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ASSESSMENT OF WATER QUALITY OF THE LOWER MEGHNA RIVER ESTUARY USING MULTIVARIATE ANALYSES AND RPI

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ABSTRACT

The present study was conducted to evaluate the surface water quality of the lower Meghna River Estuary using chemical parameters of water. Water Temperature, Secchi Depth, Total Suspended Solid (TSS), Total Organic Matter (TOM), pH, Dissolve Oxygen (DO), Biological Oxygen Demand (BOD_5), CO_2, Alkalinity, HCO_3^- and Salinity concentrations in water samples were found to be ranged from 21-31℃, 4-65 cm, 0.317-10.83 mg/l, 0.483-0.86 mg/l, 6.4-7.0, 1.9-5.5 mg/l, 0-38 mg/l, 0.33-0.99 mg/l, 0.7-2.1 mg/l, 0.000-0.0004 mg/l and 0-15 ‰ respectively. River Pollution Index (RPI) indicated that the water of river at Sandwip, Hatiya, Bhola, Barishal and Chandpur was less to highly polluted. Correlation Matrix (CM) and Multivariate statistical analyses namely Cluster Analysis (CA), Principal Component Analysis (PCA) and Factors Analysis (FA) indicated that river water was polluted and the principal causes were due to unplanned and haphazard industrialization, domestic and municipal wastes and agricultural inputs. Furthermore, the results advocate that PCA and CA techniques are useful tools for valuation of water quality. River water uses without treatment may generate serious problems to human health by biological food web. This study suggest to proper management of the river with eco-friendly mechanization for the sustainable and long lasting economic growth of the country.

Keywords: Water Quality, Multivariate Analyses, River Pollution Index, Industrialization, Meghna River Estuary.

INTRODUCTION

The most essential and important compound for all living creatures is water that form ecosystems [1, 2]. This water is being used for innumerable rural and urban communities and livestock, fish culture, recharge of ground water, control of floods etc. [3]. Due to population explosion and rapid industrialization the river has been exploited beyond its carrying capacity [4]. The water quality is being degraded continuously due to jumbled industrialization. Several features related to water quality of the River have been studied by various researchers [5, 6, 7, 8, 9, 10, 11, 12, 13]. The river water purity endangered due to unregulated human activities such as sewage and industrial wastes disposal, dead bodies disposal, deforestation, excessive use of fertilizers and pesticides etc. Cachada *et al*. [14] reported that intensive agriculture, urbanization and industrialization contribute to river water deterioration. Chemicals produced from industries are a major source of water pollution that carried through geological materials may cause problems. Most of the industries are major contributor of trace metals. According to the WHO up to 80% of all illness and ailment in the world is triggered by poor sanitation and contaminated water [15]. The incessant discharges of domestic and industrial wastewater and seasonal surface run-off all have a strong effect on the water quality. Rivers are blocked with industrial effluents and untreated sewage through several outfalls [16]. Polluted river first affects its chemical quality of water and then progressively destroys the community structure disrupting the subtle food web [17]. Land use events (urbanization and agriculture) harshly affect water quality and aquatic ecosystem of rivers, streams, lakes and estuaries [18]. However, rivers are the key water sources for domestic, industrial and agricultural irrigation purposes [19], river water quality is one of important factors unswervingly regarding with health of human and living beings [20]. Developing countries like Bangladesh, facing serious problems with water pollutions from different industries, domestic wastes and agrochemicals [21, 22, 23].

The present study identified water quality parameters that could lead to pollution of the lower Meghna River Estuary and the sources of pollution by using correlation analysis, principal component analysis, cluster analysis and RPI methods.

MATERIALS AND METHODS

Study Area

Study was conducted at Chandpur (23°13.768'N, 90°38.58'E), Barishal (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). Ganges is one of the most important rivers of the Indian subcontinent. The Ganges flows 2,510 km (1,560 mi) from the Himalayas of north central India southeast through Bangladesh and into the Bay of Bengal.

The main branch of the Ganges continues through Bangladesh, where for part of its course it is called the Padma River. The river gives rise to several distributaries that form a vast network of waterways and one of the world’s largest, most fertile deltas. The main course of the river continues south and is joined by the Brahmaputra and then by the Meghna River (the name by which it is known thereafter) before entering the Bay of Bengal. At the bay the Meghna estuary measures 30 km (20 mi) wide. Average annual discharge of water of this river system is surpassed only by those of the Amazon and Congo rivers. Because the discharge includes large deposits of sediment, the delta continues to expand into the bay.

The area of this investigation ranged from the lower estuarine zone of the Meghna River (23˚13.768″N and 90˚38.58″E) at Chandpur to near shore coastal water (22˚29.319″N and 91˚25.668″) near Sandwip of Chittagong. Average depth of the estuary is about 5-6m and total length of the study area covering 5 selected sites was about 172 miles. Five selected sampling sites (Fig. 1) being located from upstream to downstream as follow:

