (ºC) 2015	Humid. 2015	pH	
	2015	2016			2015	2016
Passur R. (Mongla Ferry Ghat)	28.38 ± 0.22	29.05 ±0.13	29.0	79	7.15 ± 0.26	6.85 ± 0.1
Passur R. (Koramjol)	28.65 ±0.13	-	32.0	65	7.45 ± 0.06	-
Sela R. (starting at Joimony Ghol)	30.07 ±0.34	29.17 ±0.31	33.0	55	6.9 ± 0.08	7.22 ±0.09
Sela R. (Tanker sinking place)	29.65±0.37	29.07±0.24	35.0	49	6.92±0.19	7.42 ±0.09
Sela R. Tambulbunia	27.42 ±0.7	29.42± 0.05	25	96	6.77 ± 0.05	7.42± 0.09
Pathuria R.	30.0 ±0.08	29.42± 0.40	29.5	70	7.22 ±0.31	6.97±0.17
Suputi R.	29.75 ±0.48	29.6± 0.455	30.5	73	7.17 ±0.2	7.05± 0.17
Choto Kotka	28.7 ±0.2	--	28	86	7.12±0.35	-
Kotka	28.3 ±0.14	28.4 ± 0.08	28	96	7.67 ±0.15	6.6 ± 0.29
Harbaria	28.2 ±0.14	28.83± 0.06	28	96	7.25 ±0.31	6.80 ±1.0
Burigualini forest office (Khalpatua R.)	28.67±0.36	-	27	82	7.25±0.379	-
Kobatak R.	30.52 ±0.3	29.57± 0.06	33	80	7.075 ±0.3	6.83 ±0.11
Khashitana Forest office (Khashitana Khal)	30.42 ±0.25	29.13± 0.11	34	75	7.57 ±0.05	6.67 ±0.32
Sibsha R.	30.62 ±0.17	-	27.5	75	7.62 ±0.15	-
Kalabogi	29.17 ±0.31	-	31.5	86	7.0 ±0.18	-
Homra Khal	-	30.27± 0.5	-	-	-	6.7±0.
Harmal R.	-	29.37 ±0.6	-	-	-	6.7 ± 0.29
Harmal R.	---	29.22± 0.25	-	-	-	6.9 ±0.18
Chawlabogi	-	29.02 ±0.05	-	-	-	6.8± 0.14
Patcosta	-	28.97 ±0.06	-	-	-	6.6 ±0.17
Ball R.	-	29.2±0.0	-	-	-	6.63±0.15

To measure the amount of total dissolved ions, a good and rapid method is to measure conductivity that is related to the amount of total solids present. Higher amount of total solids indicated that greater amount of ions is present in water (Bhatt *et al.* 1999). The conductivity of water samples at different study sites was found to vary from 8.00 to 32.30 mS/cm in April 2015 and 9.48 to 31.6 mS/cm in March 2016 (Table 4). Conductivity showed very strong positive significant correlation with salinity, K, Na, and showed weak positive significant correlation with DO (Sat); DO (ppm). Conductivity also showed

negative correlation with pH, but did not show significant correlation with other variables. Aziz *et al.* (2012) had found minimum conductivity to be 14mS/cm and maximum conductivity was 40.3 mS/cm where mean value was 26.66±7.37 mS/cm in the different rivers of the SMF. Islam (2012) showed significant variations in conductivity in the Meghna estuary. The minimum conductivity was found to be 5.15 mS/cm and maximum conductivity was 9.95 mS/cm where mean value was 6.45 mS/cm. Conductivity of the present study (8.00-32.30 mS/cm) was more than recommended value (750 µS/cm or 0.750 mS/cm) as given by WHO (1995). In the Buragaurnaga estuary, Ahmed *et al.* (2010) recorded 5.23 to 25.15 mS/cm. Ahmed (2004) reported 106.0 - 2009.0 µS/cm conductivity in the river Padma. Patra and Azadi (1987) reported 94.18µS/cm conductivity in the river Halda. The conductivity showed very strong positive significant correlation with salinity and Mg; medium positive significant correlation with Na, K and Fe; positive significant correlation with humidity and pH; conductivity also showed negative correlation with DO (ppm). Conductivity did not show significant correlation with other variables.

