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Spatio-temporal variability in hydro-chemical characteristics of coastal waters of Salimpur, Chittagong along the Bay of Bengal

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Abstract

Diverse seasonal characteristics of hydro-chemical parameters in the coastal zone are significantly related to aquaculture development. In this paper, general water quality condition derived from laboratory analysis from the coastal waters of Salimpur, Chittagong is presented. Samples were collected from onshore and offshore site of two adjacent coastal locations named as North Salimpur (experimental location) and South Kattoli (control) during a monsoon and a dry season spanning 2013-14. The spatio-temporal variability of studied parameters were found as air temperature 26.5-32.5 ˚C, water temperature 23-33 °C, pH 7.1-7.9, DO 4.29-7.11 mg/L, BOD 1.10-3.25 mg/L, salinity 1.6-21 ppt, EC 3.40-35.68 mS/cm, TDS 2.02-21.99 g/L, TSS 0.62-2.76 g/L, transparency 4.5-14 cm, precipitation 64-1992 mm, NO_2-N 1.94-2.58 µg/L, PO_4-P 0.45-1.84 µg/L, SiO_3-Si 130.46-956.31 µg/L during investigation period. Average values of physicochemical parameters were found to be in compliance with standard guidelines. The ship breaking activities near experimental location possess negative impacts on local geomorphology, freshwater inputs, precipitation and aquatic environment as well. Moreover, wind driven forces, tidal action, wave characteristics and changes in monsoon pattern regulate the coastal processes. This research suggests the importance of regular monitoring to assess present status of water quality and future prospect of aquaculture in the Chittagong coastal zone.

Keywords: Coastal zone, geomorphology, hydro-chemical, spatio-temporal variability

INTRODUCTION

Coastal water has become a major concern for aquaculture development. The life on the world depends on water and hence the hydrological study is essential to understand the relationship between aquatic environment and its processes (Sun *et al.* 2015). The environmental conditions such as salinity, dissolved oxygen, temperature and nutrients characterizing particular water masses. Seasonal variations in coastal water depends on the local condition of rainfall, tidal incursion, abiotic-biotic processes, quantum of fresh water inflow which is affecting the nutrient cycle of coastal environments (Kathiravan *et al.* 2014).

Bangladesh is a great delta formed by the world's mighty

Himalayan Rivers along with the Ganges-Brahmaputra-Meghna (GBM) riverine system which has combined peak discharge in the flood season of over 180,000 cusec. In the downstream, GBM system is flowing through the southeastern part of Bangladesh coast. Furthermore, different processes such as current, salinity variation, diffusion etc. can transport the energy of detritus into the water column (Jorcin 2000; Kumar *et al.* 2015).

Chemical composition of water is a function of hydro-geochemical processes. Thus, monitoring of water quality parameters provide important information for aquatic management (Matthieu *et al.* 2005). Coastal zone management and sustainability is complicated and difficult due to dynamic and complex characteristics of our coastal belt. Integrated coastal zone management revealed that establishment of a better understanding of the coastal zone with biogeochemical cycles and primary productivity of water medium is so essential. Skillful management of water bodies is required if they are to be used for such diverse purposes as aquaculture and fisheries activities (Shoko *et al.* 2014). The regular and periodic changes in the climate synchronized with season are ultimately reflected in environmental parameters also, which in turn have direct or indirect influence over coastal processes (Saravanakumar *et al.* 2008).

Water quality depends on a large number of physico-chemical parameters and to assess the magnitude and source of any aquaculture practices, monitoring of these parameters is indispensable (Reddi *et al.* 1993; Jackher *et al.* 2003). Ravaniah *et al.* (2010) and Singare *et al.* (2011) have notable studies on this regard.

Ship recycling zone have negative impacts on water quality deterioration and favorable aquatic condition is declining day by day. For this reason, water quality investigation in coastal belt is essential to understand the recent circumstances on the basis of aquatic biogeochemistry and coastal zone management. This study is supposed to be a useful source of information and a gap filling initiative to understand the condition of southeastern coastal regions of Chittagong. In addition, the findings would contribute to further ecological assessment and monitoring of the coastal water characteristics. Therefore, the investigation is aimed to assess spatio-temporal variation and favorable water quality of Salimpur coast, Chittagong along the Bay of Bengal.

METHODOLOGY

Research area: Two locations were selected from the Salimpur coastal belt to investigate physico-chemical variation and other hydrological parameters. Experimental location (Latitude 22˚23.87´N, Longitude 91˚44.605´E) situated at the North Salimpur, and control location (Lat. 22˚21.45´N, Long. 91˚45.0´ E) at South Kattoli (Figure 1). Experimental location is near the ship recycling zone, with extended intertidal mudflat with salt marsh, scattered seaweed and planted mangrove whereas control location is at 6 km downstream from experimental location with planted mangrove and prolonged intertidal zone.