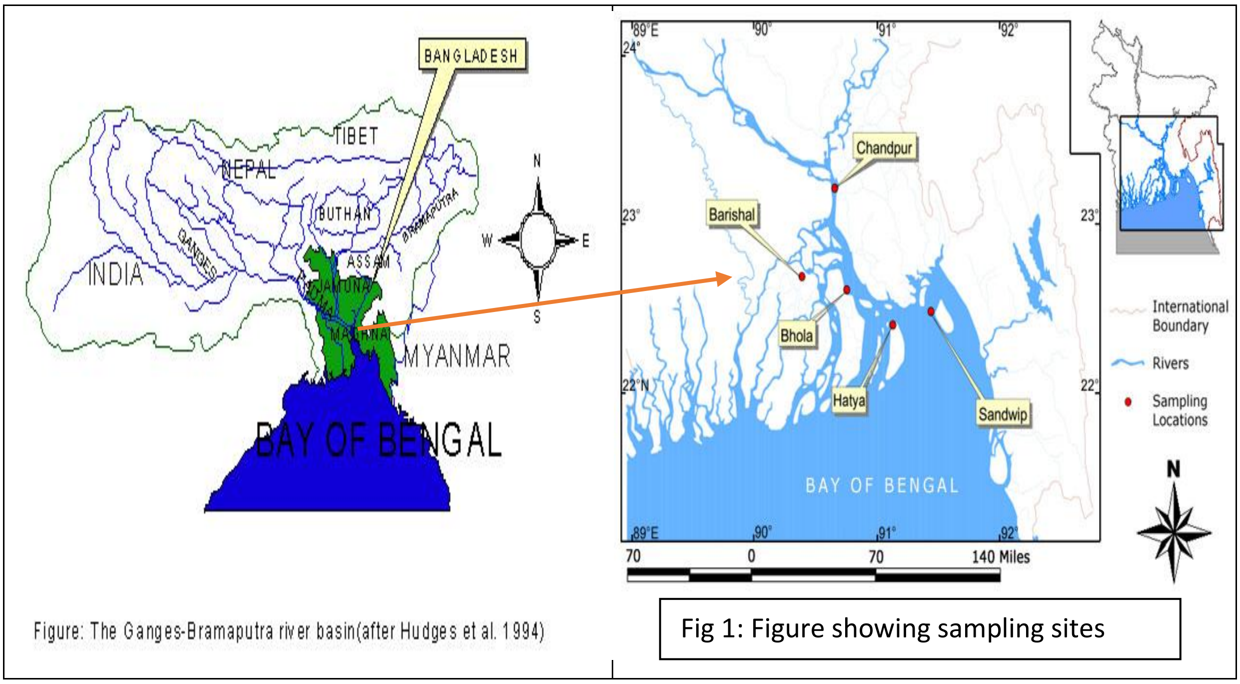


Figure 1: Map showing the sampling sites of the Meghna River Estuary

Sample Collection and Preservation

Samples were collected from on board ships of BIWTA at each site of the study area during monsoon and post-monsoon seasons.

Water samples were drawn by using a Kemmerer water sampler and collected samples were taken in different containers; for DO in BOD bottle; for CO_2 in air tight glass bottle; for salinity, pH, alkalinity, HCO_3^-, in plastic bottles; for Total Suspended Solids (TSS) and Total Organic Matter (TOM) 200 ml of water sample was filtered with Whatman GF/ C filter paper (4.7 cm diameter, premuffled and preweighted) [24].

The collected samples were preserved and fixed in different conditions considering analysis of different parameters. To determine the DO, samples were fixed immediately with one ml $MnSO_4$ and one ml of KI per 100 ml. For BOD, one bottle was kept aside. For CO_2 the air tight samples were stored in ice box at low temperature, for salinity, pH, conductivity, alkalinity, HCO_3^-, no preservatives were used in plastic bottles; for Total Suspended Solids (TSS) and Total Organic Matter (TOM) only 200 ml of water sample were filtered with whatman (Gf/c glass fiber filters, 4.7 cm) filter paper on board. The filtered paper was covered with Al foil and preserved in ice box at low temperature.

In situ water temperature was determined using a graduated Centigrade thermometer; water pH was determined using pH paper (color pH ast ®, pH, indicator, strips, Cat.9582. Made in Germany); turbidity was determined using a white secchi disc of 30 cm diameter [25]; water salinity was determined using a hand held refractometer (ATAGO, S/Mill, salinity. 0-100 ‰, Japan.). In the laboratory, Dissolved Oxygen concentration was determined by the Winkler Method [26] (H.O.PUB. No.607. 1955); Total Suspended Solids (TSS) and TOM (Total Organic Matter) were determined following Jin-Eong et al., BOD_5 was determined by Light and dark bottle method [27]. HCO_3^- was determined following [28] and CO_2 was determined following APHA [29]; Alkalinity was also determined following APHA [29].

Statistical Analysis

One Way Analysis of Variance ((Post-hoc LSD test) was done to show the variations in concentration of water parameters in terms of seasons and sites using SPSS (v.22). According to Dreher [30], Principal Component Analysis (PCA) was performed on the original data set (without any weighting or standardization). Component Analysis (CA) is an effective tool to find out the similarity and variation with the influencing factors on different data sets [31]. Moreover, CA is an important tool for the characterization and simplification of data sets with the behavior they possess. PCA was executed to sort out the principle features of variations in dataset with simplification and classification of raw data. According to Singh *et al.*, [32]. PCA delivers strategies on spatial and temporal distribution of resultant factors. Pearson's product moment correlation matrix was done to identify the relation among parameters to make the result strong obtained from multivariate analysis. CM (Dendogram) was performed to show the similarity among variables and to identify their sources of origin using PRIMER (v.6).

RESULTS AND DISCUSSION

To determine the quality of ecosystem that has great impact on the occurrence of aquatic organisms, estimating of the water quality is very important [33]. In the present study, water is mostly alkaline in nature with low salinity in major part of the estuary. The concentrations of water quality parameters are shown in Table 1, Figure 2 and Figure 3).