The salinity acts as a limiting factor in the distribution of living organisms, and its variation caused by dilution and evaporation is most likely to influence flora and fauna in the intertidal zone (Gibson 1982). The salinity of water samples at different study sites was found to vary from 5.50 to 23.00‰ in April 2015 and 5.00 to 24.00 % in March 2016 (Table 3). During first visit, salinity showed very strong positive significant correlation with conductivity and Mg; strong positive significant correlation with K; medium positive significant correlation with Fe; weak positive significant correlation with humidity, pH and Na; salinity also showed negative correlation with DO (ppm). Salinity did not show significant correlation with other variables (Table 3). During the second visit, salinity has been found to show very strong positively significant correlation with conductivity, K and Na; Salinity showed significant moderate negative correlation with pH but did not show significant correlation with other variables (Table 5). Aziz *et al.* (2012) found minimum salinity 10.4 % and maximum salinity 26.2% in the different rivers of SMF. Rahman *et al*. (2013) recorded salinity 2-23 ppt. The salinity of the water of Meghna river estuary ranged from 5.5 to 23% where the mean value was 15.019%. The salinity of Buragauranga estuary ranged from 5.00 to 10.00 % (Ahmed *et al.* 2010). Generally, changes in the salinity in the habitats, such as estuaries, backwaters and mangroves are due to the influx of freshwater from land runoff, caused by monsoon or by tidal variations. The freshwater inflow from the land moderately reduce the salinity in the Godavari estuary (Saisastry and Chandramohan 1990) and in the Bay of Bengal (Mitra *et al*. 1990).

Dissolved Oxygen (DO) plays an important role in supporting aquatic life and susceptible to slight environmental changes (Ahmed 2004). As a result of high community respiration, dissolved oxygen generally depleted. Dissolved Oxygen used as an important indicator of water quality which evaluate the freshness of a river (Fakayode 2005). It is also an important parameter indicating level of water quality and organic pollution in the water body (Wetzel and Likens 2006). The DO of water showed significant variation in the different locations studied (Table 4). The concentration of DO (ppm) of water samples at different study sites was found to vary (3.50 to 6.35 ppm) (Table 4) where the mean value was 4.76 ppm in April 2015. The concentration of DO (% Sat) was 46.60 to 82.00% in April 2015. The mean concentration of DO in location 1 was 6.17±0.16 ppm which showed significant difference with other locations, except locations 2, 6, 9, 10. The mean % saturation value of DO was 77.25±3.30 %. The mean concentration of DO in location 2 was 5.71±0.32 ppm and 73.40± 6.54 %. The mean concentration of DO in location 3 was 4.12±0.57 ppm. Location 3 showed significant differences with locations 6 and 10, but did not show any significant difference with the rest of the locations. The mean concentration of DO in the location 4 was 4.41±0.43 ppm. Location 4 showed significant difference with location 6, but did not show any significant difference with locations from 5 to15. The mean concentration of DO in

location 5 was 4.71±0.35 ppm which did not show any significant difference with the rests. The mean % saturation value of DO of the locations 3, 4, 5 were 59.37±8.74, 55.55±7.06 and 55.55±7.06 %, respectively. The mean concentration of DO in the location 6 was 5.78±0.89. Location 6 showed significant difference with locations 10, 11, 12, 13, 14, but did not show any significant difference with locations 7, 8, 9 and 15. The mean % saturation value of DO was 54.32± 2.33 %. The mean concentrations of DO of locations 7, 8 and 9 were 4.63±0.33, 4.60±0.48, 5.00±0.73, respectively. These three locations did not show any significant differences with the rest. The mean concentrations of DO of location 7, 8 and 9 were 60.10±7.89, 59.20±6.07, 69.65±3.33 %, respectively. The mean concentration of DO in location 10 was 5.31±0.53. The location 10 showed significant difference with location 13 but did not show any significant difference with location 11, 12, 14, 15. The mean concentrations of DO of location 11, 12, 13, 14, 15 were 4.02±0.08, 4.03±0.33, 4.17±0.35, 3.95±0.12, 4.82±0.49, respectively. These four locations did not show any significant difference with each rest. The mean concentrations of DO of location 10, 11, 12, 13, 14, 15 were 64.25±6.19, 52.02±2.87, 50.97±3.01, 54.95±3.86, 56.82±1.84, 59.15±3.47%, respectively. DO (% Sat) showed medium positive significant correlation with water temperature, and DO (ppm); DO (% Sat) also showed negative significant correlation with air temperature but DO (% Sat) did not show significant correlation with other variables.

The concentration of the DO of water samples at different study sites was found from 0.11 to 5.33ppm in March 2016 where the value of DO % sat was 1.2 to 95.2. The mean concentrations of DO in locations 1, 3 and 4 were 0.14±0.02, 0.24± 0.02 and 0.30±0.01 ppm, respectively. These three locations showed significant differences with the locations 5 to 10, but the location 1 and 3 did not show any significant difference with each rest. The mean concentrations of DO (% sat) in location 1, 3, 4 were 1.60±0.41, 3.16±0.10, 3.90±0.27 %, respectively. The mean concentrations of DO in locations 5, 6, 7, 9, 10, 16, 18, 19, 20, 21, 12 and 13 were 4.35±0.39, 5.01±0.80, 4.15±0.18, 4.78±0.50, 4.8±0.42, 3.91±0.23, 3.46±0.22, 4.18±0.37, 3.71±0.32, 4.99±1.40, 3.67±0.26, 5.27±2.24 and 5.47±1.23 ppm, respectively. These locations did not show any significant differences with each other (location 5 to 16) except location 9 showed significant difference only with location 15. The mean concentrations of DO (% sat) in locations 5, 6, 7, 9, 10, 12, 13, 16, 17, 18, 19, 20 and 21 were 55.00±1.82, 66.90±10.30, 56.35±3.96, 60.10±7.17, 59.33±3.05, 54.87±3.96, 73.87±18.46, 57.63±8.52, 46.00±7.87, 54.93±6.99, 51.20±5.87, 61.83±17.05, 48.83±5.26%, respectively.