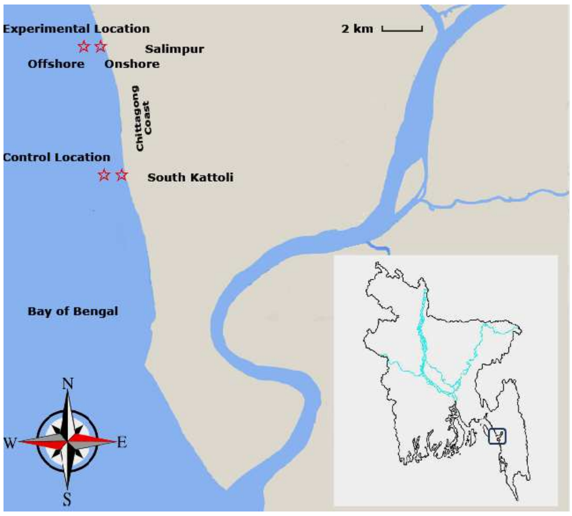

Figure 1: Geographical location of research area (Source: USGS Earth Explorer)

Sampling and sample handling: Field investigation was carried out from 2013-2014 during two high (monsoon) and low (winter) energy season at Salimpur coast. In every location two sites were considered to collect water sample with *in-situ* parameters. Onshore site is positioned in the high tide zone which is 50m towards the sea from earthen embankment while offshore site is 200m away from the coastline in low tide zone. Water samples were taken by using Nansen water sampler during high and low tides. Temperature variation was recorded by mercury thermometer, P^H determined with pen pH meter [Phillips PW 8409], conductivity and TDS were measured through conductivity meter [Model Y.12542], TSS determined by filtration method, transparency recorded by a secchi disc (30cm in diameter) and salinity measured by Mohr-Knudsen titration method (Barnes 1959; APHA 2005). To determine NO_2-N, Bendschneider *et al.* (1952) was followed. The procedure of Murphy *et al.* (1961) and Mullin *et al.* (1955) were used for determining PO_4-P and SiO_3-Si correspondingly.

Statistical analysis: Data were analyzed by IBM SPSS 22.00 software for statistical analysis, such as, seasonal variation, Two Way ANOVA, Pearson correlation and Principal Components Analysis (PCA). Pearson correlation established relationship among water quality parameters whereas PCA involves to lessen the dimensionality of the data set and to classify new significant fundamental variables.

RESULTS

Seasonal dissimilarity in general hydro-meteorological parameters: Air temperature (AT) of the coastal zone during different seasons was found to vary from 28.3 to 30.5 ˚C at experimental location whereas 26.8 to 32.3 ˚C at control location. The maximum temperature observed during monsoon and least in winter at experimental offshore site. In contrast, the maximum reported in monsoon at onshore and minimum in winter at control offshore site (Figure 2).

Maximum water temperature (WT; 31.5 ˚C) was recorded in winter at each site and minimum (30.8 ˚C) found during monsoon at experimental offshore site. In contrast, highest temperature (32.8 ˚C) recorded in monsoon onshore and lowest (23.3 ˚C) investigated during winter at control offshore site (Figure 2). Temperature was decreased from monsoon towards winter gradually with sharp increase at onshore. Water temperature positively correlated with air temperature ($p<0.01$).

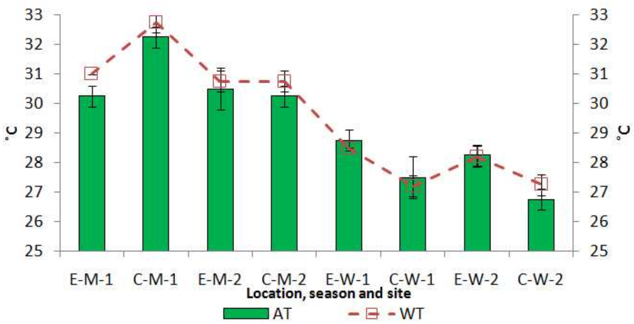

Figure 2: Seasonal variation of air and water temperature at both locations of different sites (E= experimental location, C= control location, M= monsoon, W= winter, 1= onshore site and 2= offshore site)

The highest pH (7.6) observed during monsoon at onshore and lowest (7.4) found in winter at experimental offshore site. On the other hand, uppermost pH (7.9) noted at the period of winter offshore site and minimum (7.7) reported in winter at control onshore (Figure 3). pH was found to increase from monsoon to winter moderately and was negatively correlated with air and water temperature. The variation of pH differs from monsoon to winter season from experimental to control location ($p<0.05$).

Dissolved oxygen (DO) varied from 5.51 to 6.95 mg/L at experimental location and 4.44 to 6.9 mg/L at control location. At experimental location higher value recorded in monsoon at onshore and lower value of DO observed in winter at offshore. The greater value stated from monsoon at onshore and lesser value found in winter at control onshore site (Figure 4). DO level was gently decreased from monsoon to winter in every location. DO positively correlated with air and water temperature ($p<0.01$) and negatively correlated with pH.