Water Temperature

In the recent study, highest water temperature (31^0C) was recorded at Sandwip and the minimum (21^0C) was recorded at Bhola and Chandpur during monsoon. In post-monsoon, maximum (22.5^0C) was recorded at Hatiya while the minimum (21^0C) was recorded at Chandpur (Table 1). Surface water temperature was (21-30)ºC lower than that of the air temperature. This observation has similarity with the works of [34, 35, 36, 37, 38, 39, 40, 41]. Aken [42] mentioned that water temperature is an important parameter which influences the dissolution-precipitation, adsorption-desorption, oxidation–reduction and physiology of biotic community in an aquatic environment.

Table 1: Showing physical parameters of surface water at five different sites during monsoon (M) and post-monsoon (PM)

Parameters/ Sites	Sandwip		Hatiya		Bhola		Barishal		Chandpur	
	M	PM	M	PM	M	PM	M	PM	M	PM
Water Temperature (^{0}C)	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)	10.827	1.2922	7.688	1.3377	3.659	1.300	5.443	1.326	0.317	1.333
TOM (mg/l)	0.856	0.6396	0.7955	0.6116	0.774	0.536	0.79	0.587	0.483	0.563
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_5 (ml/l)	17	0	21	2	38	13	35	6	34	7
CO_2 (ml/l)	0.396	0.34	0.396	0.4	0.594	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
HCO_3^- (mg/l)	0.0002	0.000244	0.0004	0.0002	0.000	0.000	0.000	0.000	0.000	0.000
Salinity (‰)	1	15	0	10	0	0	0	0	0	0

Secchi Depth

Maximum secchi depth (55 cm) was found at Chandpur and the lowermost (4 cm) was recorded at Sandwip during monsoon. 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 [43], Venkateswarlu et al. [44] and Haruna et al. [45] mentioned that transparency increased the occurrence of phytoplankton.

pH

pH is commonly known as the controlling variable in water since many properties, processes and reaction are pH dependent. In estuaries the pH ranges from 7.8 to 8.3 due to the buffering capacity of the sea water [46]. The highest pH (7) was recorded in present study at Barishal and Chandpur whereas the lowest (6.4) was recorded at Sandwip and Hatiya during monsoon. In post-monsoon, maximum concentration (7) was found at Sandwip and Hatiya while the minimum (6.5) was recorded at Bhola and Chandpur (Table 1). Slightly alkaline range in pH was recorded at all studied sites. Alkaline water stimulates high primary production [47]. The present results fully acquiesced with the results found by Satpathy et al. [48] studied on along the coastal waters of Kalpakkam, South east coast of India; Ali [49] studied on Greater Zab River, Iraq and George et al. studied on Tapi estuarine area of Gulf of Khambhat, India.