During the first visit, the dissolved oxygen of water showed medium positive significant correlation with DO (% sat), positive significant correlation with water temperature; DO (ppm) showed negative significant correlation with air temperature, salinity, conductivity, Na, Mg. DO (ppm) did not show significant correlation with other variables. During second visit, DO (ppm) showed weak positive significant correlation with conductivity, K, Na, showed negative correlation with pH but did not show any significant correlation with other variables (Table 5).

The standard of DO content in the water bodies ranged from 5.0-7.0 mg/l (WHO 1995). These limits permit the water for drinking purposes. The mean value and the values of the most locations during April 2015 and of the second visit during March 2016 were found to be lower than this standard value indicating the polluted nature of the Rivers of the SMF. Ahmed *et al.* (2010) has found DO to be 7.7-12.0 mg/l in the Buragauranga river estuary. The primary source of oxygen in the marine environment is the gaseous exchange of atmospheric oxygen across the air-sea surface interface and *in situ* production by photosynthesis (Best *et al*. 2007). In estuaries the dynamic pattern of dissolved oxygen is a result of complex interactions among physical, chemical and biological processes (Borsuk *et al*. 2001). Strong dissolved oxygen gradient is formed in estuaries due to the combination of variations in temperature, freshwater discharge, saltwater intrusion, circulation, biological productivity and respiration (Stanley 1993).

Table 3. Correlation matrix of various variables of water samples collected from the study area during first visit (April 2015) (Temp. = Temperature, Humid. = Humidity, Cond. = conductivity, Sat. = saturation).

Variables p-value→ R - value↓	**Water Temp. (ºC)**	**Air Temp. (ºC)**	**Humid.**	**pH**	**Salinity (‰)**	**Cond. mS/cm**	**DO (%Sat.)**	**DO (ppm)**	**K (ppm)**	**Na (ppm)**	**Ca (ppm)**	**Mg (ppm)**	**Fe (ppm)**	**Zn (ppm)**
Water Temp. (ºC)		**0.000**	**0.000**	0.349	0.467	0.512	**0.000**	**0.000**	0.095	0.160	0.248	0.104	0.724	0.659
Air Temp. (ºC)	**0.782**		**0.000**	0.551	0.591	0.679	**0.048**	**0.022**	0.185	0.072	0.467	0.261	0.808	0.755
Humid.	**-0.560**	**-0.749**		0.324	**0.003**	**0.002**	0.195	0.381	**0.001**	0.387	0.637	**0.022**	0.133	0.659
pH	0.123	0.079	0.129		**0.012**	**0.004**	0.632	0.932	0.118	**0.050**	0.680	**0.003**	0.223	0.624
Salinity ‰	0.096	0.071	**0.382**	**0.129**		**0.000**	0.202	**0.003**	**0.000**	**0.000**	0.881	**0.000**	**0.000**	0.177
Cond. mS/cm	0.086	0.055	**0.393**	**0.362**	**0.960**		0.436	**0.010**	**0.000**	**0.000**	0.712	**0.000**	**0.000**	0.374
DO % Sat.	**-0.554**	**-0.256**	0.170	0.063	-0.167	-0.102		**0.000**	0.350	0.285	0.279	0.140	0.727	0.533
DO (ppm)	**-0.448**	**-0.296**	0.115	0.011	**-0.373**	**-0.329**	**0.647**		0.202	**0.031**	0.685	**0.002**	0.544	0.289
K(ppm)	**0.217**	0.173	**0.431**	0.204	**0.611**	**0.581**	-0.123	-0.167		**0.001**	**0.041**	**0.000**	0.225	0.729
Na(ppm)	0.184	0.234	0.114	**0.254**	**0.499**	**0.475**	-0.140	**-0.279**	**0.427**		0.059	**0.000**	**0.011**	0.772
Ca (ppm)	-0.152	-0.096	-0.062	-0.054	-0.020	-0.049	0.142	0.685	-0.053	0.159		0.514	0.688	0.067
Mg (ppm)	0.212	0.148	0.296	0.382	0.965	0.960	-0.193	-0.396	0-.568	0.551	-0.086		**0.000**	0.225
Fe (ppm)	-0.047	-0.032	0.196	0.160	0.546	0.549	0.046	-0.080	0.159	0.325	-0.053	0.588		0.063
Zn (ppm)	-0.058	-0.041	0.058	0.065	0.177	0.117	0.082	0.139	0.046	0.038	0.238	0.159	0.241	

Table 4. Physico-chemical properties of water of different rivers and khals flowing within the Sundarban mangrove forests. (- = not studied)