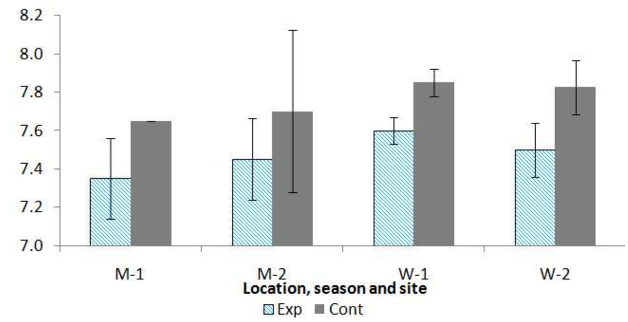

Figure 3: Seasonal variation of pH at each location of different sites (Exp= experimental location, Cont= control location)

Biochemical oxygen demand (BOD) of the coastal water ranged from 2.95 to 1.32 mg/L and 2.57 to 1.17 mg/L at experimental and control location in turn. The higher value of BOD noted in monsoon at onshore and lower value observed in winter at experimental offshore. Contrariwise, in control location, higher value reported in monsoon and lower value investigated during winter onshore (Figure 4). BOD level was gradually decreased from monsoon to winter at each location. BOD positively correlated with both temperature and DO ($p<0.05$).

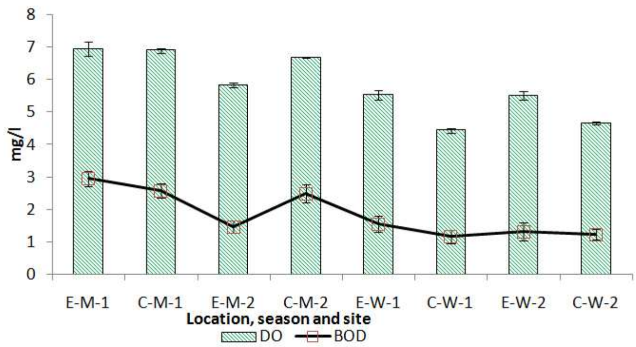

Figure 4: Spatio-temporal variations of DO and BOD at both transects of different sites

Seasonal fluctuation in salinity and associated features: Salinity was recorded between 1.8 to 20.9 ppt and 1.7 to 19.4 ppt at experimental and control correspondingly. The minimum value of salinity observed in monsoon at onshore site and maximum found in winter at offshore site of both locations (Figure 5). Salinity concentration positively correlated with transparency; negatively correlated with air temperature, DO and BOD ($p<0.01$); negatively correlated with water temperature ($p<0.05$).

The minimum value (2.03 g/L and 2.12 g/L) stated in monsoon at onshore site and the maximum (21.88 g/L, 20.49 g/L) in winter offshore site of each location (Figure 5). TDS positively correlated with transparency and salinity; negatively correlated with air temperature, DO, BOD ($p<0.01$); with water temperature ($p<0.05$).

The minimum value (3.42 mS/cm; 3.56 mS/cm) recorded in monsoon at onshore site and maximum (35.52 mS/cm; 33.34 mS/cm) during winter at offshore site of both experimental and control location (Figure 5). EC positively correlated with transparency, salinity, TDS; negatively correlated with air temperature, DO, BOD ($p<0.01$) and water temperature ($p<0.05$).

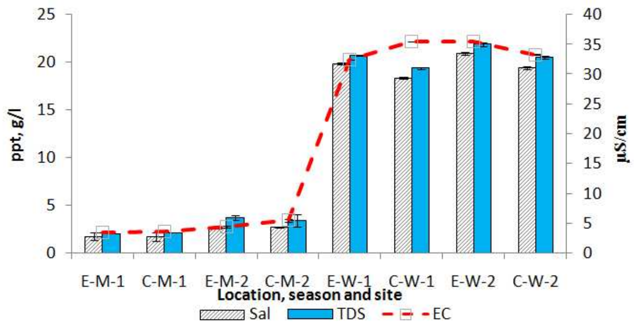

Figure 5: Seasonal variations of salinity, TDS and EC at both locations of different sites

TSS of coastal water investigated between 0.62 to 1.5 g/L and 1.31 to 2.71 g/L at experimental and control location correspondingly. The minimum TSS value was found in monsoon at onshore site and maximum in the period of winter at offshore of each location (Figure 6). TSS positively correlated with air temperature, transparency, salinity, TDS; negatively correlated with air temperature, BOD, transparency, salinity, TDS, EC ($p<0.01$) and positively correlated with DO ($p<0.05$). Variation during monsoon and winter period in salinity, electro-conductivity, total dissolved solids and total suspended solids found to differ from wet to dry season ($p<0.05$). Changes in salinity and turbidity depend on annual rainfall characteristics and rainfall rates.

The level of transparency level gently decreases from winter to monsoon at both locations. The higher value (13.5 cm; 12.0 cm) of transparency found in monsoon onshore and lower value (4.8 cm; 6.1 cm) investigated in winter offshore of both locations (Figure 6). Transparency negatively correlated with air temperature, DO and BOD ($p<0.01$). Seasonal variation in air temperature, Dissolved oxygen, Biochemical oxygen demand and coastal water transparency found to differ from monsoon to winter season ($p<0.05$). During monsoon heavy rainfall reported from onshore (1364 mm) and offshore (951 mm) of experimental location whereas 1992 mm and 1061 mm recorded from control onshore and offshore correspondingly. In contrast, only 64 mm observed from experimental location and 103 mm precipitation recorded from control site. Precipitation rate differ from monsoon to winter due to seasonal phenomenon change and local geomorphological characteristics ($p<0.01$).