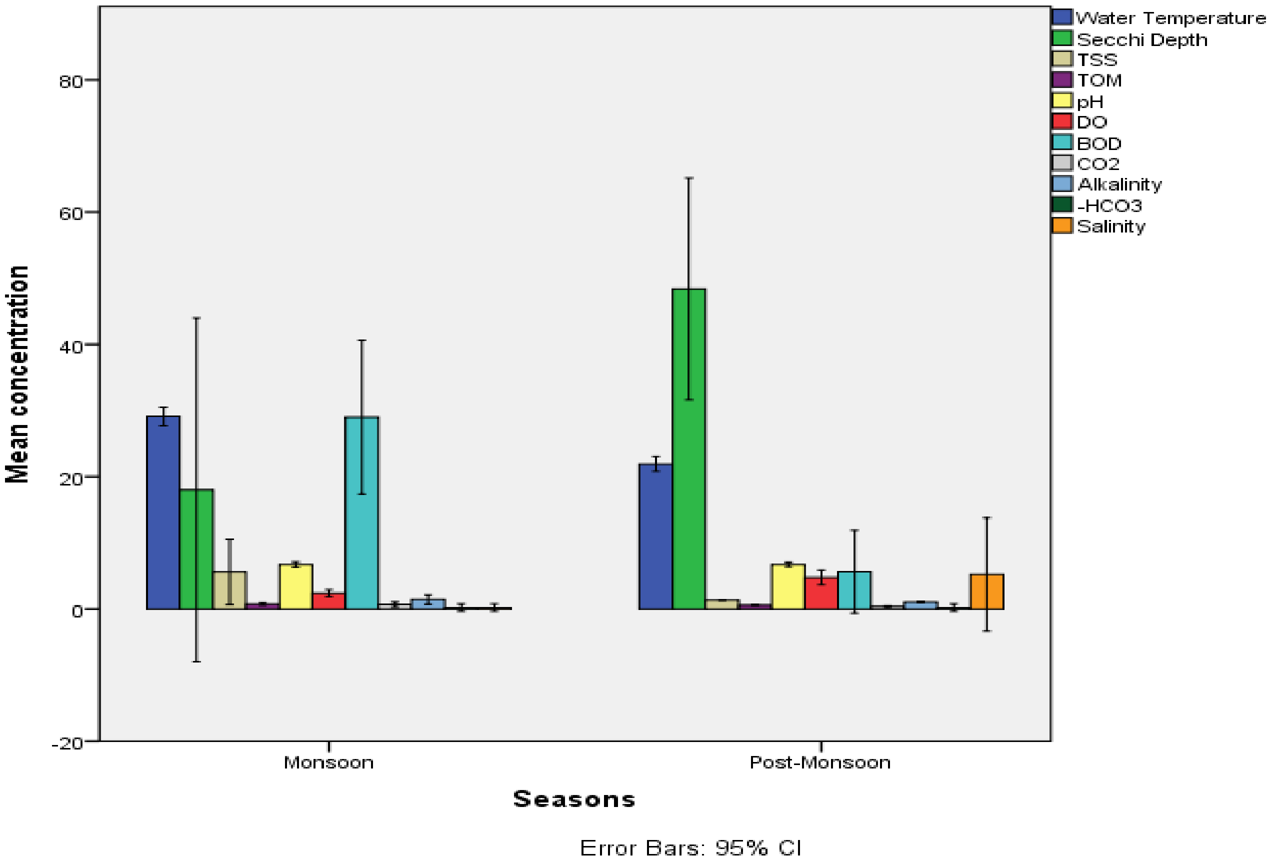


Figure 2: Graph showing the concentrations of water quality parameters during different seasons

Dissolved oxygen (DO)

Dissolved oxygen (DO) an important ecological factor that decides environmental health of water bodies and support a well-balanced aquatic living organisms [50]. In the present study, the concentration of DO ranged (1.9-5.5 ml/l). During post-monsoon, maximum DO was recorded (5.5 ml/l) at Chandpur and Barishal and the minimum was 3.7 ml/l at Sandwip. During monsoon, the highest DO was recorded (2.8 ml/l) at Chandpur and the lowest was 1.5ml/l at Sandwip (Table 1). Highest DO concentration was recorded during post-monsoon period because of supreme occurrence of the phytoplankton density [51]. 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 [52]. Maximum value of DO in post-monsoon and minimum in monsoon were also recorded in some rivers of the Central Himalayas including the Chan-drabhaga River [53]; Haraz River in Iran [54]; the Tons River [55]; several rivers of Gangetic plain, India [56] and head water stream of Garhwal Himalayas [57].

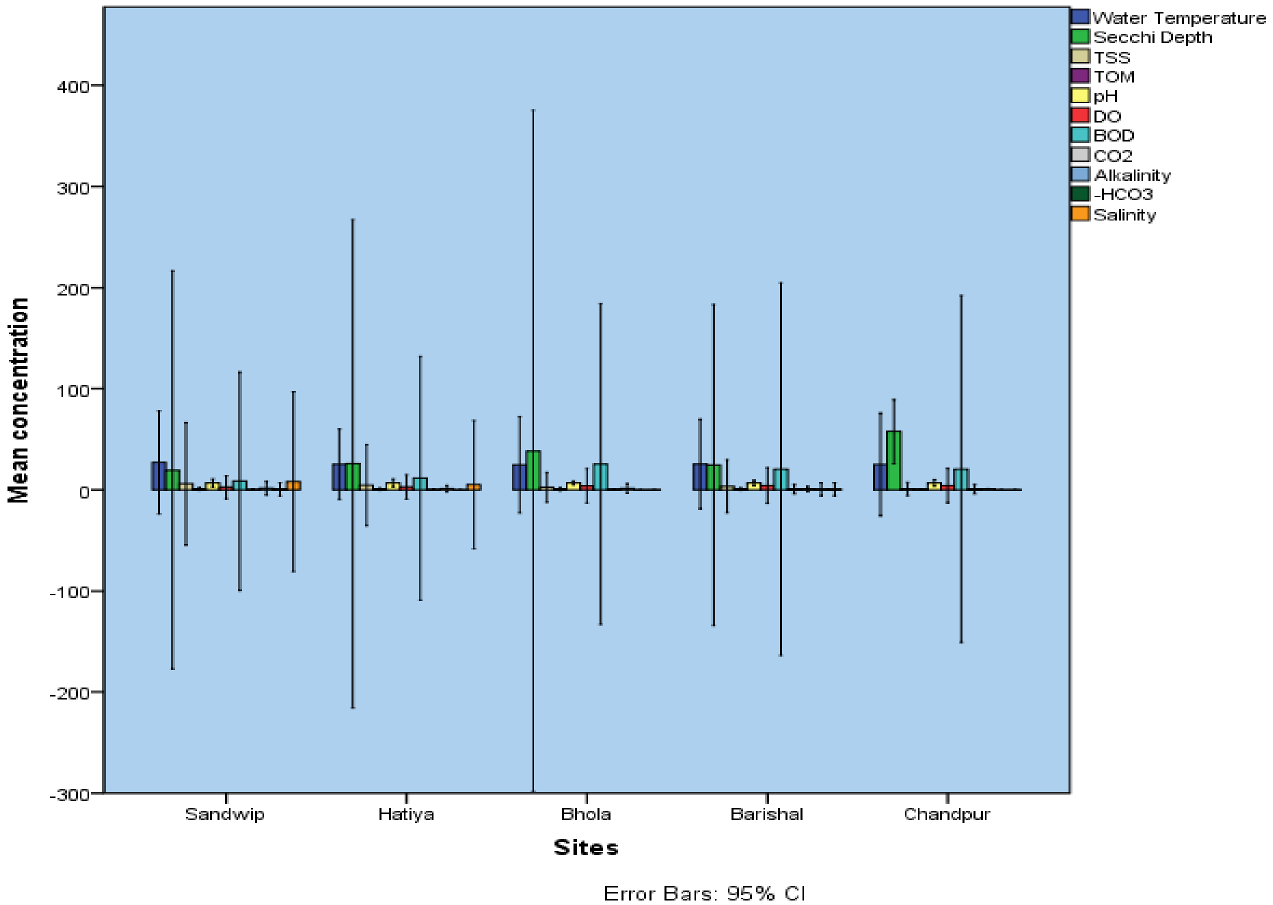


Figure 3: Graph showing the concentrations of water quality parameters at different sites

Bio-chemical Oxygen Demand (BOD_5)

Biochemical Oxygen Demand (BOD) is the volume of oxygen used by microbes to decay carbon-based materials in water within five days period [58]. Low BOD in water directed that the riverside was free from organic pollution [59] while high BOD is harmful because it will reduce the DO [60]. Paul [61] mentioned that, river water having BOD more than 10mg/l is regarded to be moderately and more than 20 mg/l as to be highly polluted water.