Loc No	**Salinity (‰)**		**Conductivity**		**D0 (% sat)**		**DO (ppm)**		**K ppm**		**Na ppm**	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
1	13.25±1.5	12.5±1.91	21.32± 1.4	16.3± 0.16	77.25 ± 3.3	1.6±0.41	6.17±0.16	0.14±0.02	352.75±112.33	225.0±19.15	19000± 5944	5342±2205
2	12.62±0.48	-	19.93 ±0.52	-	73.4 ±6.54	-	5.7 ±0.32	-	197.25±15.76	-	20750±14886	-
3	11.4 ±1.15	9.75±1.55	15.99 ±0.29	11.97±0.16	59.37 ±8.72	3.17± 0.09	4.12 ±0.57	0.24±0.01	213.00±11.22	165.00±5.77	13500± 4359	5854± 837
4	10.0 ±0.0	8.75±0.96	15.07 ±0.16	10.96±0.08	55.55 ±7.06	3.9±0.27	4.41 ±0.43	0.29±0.01	241.00±35.69	147.50±5.00	16000± 3162	6147± 396
5	9.0 ±0.82	8.5±0.71	14.03 ±0.37	10.86±0.31	63.3±10.0	55.0±1.82	4.71 ±0.36	4.35±0.38	287.50±43.68	192.50±30.96	12000± 8165	6586±1773
6	6.12 ±0.63	5.37±0.48	11.07 ±2.19	9.59±0.14	54.32 ±2.34	66.9±10.3	5.79 ±0.89	5.01±0.8	247.50± 25.33	167.50±49.24	10250± 1708	4684± 727
7	7.5 ±1.29	5.75±0.96	12.87 ±0.39	10.49±0.13	60.1 ±7.89	56.35±3.96	4.62±0.33	4.15±0.18	220.00±54.92	222.50±43.49	14000± 8756	4830± 665
8	19.75 ±0.5	-	26.97 ±0.56	-	59.2 ±6.07	-	4.6 ±0.48	-	441.25±25.62	-	16250 ± 2500	-
9	20.0 ±0.0	16.62±0.95	27.82 ±0.09	24.82±0.41	69.65±3.34	60.1±7.17	5.0 ±0.73	4.77±0.5	458.75± 20.56	445.00±47.96	28000± 22136	10757±1079
10	13.75 ±1.5	9.83 ± .29	21.32 ±0.74	15.97±0.28	64.25± 6.19	59.33±3.05	5.31 ±0.53	4.85±0.42	370.00± 36.51	263.33±20.82	14000 ± 4082	6001±1396
11	21.12±1.31	-	30.25 ±0.06	-	52.02±2.87	-	4.02 ±0.09	-	151.25± 25.62	-	23000± 6733	-
12	20.25 ±0.5	20.67±0.58	28.92 ±5.12	28.83±0.35	50.97±3.01	54.87±3.96	4.03 ±0.34	5.27±2.23	576.25± 66.25	530.00±121.6	41750± 16879	12099±1108
13	20.0 ±0.0	20.67±0.57	29.0 ±0.58	29.2±0.36	54.95±3.86	73.87±18.5	4.17 ±0.36	5.47±1.23	501.25± 40.08	463.33±35.12	27750± 10813	11855±1542
14	20.0 ±0.0	-	28.35±0.17	-	56.82±1.84	-	3.95 ±0.13	-	430.00± 12.25	-	24250± 9912	-
15	20.5 ±0.58	-	27.32±0.42	-	59.15±3.47	-	4.82 ±0.49	-	477.50± 11.90	-	23250± 4500	-
16	-	16.37±0.48	-	24.82±0.39	-	57.62± 8.52	-	3.90±0.23	-	395.00±53.23	-	9879±1222
17	-	10.62±0.48	-	16.94±0.48	-	46.0± 7.8	-	3.46±0.22	-	317.50±97.43	-	8013±2001
18	-	8.75±2.02	-	15.38±0.24	-	54.92±6.99	-	4.18±0.37	-	242.50±86.55	-	7281±897
19	-	11.87±1.44	-	18.120.62	-	51.2±5.87	-	3.71±0.32	-	360.00±36.51	-	9038±1155
20	-	21.0±1.0	-	30.83±1.0	-	61.83±17.0	-	4.99±1.40	-	406.67±64.29	-	10879±1830
21	-	22.33±1.53	-	30.43±0.32	-	48.83±5.26	-	3.67±0.25	-	430.00±17.32	-	12294±890

Table 5. Correlation matrix of various variables of water samples collected from the study area during second visit (March 2016).