Seasonal variation in nutrients characteristics: NO_2-N concentration level reached its peak (2.24 µg/L) during winter at offshore site of experimental location but downed to the lowest level (1.96 µg/L) observed in onshore of each season. On the other hand, in control minimum (1.97 µg/L) investigated in winter at offshore site and maximum (2.57 µg/L) in monsoon at offshore (Figure 7). Nitrite nitrogen negatively correlated with TDS and TSS ($p<0.01$).

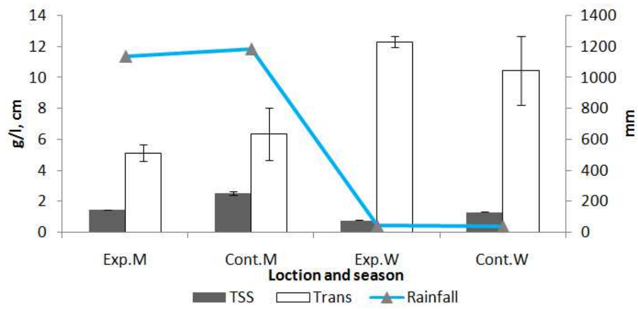

Figure 6: Seasonal variations of TSS, transparency and rainfall at both locations of different sites

Phosphate phosphorus fluctuated from monsoon to winter. The lowest value (0.45 µg/L) found at onshore and the highest (0.81 µg/L) at offshore in monsoon of experimental location. Otherwise, minimum concentration (0.91 µg/L) examined in winter at onshore and maximum (1.84 µg/L) in monsoon at control offshore (Figure 7). PO_4-P positively correlated with NO_2-N and negatively correlated with TSS ($p<0.01$). PO_4-P values fluctuate from monsoon to winter of control to experimental location.

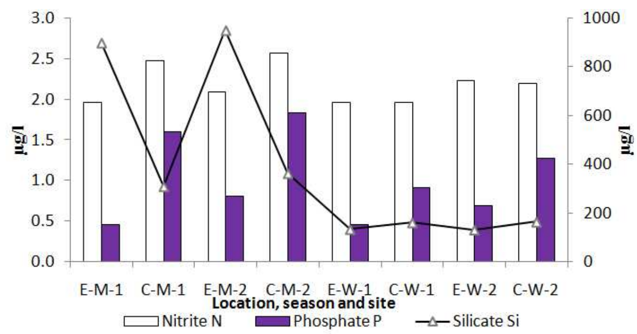

Figure 7: Seasonal variations of NO_2-N and PO_4-P at each location of different sites

The concentration level of SiO_3-Si observed in its peak (949.82 µg/L) from monsoon offshore and downed to its lowest level (131.04 µg/L) in winter experimental offshore. In control, minimum (161.14 µg/L) recorded in winter at onshore while maximum (362.69 µg/L) in monsoon at control offshore (Figure 7). Silicate silicon negatively correlated with transparency, salinity, TDS, EC ($p<0.01$); positively correlated with air temperature and DO, negatively with pH ($p<0.05$). The concentration of silicate silicon found to differ from wet to dry season ($p<0.05$).

Principal component analysis: Principal component explained the most important factors that affecting the water quality of the study area. PCA result listed in Table 1, Including rotated loading, percentage of each major factor and initial eigenvalues. PCA-1 had a highest initial eigenvalue 8.9 and explained 63.4% of total variance, with strong positive loading of AT, WT, DO, BOD, TSS, Rainfall, Siand strong negative loading of Salinity, EC, TDS, transparency with a moderate negative loading of pH (Figure 8, 9; Table 1). PCA-2 comprised with the eigenvalue 2.9 and explained 20.9% of total variance, with strong positive loading of pH, N, P; moderate negative and positive loading of Si and TSS correspondingly. PCA-3 had a highest initial eigenvalue 1.4 and explained 9.8% of total variance, with moderate positive loading of water temperature (Figure 8, 9; Table 1).

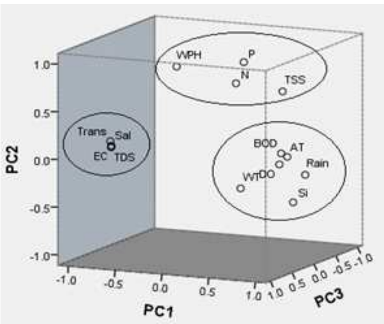

Figure 8: Varimax rotation plot of the two study locations based on PC1, PC2 and PC3 of the physico-chemical water quality parameters of each site

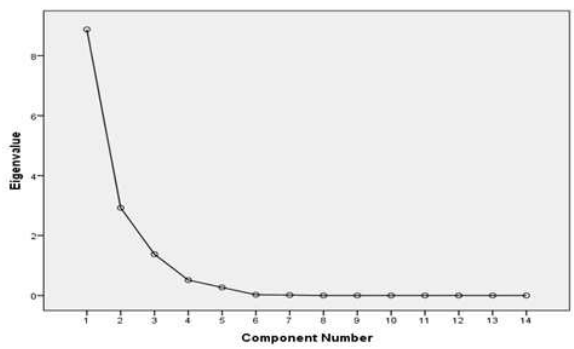

Figure 9: Scree plot represents the contribution of principal components in accordance with Eigen values