The BOD in the lower Meghna River Estuary ranging 0-38 mg/l (Table 1). Similar results observed by Kataria *et al.* at Bhopal city water and by Sikder *et al.* [62] at the Turag River.

Alkalinity

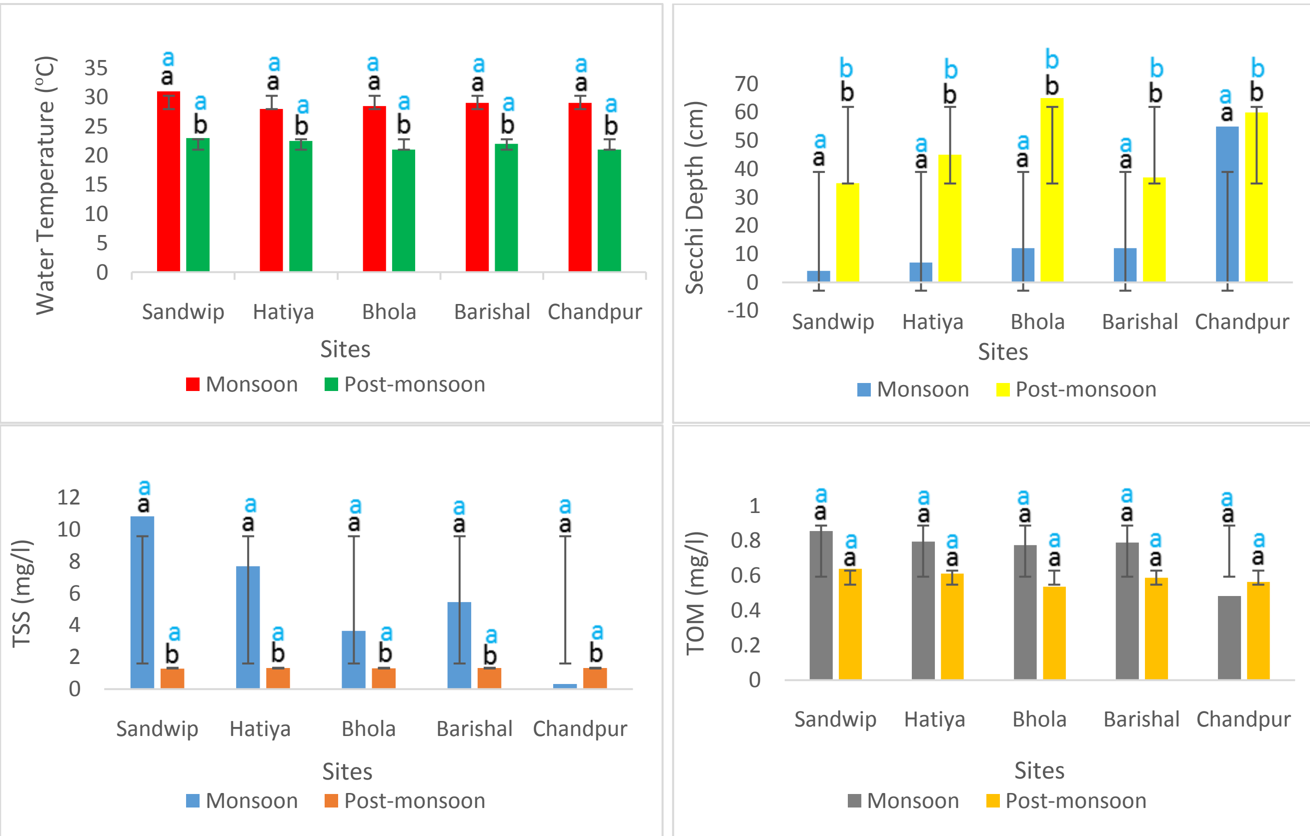
In the present study alkanity ranged from 0.7-2.1 mg/l. The highest concentration (2.1 mg/l) found at Sandwip during monsoon. The lowest amount (0.7 mg/l) was found at Barishal during monsoon and pre-monsoon (Table 1). Hoque *et al.* [63] stated that the amount of alkalinity in monsoon season was 50.4 mg/l and in winter season it was 146.5 mg/l in the Bansi River.