Variables p value → R - value↓	Water temp. (ºC)	pH	Salinity ‰	Cond.	DO % Sat.	DO (ppm)	K (ppm)	Na (ppm)
Water Temp. (ºC)	1.00	0.462	0.526	0.637	0.260	0.535	0.675	0.799
pH	0.098	1.00	**0.000**	**0.000**	**0.001**	**0.002**	**0.000**	**0.000**
Salinity ‰	-0.084	**-0.568**	1.00	**0.000**	0.099	0.054	**0.000**	**0.000**
Conductivity	-0.063	**-0.688**	**0.960**	1.00	**0.005**	**0.002**	**0.000**	**0.000**
DO % Sat.	0.149	**-0.408**	0.217	**0.363**	1.00	**0.000**	**0.001**	**0.004**
DO (ppm)	0.082	**-0.394**	0.252	**0.387**	**0.960**	1.00	**0.001**	**0.004**
K (ppm)	-0.056	**-0.652**	**0.808**	**0.865**	**0.422**	**0.434**	1.00	**0.000**
Na (ppm)	-0.034	**-0.519**	**0.845**	**0.867**	**0.369**	**0.372**	**0.781**	1.00

Cond. = conductivity, Sat. = saturation

Table 6. Spatial variations of heavy metals (ppm) of water of different rivers and khals flowing within the Sundarban mangrove forests (first visit, April 2015).

Locations	Ca (ppm)	Mg (ppm)	Fe (ppm)	Zn (ppm)
1	251.00±12.49	560.50±8.81	0.167±0.014	0.065±0.013
2	263.50±15.35	549.75±10.28	0.199±0.017	0.055±0.013
3	322.50±18.48	472.25±12.71	0.192±0.015	0.0525±0.017
4	276.50±15.44	432.0±8.64	0.068±0.012	0.042±0.017
5	224.75±14.17	365.75±11.44	0.101±0.008	0.045±0.013
6	261.25±12.12	336.50±12.23	0.10 ±0.007	0.045±0.013
7	259.0±13.04	358.75±12.18	0.065±0.013	0.045±0.013
8	275.75±8.77	687.5±9.61	0.135±0.013	0.055±0.013
9	300.0±24.71	774.25±16.94	0.165±0.013	0.045±0.013
10	253.75±21.3	516.25±18.23	0.18±0.025	0.055±0.013
11	290.25±19.99	876.0±13.47	0.23±0.018	0.055±0.013
12	63.0± 18.0	855.75±13.07	0.232±0.017	0.047±0.017
13	179.23±205.7	809.5±11.5	0.10±0.01	0.047±0.017
14	317.75±55.16	829.5±9.71	0.17±0.017	0.06±0.018
15	317.75±55.16	744.5±13.60	0.17±0.018	0.055±0.013

Potassium is required for all cells principally as an enzyme activator and stored in the plant tissues than in surrounding medium (Hornes and Goldman 1983). Maximum value of potassium was 630.0 mg/l and minimum 125.0 mg/l where mean value was 344.4 mg/l during April 2015 (Table 7). The concentration of K of water samples at different study sites was found to vary (110 to 670 ppm) in March 2016. Ahmed *et al* (2010) found 47.00 to 205.00 mg/l in their study. The mean value was above the standard limit of K in the water 50 mg/l as recorded by WHO (1995).The values of K in the present studies were more than the Manipur river system (2-9 mg/l) (Singh *et al.* 2010).

Table 7. Descriptive statistics different variables (overall) of rivers of SMF (first visit, April 2015).

Variables	Mean	StDev	Coef Var	Minimum	Median	Maximum
Water temp (ºC)	29.23	1.00	3.43	26.300	29.20	30.80
pH	7.21	0.33	4.63	6.6000	7.30	7.80
Cond (mS)	22.01	6.76	30.70	8.000	21.6	32.30
Salinity ‰	15.01	5.34	35.56	5.500	15.00	23.00
DO ppm	4.76	0.79	16.74	3.500	4.640	6.35
DO % sat	60.69	8.97	14.79	46.60	58.10	82.00
Na(ppm)	20250	11852	58.53	6000	17000	61000
K (ppm)	344.4	133.70	38.81	125.0	335.00	630.00
Ca (ppm)	261.10	89.40	34.24	0.900	271.00	395.00
Fe (ppm)	0.15	0.05	35.78	0.05	0.16	0.25
Mg (ppm	611.3	190.50	31.16	320.00	561.50	892.00

The concentration of Na of water samples at different study sites was found to vary. Lowest concentration was found to be 10250 ppm in the location 6, whereas highest was 41750 ppm in the location 12 during April 2015 (Table 7). Comparatively, very low concentration of Na was found in March 2016. Lowest Na content was also found in the location 6 where the value was 4684 ppm whereas higher 12294 ppm was found in the location 21 which might be due to fresher water supply received from the upstream rivers.