Table 1: Component matrix of principle component analysis

Variable	*PC-1*	*PC-2*	*PC-3*
AT	**0.93**	0.04	0.22
WT	**0.65**	-0.23	**0.70**
pH	-0.51	**0.77**	-0.33
DO	**0.91**	-0.02	0.37
BOD	**0.85**	0.06	0.20
Sal.	**-0.99**	-0.03	0.16
EC	**-0.99**	-0.02	0.16
TDS	**-0.99**	-0.03	0.15
TSS	**0.73**	**0.65**	-0.10
Transparency	**-0.89**	0.08	0.38
Rainfall	**0.87**	-0.25	-0.31
N	0.42	**0.78**	0.31
P	0.32	**0.93**	-0.09
Si	**0.71**	-0.56	-0.37
Eigenvalue	8.9	2.9	1.4
% of total variance	63.4	20.9	9.8
Cumulative (%)	63.4	84.3	94.1

Extraction method: *Principal Component analysis; Rotation method: Varimax with Kaiser Normalization and rotation converged in 6 iterations. Bold data are the main contribution elements to the component.*

DISCUSSION

Seasonal dissimilarity in general water parameters: During the investigation period air temperature varied 30.4±0.2 ˚C, 28.5±0.4 ˚C in monsoon and winter season at experimental site in turn. Ahmed *et al.* (2010) investigated between 18.3 and 35.0 ˚C from Karnaphuli River along the Chittagong coast, similar trend was reported in the study conducted by Chowdhury *et al.* (2012) and Kamal *et al.* (2009). Furthermore, Raju *et al.* (2015) noted temperature varied between 28.8-35.0 ˚C with a marked seasonal fluctuation.

Water temperature significantly differs with fluctuation of air temperature and pattern of seasonal variation. Average temperature observed 30.9±0.2 ˚C in monsoon whereas 31.4±0.2 ˚C found at winter from experimental site. Temperature during winter remains lower than monsoon in general but in present investigation winter temperature was slightly high. The fluctuation of temperature was due to the change in intensity of radiant energy, diverse tidal phenomenon, coastal mangrove and salt marsh vegetation. Munisamy *et al.* (2011) reported average 29 ˚C from coastal water of Kudankulam. Kamalkanath *et al.* (2012) and Raj *et al.* (2013) also reported the similar trend of temperature. Atmospheric and water temperature is regulated by solar radiation, evaporation, freshwater mixing, influx and cooling from adjacent neritic water (Govindasamy *et al.* 2000). Temperature during winter was low due to strong land breeze and precipitation. Moreover, peak temperature observed in summer could be attributed due to intensity of solar energy (Das *et al.* 1997; Hänninen *et al.* 2000).

Temporal fluctuation of pH attributed to factors like CO_2 removal by photosynthesis, influence of seawater and other biological activities (Balasubramanian *et al.* 2005; Sridhar *et al.* 2006; Kamalkanth *et al.* 2012; Rajasegar 2013; Raju *et al.* 2015). pH varies with local geomorphological characteristics and investigated as 7.4±0.1, 7.6±0.1 from monsoon and winter from experimental site. pH of experimental site was slightly acidic than control site due to the present heavy metals released from ship recyclingactivities. From ship yard various types of persistent organic pollutants [POPs] release in natural water and the acidity of adjacent coastal water increased. pH ranged 7.6 to 7.9 from the estuary of Calabar river (Onojake *et al.* 2015). Raj *et al.* (2013) also investigated similar trends of pH.

Dissolved oxygen content varies from site to site due to the dynamic properties of water chemistry and investigated to vary as 6.4±0.8 mg/L at experimental and 5.5±0.01 mg/L in control. Kamalkanth *et al.* (2012) investigated 4.52-6.96 mg/L from the Nagapattinam coast, 4.53-6.65 mg/L from Calabar river estuary (Onojake *et al.* 2015). During monsoon higher dissolved oxygen fluctuation occurred at the coastal region due to heavy rainfall and freshwater mixing processes (Paramasivam *et al.* 2005). The concentration of DO inspected 3.01 to 6.89 mg/L from Chittagong coast (Islam *et al.* 2013), 2.9 to 10.9 mg/L from Mahanadi river estuary (Behera *et al.* 2014), 6.30±0.25 mg/L reported from Tamilnadu coast and 3.5 to 7.2 mg/l from Arasalar Estuary (Raju *et al.* 2015). BOD value found as 2.2±1.1 mg/l at monsoon, 1.4±0.2 mg/l from winter at experimental location. BOD is affected by the same factors that affect dissolved oxygen (APHA 2005). Ahmed *et al.* (2010) reported BOD ranges from 0.21 to 9.17 mg/L from the coastal water of Chittagong, 0.51-3.17 mg/L studied from the ship recyclingregion of Chittagong coast (Islam *et al.* 2013) and 1.72 mg/L reported from the Calabar estuary (Onojake *et al.* 2015) .