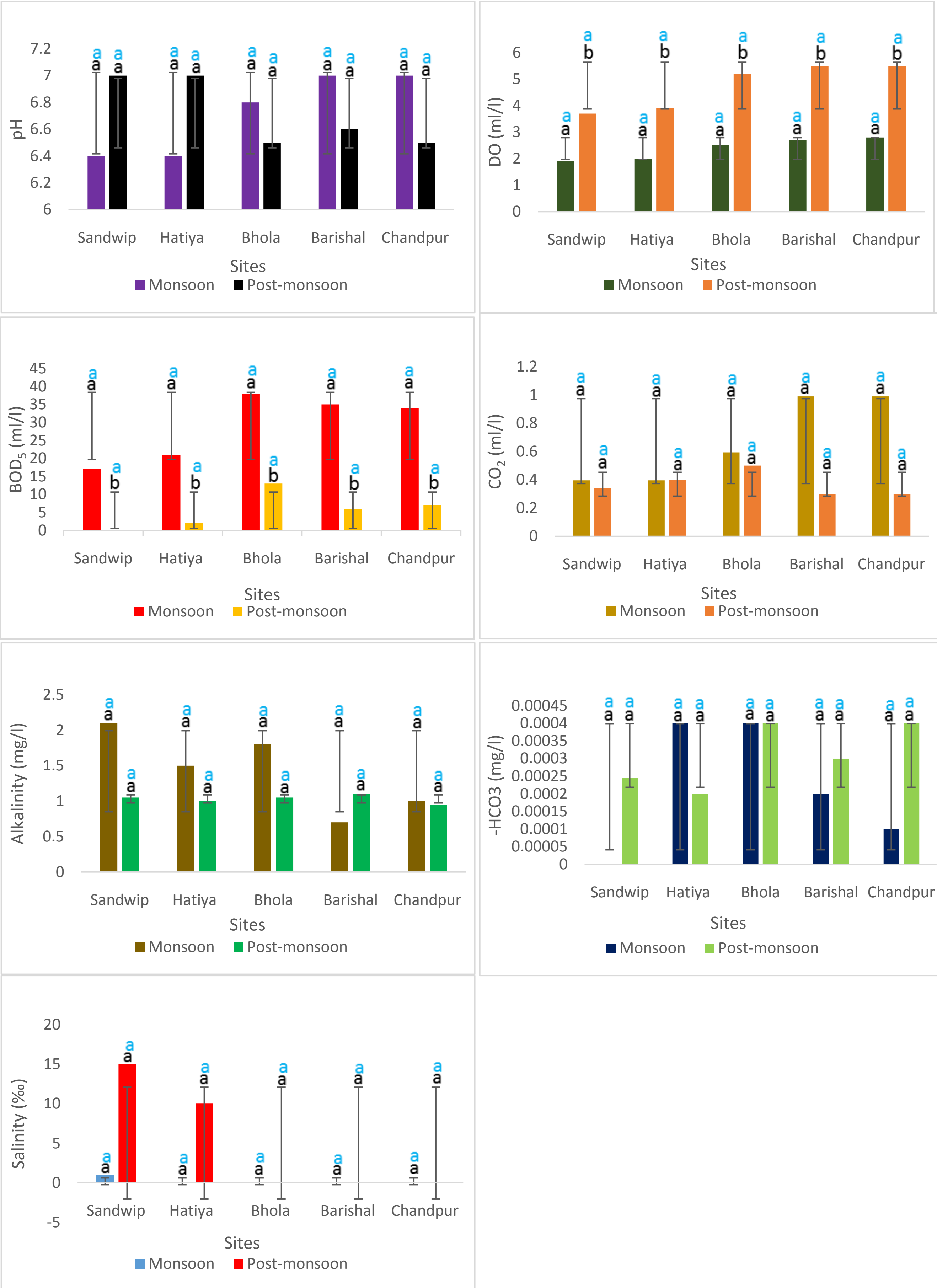
Salinity

Salinity is the pointer of freshwater intrusion in the near shore coastal water as well as extrusion of tidal water in inland water bodies [41]. Salinity acts as a limiting parameter that hugely influences the dispersal of plankton community [64]. During monsoon, only (1‰) salinity was recorded at Sandwip, while at all other sites salinity was almost zero. During post-monsoon maximum salinity was (15‰) at Sandwip and minimum was (8‰) at Hatiya (Table 1). Murugan and Ayyakkannu [65] mentioned salinity to be an important controlling factor in determining the species composition and succession in estuary.

Spatial and Temporal Changes in Water Quality Parameters

Significant variations were found for Water Temperature, Secchi Depth, TSS, DO, BOD_5 in terms of seasons ($p<0.05$) except TOM, pH, CO_2, Alkalinity, HCO_3^- and Salinity ($p>0.05$). But Water Temperature, TSS, TOM, pH, DO, BOD_5, CO_2, Alkalinity, HCO_3^- and Salinity showed no significant variations with sites ($p>0.05$) except Secchi Depth ($p<0.05$) (Fig. 2).





Black a & b= Variation with seasons, Blue a & b= Variation with sites

Figure 4: Variations (Mean±SD) of water quality parameters. Bars with the same letter are statistically indifferent

Cluster Analysis (CA)

Different multivariate statistical analyses viz: CA, PCA and FA act as fruitful guide for eloquent explanation of spatio-temporal parametric data. Many scholars have used these methods to evaluate and categorized the water quality. Wang *et al.* used these statistical analyses for the depict interpretation of the water chemistry. Furthermore, Talukder *et al.* [66]; Wang *et al.* [67], Jiang-Qu *et al.* [68], Venkastesharaju *et al.* [69], Qadir *et al.*, [70] and Kowlkowski *et al.* [71] stated that multivariate statistical methods (PCA, CA, FA) can be very effective tools for easy and clear interpretation of the complex data sets, recognizing pollution factors and assessing water quality parameters with spatio-temporal deviation.