The concentration of Ca of water sample at different study sites was found to vary (63 to 322 ppm) in April 2015 (Table 6). Ahmed *et al.* (2010) found 96-256mg/l in the Buragauranga river estuary. The amount of Ca ranged from 44.40 to 73.50 mg/l of Meghna estuary where mean value was 57.38 mg/l (Islam 2012). The calcium content was high in the Arabian Sea and Mandovi and Zuari estuaries (Gupta and Sugandhini 1981), west coast of India (Sugandhini and Dias 1982) and Vellar estuary (Palanichamy and Balasubramanian 1989). Naik (1978) reported that the lowering of the Ca level in the near shore water of Goa during monsoon months was due to dilution effect. According to WHO (1995), the amount of Ca recommended below 100 mg/l in the water for drinking purpose. The value of present study was overall higher than the WHO limits. The minimum value of Mg was 336.5 mg/l which was found in the location 6 where maximum value was 876.0mg/l found in location 11 (Table 6). Ahmed *et al.* (2010) found 58.70-409.50 mg/l in their study. The higher Mg content was found (average 1243mg/l) in the Vellar estuary (Palanichamy and Balasubramanian 1989) than the present studies. The standard limit for Mg in the water is 150mg/l (WHO 1995). The mean value of the present study was higher than the WHO limit. The minimum value of Fe was 0.1 mg/l where maximum value was 0.232mg/l. Zinc content of the different river water of SMF was very low and varied between 0.042 and 0.065mg/l. The descriptive statistics of different variables of both sampling occasions and one way ANOVA have been shown in Tables 7-10.

Table 8. Summary of analysis of variance of different variables of water in fifteen locations of SMF (first visit, April 2015).

Variables	F	P	Variables	F	P
pH Location	5.29	0.000	Na (ppm) Location	2.66	0.007
Conductivity Location	79.31	0.000	K(ppm) Location	35.47	0.000
Salinity ‰ Location	155.69	0.000	Ca (ppm) Location	4.88	0.000
DO (ppm) Location	9.21	0.000	Mg Location	983.56	0.000
DO (% Sat) Location	7.36	0.000	Fe Location	50.46	0.000
Water Temp Location	35.74	0.000			

DO = dissolved oxygen

Table 9. Descriptive statistics different variables (overall) of rivers of SMF (second visit, March 2016).

Variables	Mean	SE Mean	StDev	Coef Var	Minimum	Median	Maximum
Water temp. (°C)	29.24	0.063	0.47	1.64	28.30	29.20	31.00
pH	6.91	0.037	0.302	4.41	6.300	6.900	7.500
Salinity	12.59	0.70	5.44	43.25	5.00	11.00	24.00
Conductivity	18.42	0.96	7.38	40.11	9.48	16.30	31.60
DO (ppm)	3.55	0.24	1.88	53.10	0.11	3.93	7.85
DO % sat	46.16	3.11	23.85	51.68	1.20	54.30	95.20
K(ppm)	301.7	16.5	126.9	42.08	110.00	280.0	670.0
Na (ppm)	8018	369	2834	35.35	3074	8050	13465

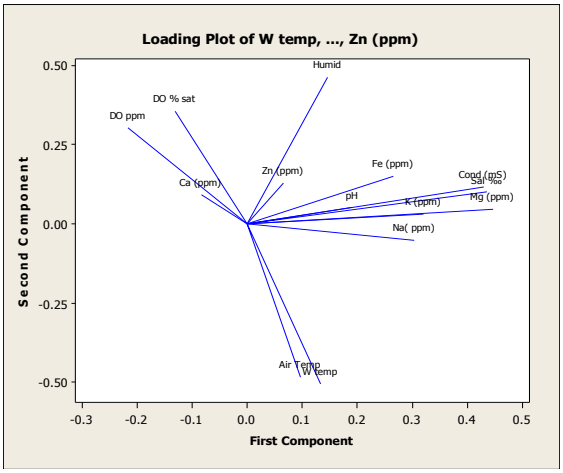
Table 10. Summary of analysis of variance of different variables of soil in sixteen locations of SMF (second visit, March 2016).

Variables	F	P	Variables	F	P
pH Location	8.06	0.000	DO (% Sat.) Location	34.18	0.000
Conductivity Location	1409.76	0.000	Water Temp Location	7.22	0.000
Salinity ‰ Location	84.25	0.000	Na (ppm) Location	14.88	0.007
DO (ppm) Location	24.44	0.000	K(ppm) Location	17.86	0.000

DO = dissolved oxygen

Principal component analysis (PCA) of different variables was measured during 2015 (Fig. 1). PC-1 showed positive loading of water temperature, air temperature, humidity, pH, conductivity, Salinity, Na, K, Fe, Mg, Zn with negative loading of DO(ppm), DO (%Sat) and Ca. Islam (2010) found positive loading of pH, conductivity, salinity, filtrable residue, non-filtrable residue, total residue, DO, BOD_5, free CO_2, K, Ca, Mg with negative loading of alkalinity and Fe. Prasanna and Ranjan (2010) found positive loading of salinity, conductance, pH and BOD in Dharma estuary which was similar with present studies. PC-2 showed positive loading of positive loading of humidity, pH, conductivity, the salinity, Na, K, DO(ppm), DO (%Sat), Fe, Mg, Zn with negative loading of water temperature, air temperature and Na. PC-3 showed positive loading of water temperature, air temperature, pH, conductivity, salinity, DO(ppm), DO (%Sat), Ca, Mg, Zn with negative loading of humidity, Na and