Seasonal fluctuation in salinity and associated features: Coastal salinity observed as 2.2±0.6 ppt at monsoon and 20.4±0.7 ppt in winter at experimental location. It is evident from the previous studies that the changes in marine water salinity are due to rainfall, tidal fluctuation, evapotranspiration and influx of freshwater. Coastal water with a prolonged low salinity (<15‰) prevails mostly during monsoon and certain period of post-monsoon. Munisamy *et al.* (2011) studied average salinity 32.4 ppt from Kudankulam. Kamalkanth *et al.* (2012) reported average salinity 29.8 ppt from Tamil Nadu coast, India. Onojake *et al.* (2015) reported 15.33 to 15.5 ppt salinity from Calabar river estuary. Srilatha *et al.* (2012) also examined a wide range of salinity (15-35ppt) from the south east coast of India. TDS of this coastal experimental location reported as 2.9±1.2 g/L, 21.3±0.8 g/L at monsoon and winter correspondingly. TDS 4.5 g/L to 11.9 g/L reported from Mahanadi River Delta (Behera *et al.* 2014), 9370 to 17740mg/L from Chittagong coast (Islam *et al.* 2013). TDS and EC are closely related with salinity concentration. Electro-conductivity ranged as 3.9±0.7 mS/cm at monsoon and 35.1±0.6 mS/cm in winter. EC 5.16-17.33 mS/cm reported from Mahanadi River Delta (Behera *et al.* 2014) and 33,489 to 33,592 µS/cm observed from Calabar River estuary (Onojake *et al.* 2015). The EC of water was found to vary from 32,500 to 25,150 µS/cm from Chittagong coast (Islam *et al.* 2013). Ahmed *et al.* (2010) observed 0.014 to 5.1 g/L from the Karnaphuli River along the Bay of Bengal.

Total suspended solids investigated 1.45±0.02 g/L at monsoon and 0.79±0.01 g/L in winter. The findings are also harmonious with previous investigations. Estuarine and coastal zone were highly dynamic, diverse and turbid due to the monsoon effect (Desouza *et al.* 1981). TSS recorded 22,111 to 23,263 g/m^3 from the Calabar river estuary (Onojake *et al.* 2015). Transparency of the water depends on various factors like land drainage, freshwater discharge and pattern of water circulation. Secchi depth recorded as 5.1±0.5 cm, 12.3±1.7 cm from monsoon and winter of experimental site respectively. 1.50 to 150cm secchi depth observed from Chittagong coast (Ahmed *et al.* 2010). Mahmood *et al.* (1976 a,b) reported 10.5 to 29 cm secchi depth during the cruise in the Bay of Bengal on BNS Padma. Secchi depth is inversely related with organic particles and total suspended solids present in coastal water. High turbid water may cause decrease the DO concentration and substantially increase the BOD level (Islam *et al.* 2013). Salinity and associated features related closely with rainfall rate. Heavy precipitation during the monsoon is generally indicated in lower salinity, higher TSS and less transparency and winter showed opposite characteristics (Kathiravan *et al.* 2014).

Seasonal variation in nutrients characteristics: Variation in nitrite nitrogen ions could be attributed due to the variation in phytoplankton, excretion and oxidation of ammonia and reduction of nitrate. Nitrite Nitrogen ranged as 2±0.1 µg/L and 2.1±0.2 µg/L from monsoon and winter at experimental location. The low content of nitrites during the winter was due to less freshwater input, higher salinity and pH. The concentration 0.33±0.22 mg/L observed from Tamil Nadu coast (Raj *et al.* 2013).

The concentration of phosphate phosphorus found as 0.63±0.25 µg/L at monsoon and 0.57±0.16 µg/L in winter from coastal water. Raju (2015) investigated 0.29 to 2.15

µg/L level of PO_4-P from southeast Indian coast. PO_4 concentration ranged from 0.55 mg/L to 2.59 mg/L from Mahanadi river estuary (Behera *et al.* 2014) and ranged from 0.88±0.66 mg/L from Tamilnadu coast (Raj *et al.* 2013). Ahmed *et al.* (2010) stated 0-5.18mg/L from Karnafully River. High concentration observed during monsoon due to salinity increase, regeneration and release of phosphate from bottom into the water column by turbulence and mixing processes (Nair *et al.* 1999; Choudhury *et al.* 1991; Kumar *et al.* 2015). Buffering action, adsorption and desorption of phosphate is also responsible in this regards (Govindasamy *et al.* 2000).

Salimpur coastal silicate silicon concentrationof water was examined as 924.1±36.4 µg/L and 132.2±1.7 µg/L in monsoon and winter respectively from experimental location. Raju *et al.* (2015) reported 28.25 to 98.94µg/L from Arasalar estuary. Kamalkanth *et al.* (2012) investigated maximum12560 µg/L and Raj *et al.* (2013) 1.11±0.07 mg/L from the Tamil Nadu coast, India. The spatio-temporal variation of silicate in coastal water is influenced by several factors, more importantly the proportional physical mixing of seawater with fresh water adsorption of reactive silicate into suspended sedimentary particles and other related chemical interaction.

Principal component analysis: Datasets were collected and the scree plot of both seasons and sites shows their Eigenvectors against their principal components. Varimax rotation plot of the two study locations and normalized factors were extracted using Principal Component Analysis (PCA) of the physico-chemical water quality parameters. Factors loading at greater than 0.75 treated as strong, in between 0.50 to 0.75 specify as moderate and weak factors remain in between 0.40 to 0.50 (Liu *et al.* 2003).