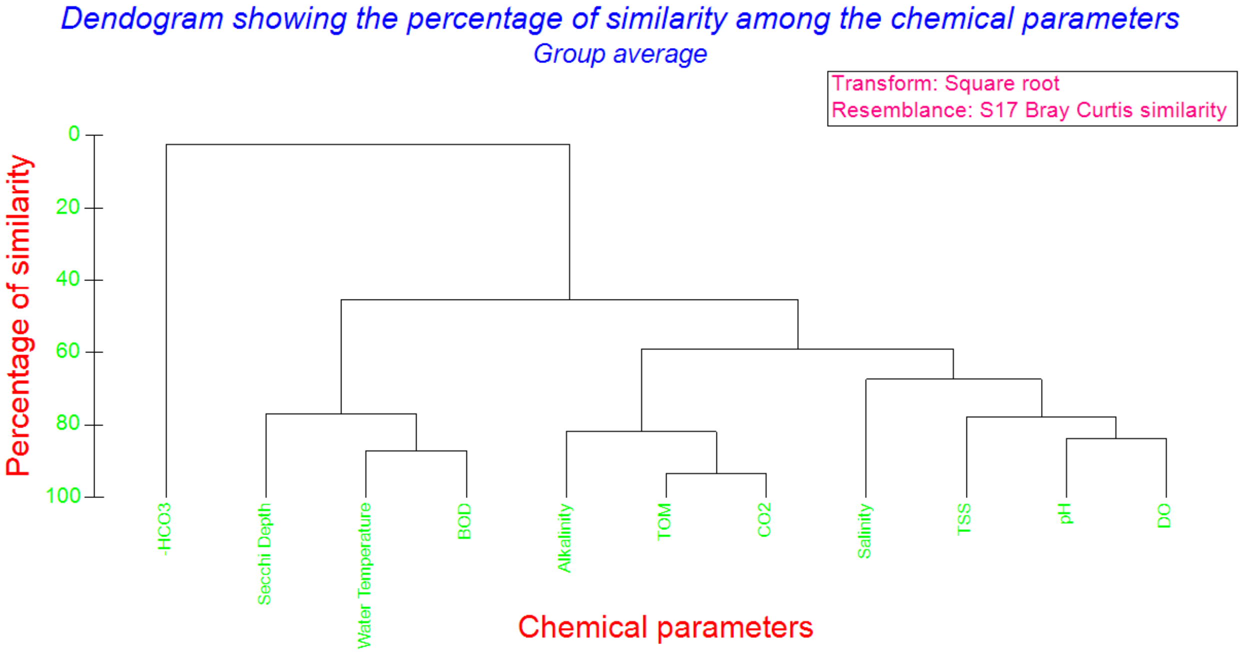


Figure 5: Dendogram showing the percentage of similarity among water parameters during different seasons (BOD_5= Bio-chemical Oxygen Demand; DO= Dissolve Oxygen; TOM= Total Organic Matter; TSS= Total Suspended Solid).

Cluster analyses (CA) were executed using square root and Bray Curtis Similarity to show the similarity among the parameters that contribute hugely in water pollution. From the output of the cluster analysis total three clusters were found during different seasons. Cluster 1 include: Water Temperature, Secchi Depth and BOD_5; Cluster 2: Alkalinity, TOM and CO_2; cluster 3: Salinity, TSS, pH and DO (Fig. 5). Water Temperature, Secchi Depth and BOD_5 represent strong linkage with minimum cluster distance that indicates those parameters have influencing power during seasonal variations. Parameters are grouped together in less distance have higher affinity with similar identical behavior during temporal variations and also exert a probable effect to each other. Furthermore Alkalinity, TOM and CO_2 have also strong linkage but lesser than cluster 1 but contribute largely in environmental process. Salinity, TSS, pH and DO are under the group of cluster 3 with minimum distance than cluster 1 and cluster 2 but have effects on environment. Impacted site is the effluents discharged area of the river which highly affected by untreated industrial effluents, agricultural inputs and domestic wastes.

Correlation Matrix (CM)

In river water environment, the inter linkage among water parameters deliver noteworthy information sources and pathways of parameters. The results of correlation between water parameters fully consented with the results obtained by PCA and CA that approve some new associations between variables. Very strong positive linear relationships were found between TOM vs TSS (0.896), CO_2 vs BOD_5 (0.804) at the significance level 0.01 (Table 2). Secchi Depth vs DO (0. 780), Water Temperature vs BOD_5 (0. 767) showed strong positive linear relationships at the alpha level 0.01. Strong positive correlations were recorded between Water Temperature vs TSS (0.703), TSS vs Alkalinity (0.696) at the significance level 0.05.

The very strong and strong correlations indicate that the parameters were originated from similar sources particularly from industrial effluents, domestic wastes and agricultural inputs. Besides, very strong negative correlations were found between Secchi Depth vs TOM (-0.957), Water Temperature vs DO (-0.926) in river water.