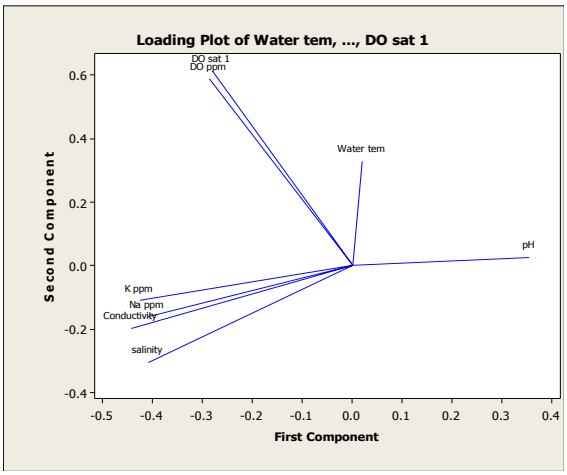
K. Principal component analyses (PCA) were carried out with the variables of river water of the second visit (March 2016) (Fig. 2).



Variable	PC1	PC2	PC3
Water temp.	0.133	-0.505	0.082
Air Temp.	0.096	-0.483	0.248
Humid.	0.146	0.462	-0.338
pH	0.190	0.051	0.152
Cond. (mS)	0.430	0.116	0.050
Sal ‰	0.436	0.100	0.064
Na(ppm)	0.304	-0.052	-0.064
K (ppm)	0.320	0.031	-0.230
DO ppm	-0.217	0.303	0.182
DO % sat	-0.132	0.355	0.239
Ca (ppm)	-0.084	0.091	0.509
Fe (ppm)	0.266	0.151	0.260
Mg (ppm)	0.447	0.046	0.086
Zn (ppm)	0.065	0.129	0.553

Fig. 1. Principal component analysis among the different variables of water during the 1st visit (April 2015)

The PC-1 of different variables of the year 2016 showed positive loading of water temperature, pH with negative loading of salinity, conductivity, DO (ppm), K, Na, DO (%Sat). The PC-2 showed positive loading of positive loading of water temperature, pH, DO (ppm), DO (%Sat) with negative loading of salinity, conductivity, K, Na. PC-3 showed positive loading of positive loading of water temperature, pH with negative loading of Salinity, Conductivity, K, Na, with negative loading of DO (ppm), DO (%Sat). Positive loading of salinity, total hardness**,** conductance, and total dissolved solids are common phenomenon in an estuarine environment (Panigrahi *et al*. 2007). Positive loading of DO and BOD indicates that the healthy state of the ecosystem is maintained by the proper nutrient supply, phytoplankton growth as well as decomposition of organic materials in the ecosystem (Upadhyay 1988, Panigrahy *et al*. 1999).



Variable	PC1	PC2	PC3
Water temp.	0.019	0.328	0.927
pH	0.354	0.026	0.148
Salinity	-0.409	-0.304	0.142
Conductivity	-0.443	-0.199	0.094
DO ppm	-0.287	0.588	-0.212
K (ppm)	-0.425	-0.111	0.044
Na (ppm)	-0.410	-0.162	0.136
DO % sat.	-0.281	0.613	-0.155

Fig. 2. Principal component analysis among the different variables of water during the 2nd visit (March 2016).

Phytoplankton diversity

The Sundarbans has a highly diverse algal flora comprised of both benthic and planktonic forms ranging from the freshwater to marine environments although the algal flora of the area is very poorly

known (Rahman *et al.* 2013). Work of Islam (1973) stands as the pioneer work on algal flora of Sundarbans as no previous record is available. After that some works have been done on the phytoplankton community structure and its relation to abiotic variables in the Sundarbans river systems of Bangladesh (Hossain and Chowdhury 2008, Shah *et al.* 2008, Mamun *et at*. 2009 and Aziz *et al*. 2012 and Rahman *et al*. 2013). The present study has focused on the species composition and diversity of the different rivers flowing within the Sundarban mangrove forests of Bangladesh (Table 11).

Table 11. Summary of the Species diversity (H), Species richness index (d), Equitability index (e) of phytoplankton of the different rivers and khals of SMF (March 2016).

Locations	Name of the rivers/khals (locations)	H	d	e
1	Passur R (Mongla Ferry Ghat)	4.853	14.810	3.196
3	Sela R. (Joimony Ghol)	3.892	8.747	3.232
4	Sela R. (Tanker sinking place)	0.000	0.000	0.000
5	Sela R. (Tambulbunia)	3.573	7.200	3.207
6	Pathuria R.	4.797	14.556	3.132
7	Suputi R./ Dudmukhi R.	3.866	8.567	3.142
9	Betmar Gang (Kotka)	2.999	5.582	2.999
10	Passur R. (Harbaria)	3.328	6.096	3.196
12	Kobatak R. (Forest office)	3.970	9.001	3.297
13	Khashitana Khal (Khashitana Forest office)	3.922	8.635	3.257
16	Homra Khal	6.825	10.050	5.437
17	Sela R.	4.522	12.486	3.060
18	Harmal R.	4.257	10.895	3.111
19	Chawlabogi	4.407	12.687	3.013
20	Patcosta Khal	3.000	5.227	3.322
21	Ball R. North of Jalia forest office	4.061	9.558	3.235