PCA 1, which was accounted for 63.4% of the total variance which is highly dominated by air temperature (r=0.93), dissolved oxygen (r=0.91) and precipitation (r=0.87). The land runoff helps to enrich coastal water with silicate silicon ions during monsoon from terrestrial environment. High DO content indicate also in biochemical oxygen demand and water temperature that is closely related with atmospheric temperature. Higher negative domination of salinity, EC and TDS (r=-0.99) is also an indication of vulnerabilities of these parameters throughout the coast, like sudden salinity declination in monsoon season, irregular fluctuation rate etc. Salinity of monsoon and winter varies due to the change in water temperature and the change in T-S [Temperature-Salinity gradient. Electro-conductivity and total suspended solids were highly correlated with the salt content. Temperature fluctuation regulates the dissolved oxygen distribution through the coastal zone. Furthermore, 1st PCA correlates more strongly with temperature related parameters and oxygen criteria in coastal water body and can be viewed as a measure of water quality which is noted significantly differ from monsoon to winter.

PCA 2 was investigated for 20.9% of the total variance within strong positive factors of p^H (r=0.77), NO_2-N (r=0.78) and PO_4-P (r=0.93). Nutrients characteristics indicate the addition of nutrients especially NO_2-N and PO_4-P from precipitation and other weathering processes. During winter, when pH remains slightly alkali, nutrients conditions also show positive trends of increase. The prime cause of this pattern is due to the fertilizers use in the coastal aquaculture activities.

PCA 3 was examined for 9.8% of the total variance within positive attributes of water temperature (r=0.70) and indicates that coastal process largely governed by water temperature, with an enormous effect on biogeochemical cycle. Moreover, 3rd PCA correlates more significantly with the water temperature.

The PCA assisted in extracting and recognizing seasonal variations or sources of origin responsible for aquatic chemistry. PCA identified three prime factors that explained more than 80% of the total variance of 14 parameters. The main anthropogenic impacts on the coastal waters of the study area are due to the ship recycling activities, fishing, urbanization and settlement directly into the sea. The toxic discharge will lead to degradation of coastal water quality causing significant negative impacts on marine biogeochemical cycle and aquatic organisms (Mokhtar *et al.* 2009; Praveen *et al.* 2013; Kathiravan *et al.* 2014). This study reveals that, the usefulness of principal components analysis and interpretation of results for better understanding of seasonal variations in water quality for effective coastal water quality management.

CONCLUSION

Monsoon is the period of boosted primary productivity in the Chittagong coastal zone due to heavy rainfall, frictions among water particles, heavy runoff from river and land as well as collision with rigid coastal belt. In addition, coastal erosion-accretion, sedimentation, and flood discharge create an optimum environment for aquaculture production as they carry enormous nutrients to the intertidal zone. During monsoon the coastal water remains turbid and higher temperature also accelerates the rate of productivity. In contrast, highest primary productivity was recorded in the monsoon at north Salimpur onshore; higher transparency prevailed during winter at offshore site of same location. pH remained within normal range at each site during investigation period except slightly acidic condition in experimental location. Highest nutrients concentration was observed during the strong monsoon at every site because of sediment transport and dynamic properties of the coast. In contrast heavy evaporation during clam season indicated by higher salinity, total dissolved solids and electro-conductivity. Recent investigation suggests the necessity of continuous monitoring and assessment of coastal water quality including productivity and nutrients budget in the coastal zone. Moreover, it is expected that the assessment and outputs of the present investigation would help to conduct future research for gaining further knowledge of integrated coastal zone management, sustainability and potentiality of aquaculture.

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REFERENCES

Ahmed MJ, Haque MR, Ahsan A, Siraj S, Bhuiyan MHR, Bhattacharjee SC and Islam S (2010) Physicochemical assessment of surface and groundwater quality of the greater Chittagong region of Bangladesh. Pakistan Journal of Analytical and Environmental Chemistry 11(02): 1-11.

APHA (American Public Health Association) (2005) Standard methods for examination of water and wastewater. Eaton AD, Clesceri LS, Rice EW and Greenberg AE (eds), 21st edition, American Water Works Association, Water Pollution Control Federation, Wahington DC, New York. 1368 pp.

Balasubramanian R and Kannan L (2005) Physico-chemical characteristics of the coral reef Environs of the Gulf of Mannar Biosphere Reserve, India. International Journal of Ecology and Environmental Sciences 31: 265-271.

Barnes H (1959) Apparatus and Methods of Oceanography. Chemical Interscience Publishers Inc., New York Academic Press. 341 pp.

Behera BC, Mishra RR, Patra JK, Dutta SK and Thatoi HN (2014) Physico-chemical properties of Mahanadi river delta, Odisha, India. American Journal of Marine Science 2(1): 19-24.

BendschneiderK and Robinson RJ (1952) A new spectrophotometric method for the determination of nitrite in seawater. Journal of Marine Research 11: 87-96.

Choudhury SB and Panigraphy RC (1991) Seasonal distribution and behaviour of nutrients in the creek and coastal waters of Gopalpur, east coast of India. Mahasagar 24(2): 81-88.