Table 2: Correlation matrix of chemical parameters in river water

Correlations	Water Temperature	Secchi Depth	TSS	TOM	pH	DO	BOD_5	CO_2	Alkalinity	HCO_3^-	Salinity
Water Temperature	1										
Secchi Depth	-0.743*	1									
TSS	0.703*	-0.834**	1								
TOM	0.667*	-0.957**	0.896**	1							
pH	0.053	0.121	-0.483	-0.233	1						
DO	-0.926**	0.780**	-0.705*	-0.721*	-0.117	1					
BOD_5	0.767**	-0.408	0.282	0.338	0.166	-0.618	1				
CO_2	0.559	-0.065	-0.042	-0.018	0.546	-0.417	0.804**	1			
Alkalinity	0.534	-0.610	0.696*	0.628	-0.510	-0.548	0.199	-0.294	1		
HCO_3^-	-0.333	-0.034	0.108	0.164	-0.688*	0.281	-0.117	-0.551	0.286	1	
Salinity	-0.328	0.104	-0.275	-0.111	0.521	0.053	-0.602	-0.319	-0.191	-0.308	1

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

Principal Component Analysis (PCA)

The extraction method was used in PCA analysis that was Eigen values. The components were regarded as principal components whose Eigen values was greater than 0.6. Principal component highlighted the most vital factors that affecting the water quality of the study area. PC 1 had a highest initial Eigen value 7.086 and total variance 64.415%, with strong positive loading of Secchi Depth, pH, DO, BOD_5, CO_2 and strong negative loading of TSS, TOM, Alkalinity resembled the loading of pollution mainly caused by untreated organic load with crucial anthropogenic effect (Table 3). PC 2 had Eigen value 1.827 and explained 16.612% of total variance, with strong positive loading of $^-HCO_3$ and moderate positive loading of TOM can be represented as effect geological changes on environmental parameters. PC 3 explained 13.497 percent of total variance, with strong positive loading of Water Temperature and moderate loading of Salinity. The total variance of the PC4 was 5.477%. PC 4 moderately correlated with Alkalinity. From the present PCA study, it may be concluded that the source of PC 1 and PC 2 can be mixed source from anthropogenic inputs particularly from industrial wastes and agricultural actions in the study area.

Table 3: Component matrix of four factors model with strong to moderate loadings in river water

Component Matrix				
Eigen value (0.6)	Component			
	1	2	3	4
Water Temperature	-0.494	-0.041	0.859	0.131
Secchi Depth	0.745	-0.588	0.257	-0.183
TSS	-0.928	0.332	0.102	-0.133
TOM	-0.754	0.605	-0.157	0.201
pH	0.945	0.147	0.217	0.196
DO	0.975	0.062	0.138	0.165
BOD_5	0.863	0.129	-0.129	0.471
CO_2	0.920	0.173	0.345	-0.067
Alkalinity	-0.827	-0.362	-0.071	0.624
HCO_3^-	0.381	0.889	0.223	-0.119
Salinity	-0.771	-0.095	0.624	0.087
Eigen value	7.086	1.827	1.485	0.602
% Total variance	64.415	16.612	13.497	5.477
Cumulative %	64.415	81.026	94.523	100.000

River Pollution Index (RPI)

In recent time, River pollution index (RPI) simple method used concurrently by different organization like Taiwan EPA to assess the surface water quality. This method comprising with concentration level of four parameters: DO, BOD_5, SS, and NH_3-N. Pollution status is calculated using four-state of each parameter. The RPI is computed using following equation [72]:

$$\mathrm{RPI} = 1/4 \sum_{i=1}^{4} \mathrm{Si}$$

Table 4: River Pollution Index (RPI) Chart [72, 73]

Items/ ranks	Good	Less polluted	Moderately polluted	Highly polluted
DO (mg/L)	>6.5	4.6-6.5	2.0-4.5	<2.0
BOD_5 (mg/L)	<3.5	3.0-4.9	5.0-15	>15
SS (mg/L)	<2.0	20-49	50-100	>100
NH_3-N (mg/L)	<0.5	0.5-0.9	91.0-3.0	>3.0
Index scores (Si)	1	3	6	10
Sub-index	<2	2.0-3.0	3.1-6.0	>6.0

In present study, the concentrations of DO, BOD_5 and TSS were compared with concentrations of RPI table to weigh the status of particular water variables (Table 4). Average DO in the Sandwip and Hatiya was found 1.9 mg/L and 2 mg/L during monsoon season that indicate the water is highly polluted in comparison with RPI but the water of Bhola, Barishal and Chandpur contained 2.5 mg/L, 2.7 mg/L and 2.8 mg/L DO that indicate the water is moderately polluted. Averages DO in the Sandwip, Hatiya, Bhola, Barishal and Chandpur was recorded (3.7-5.5 mg/L) during post-Monsoon season which can be treated as less to moderately polluted zone according to RPI index. Average amount of BOD_5 were found above the >15 mg/L at Sandwip, Hatiya, Bhola, Barishal during monsoon indicating that the water of these zone was highly polluted except Chandpur (7 mg/L) (Table 4). During post-monsoon the average BOD_5 was recorded <3.5 mg/L at Sandwip, Hatiya and Chandpur revealed that the water of these zones was good except Bhola and Barishal (Table 4). The average value of TSS was recorded 10.8275 mg/L, 7.688 mg/L, 3.6595 mg/L and 5.4435 mg/L at Sandwip, Hatiya, Bhola, Barishal during monsoon indicating the water was less polluted. But during post-monsoon the average TSS was recorded <2.0 mg/L at all sites which exposed that the water was good.

CONCLUSION

Multivariate statistical analyses and River Pollution Index (RPI) indicated that river water was less to highly polluted. From the present findings of the current study it can be reported that the water of the river is being polluted day by day due to unplanned urbanization, haphazard industrialization, and agricultural inputs. The water of the lower Meghna River Estuary is not completely safe for aquatic organisms, irrigation and other purposes. Besides, the high concentrations of some water parameters compared to RPI index can pose great risk to fish and human community dwelling in and nearby to the lower Meghna River Estuary. To protect, develop and for better management of the lower Meghna River Estuary, a proper planning of the river should be taken.

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