In the present study the phytoplankton diversity and community assemblage were studied with the samples collected during 2016 (Table 11). Maximum number of taxa was recorded from Sela river (Tambulbunia) where 34 taxa (with the unknown ones) were recorded followed by Passur river (near Mongla Ferry Ghat). In the study *Coscinodiscus* was found as the dominant genus. Maximum Shannon-Weaver index of diversity was found in location 16 (Homra Khal) and the values was 6.825 and minimum was found in the location 4 (Sela river, where the tanker sank) and value was 0. Only one species of phytoplankton was recorded from this place. Aziz *et al*. (2012) found maximum Shannon-Weaver index of diversity (H = 3.494) and the maximum number of species at the confluence of Hangsha river with the river Murdat at Patcosta. They recorded minimum Shannon-Weaver index of diversity (H = 1.661) at Bal river, Bisandri khal and Kalabogi. In the present study, maximum number of taxa was recorded from the location 5 (Sela river at Tambulbunia) where 34 taxa (with the unknown ones) were recorded followed by Location 1 (Passur river near Mongla Ferry Ghat). Aziz *et al*. (2012) found 36 species in their study whereas Rahman *et al*. (2013) recorded 134 phytoplankton species from the three major river systems, namely Rupsha-Passur, Khalpatua-Arpangachia and Bhola-Baleswar in three different seasons. They did not find any phytoplankton during summer from Khalpatua-Arpangachia river system and only 3 spp. of phytoplankton each from the other two river systems. In the present study maximum species richness (d) was found in Passur river at Mongla ferry ghat with a value of 14.81 whereas maximum evenness (e) was found in the location 16 (Homra khal) with a value of 5.44 (Table 11). Besides the maximum and minimum values (0.0 in the location 3, Sela river at Joimoni ghol), the values of evenness of phytoplankton was more or less the same in all the rivers/khals studied and ranged from 2.99 to 3.26. Rahman *et al*. (2013) found species diversity, richness and evenness index

varied between 2.03 and 4.64, 1.20 and 2.44, 0.77 and 1.50 in Rupsha-Passur; 2.47-3.85, 1.80-5.84 and 0.78-0.94, respectively in Khalpatua-Arpangachia; and 0.66-4.27, 1.19-5.12 and 0.59-1.29, respectively in Bhola-Baleswar. Present study has found higher values of Shannon-Weave indices, richness and evenness than those of Aziz *et al*. (2012) and Rahman *et al*. (2013).

The ecology of Sundarbans is regulated by tidal impact from the Bay of Bengal. The tidal action of the sea inundates the whole of Sundarbans to varying depths, pushing back silt to the channels and creeks. The Sundarbans delta is one of the dynamic estuarine deltas of the world (Banerjee *et al*. 2012). Fresh water supply from the Ganges river also play a vital role in the ecology of Sundarbans. The findings of the present study will be of extreme importance and can be extrapolated with the practical situation prevailing in the mangrove ecosystem of Sundarbans. The Bangladesh part of Sundarbans has also been affected by the same problem due to the withdrawal of fresh water from the Ganges river with Farakkah barrage and it was made on the western part of our coastal zone where SMF is situated a "dead delta". The concentration of salinity of water samples at different study sites was found to vary. The present study showed that pH decreased which is an indication of slight acidification of the rivers' water of the SMF. The concentration of DO (ppm) of water samples at different study sites was found to vary (3.5 to 6.35 ppm) but the values decreased dramatically during March 2016 and it was only 0.11 to 5.33 ppm. These values indicated the pollution nature of the river water (EPA 2000). Safe standard of DO concentration in estuary as recommended by CSTT (1994) was a median value of 7 mgl^{-1} with changes of <1 mgl^{-1} above the level was safe (Painting *et al*. 2007). But in the present study the median value was observed as high as 4.64 mgl^{-1}.

The distribution of phytoplankton assemblage is often studied in relation to physical and chemical variables like gradient and salinity in coastal ecosystem. It helps in coastal ocean characterization in spatial variability found horizontally or vertically (Lunven *et al*. 2005). In the present study, phytoplankton structure and assemblage showed an important spatial change in horizontal distribution. Typical river plankton like *Melosira* sp. (Reynolds 1988) were found only in the zone 1. Ahmed *et al.* (2010) also found *Melosira* sp. in the Buragauranga estuary at Rangabali, Patuakhali district. Presence of *Coscinodiscus* sp. in almost all sampling locations might be due to capacity of the genus to tolerate habitat fluctuation. Diversity of phytoplankton was found to be higher than the other studies (Aziz *et al*. 2012, Rahman *et al*. 2013).

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