Chowdhury SR, Hossain MS, Shamsuddoha M and Khan SMMH (2012) Coastal Fishers' Livelihood in Peril: Sea Surface Temperature and Tropical Cyclones in Bangladesh. CPRD, Dhaka, Bangladesh. 54 pp.

Das JSN and Sahoo RK (1997) Semidiurnal variation of some physicochemical parameters in the Mahanadi Estuary, East coast of India. Indian Journal of Marine Sciences 26: 323-326.

Desouza SN, Sengupta R, Sanzigiri S and Rajgopal MD (1981) Studies on Nutrients of Mandovi and Zuari River Systems. Indian Journal of Marine Sciences 10: 314-321. DOI: 10.1007/s10653-005-9001-5

Govindasamy C, Kannan L and Azariah J (2000) Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel coast, Indian Journal of Environmental Biology 21(1): 1-7.

Hänninen J, Vuorinen I, Helminen H, Kirkkala T and Lehtila K (2000) Trends and gradients in nutrient concentrations and loading in the Archipelago Sea, Northern Baltic, in 1970-1997. Estuarine, Coastal and Shelf Science 50(2): 153-171. DOI: 10.1006/ecss.1999.0568

Islam MN, Ahmed MJ, Hossain MA and Siraj S (2013) Physicochemical assessment of water pollutants due to the ship breaking activities and its impact on the coastal environment of Chittagong, Bangladesh. European Chemical Bulletin 2(12): 1053-1059.

Jackher GR and Rawat M (2003) Studies on physico-chemical parameters of a tropical lake, Jodhpur, Rajasthan, India. Journal of Aquatic Biology 18(2): 79-83.

Jorcin A (2000) Physical and Chemical characteristic of the sediment in the estuarine region of cananeia (SP), Brazil. Hydrobiologia 431(1): 59-67.

Kamal AHM and Khan MAA (2009) Coastal and estuarine resources of Bangladesh: management and conservation issues. Maejo International Journal of Science and Technology 3(2): 313-342.

Kamalkanth S, Muniyan M and Ponni AC (2012) Seasonal variations in physico-chemical parameters at Tranquebar coastal Nagapattinum, Tamilnadu, India. International Journal of Environmental Biology 2(4): 203-207.

Kathiravan K, Natesan U and Vishnunath R (2014) Spatio-temporal variability of hydro-chemical characteristics of coastal waters of Gulf of Mannar Marine Biosphere Reserve (GoMMBR), South India. Applied Water Science. DOI: 10.1007/s13201-014-0251-1

Kumar N, Kumar P, Basil G, Kumar RN, Kharrazi A and Avtar R (2015) Characterization and evaluation of hydrological processes responsible for spatiotemporal variation of surface water quality at Narmada estuarine region in Gujarat, India. Applied Water Science 5(3): 261-270. DOI: 10.1007/s13201-014-0187-5

Liu CW, Lin KH and Kuo YM (2003) Application of factor analysis in the assessment of ground water quality in a Blackfoot disease area in Taiwan. Science of the Total Environment 313(1-3): 77-89.

Mahmood N, Khan YSA and Kabir A (1976a) Preliminary observations on the hydrological conditions of the BOB off the coast on Bangladesh. Journal of the Asiatic Society of Bangladesh [Science] 1(2): 117-122.

Mahmood N, Khan YSA and Kabir A (1976b) Studies on the hydrology of the Karnaphuli estuary. Journal of the Asiatic Society of Bangladesh [Science] 2(1): 89-99.

Matthieu W, Ricardo DR and Pierre LC (2005) Seasonal variations of dissolved and particulate copper species in estuarine waters. Estuarine, Coastal and Shelf Science 62: 313-323.

Mokhtar MB, Aris AZ, Munusamy V and Praveena SM (2009) Assessment level of heavy metals in *Penaeus monodon* and *Oreochromis* spp in selected aquaculture ponds of high densities development area. European Journal of Scientific Research 30(3): 348-360.

Mullin JB and Riley JP (1955) The spectrophotometer determination of Silicate in the natural water with special reference to sea water. Analytica Chimica Acta 12: 162-176. DOI: 10.1016/S0003-2670(00)87825-3

Munisamy G, Ponnuchamy K,Selvaraj M, Rajina C (2011) Study on Physico-chemical Parameters along the coastal waters around Kudankulam nuclear power plant. International Journal of Oceans and Oceanography 5(1): 73-83.

Murphy J and Riley JP (1961) A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27(1): 31-36. DOI: 10.1016/S0003-2670(00)88444-5

Nair VR, Krishnamurti AJ and Gajbhiye SN (1999) Tropics structure and levels of selected metals in the zooplankton community of Thane-Bassein creek, Bombay. Indian Journal of Marine Sciences 28(2): 173-183.

Onojake MC, Sikoki FD, Omokheyeke O and Akpiri RU (2015) Surface water characteristics and trace metals level of the Bonny/New Calabar River Estuary, Niger Delta, Nigeria. Applied Water Science. DOI: 10.1007/s13201-015-0306-y

Paramasivam S and Kannan L (2005) Physico-chemical characteristics of Muthupettai mangrove environment, southeastern coast of India. International Journal of Ecology and Environmental Sciences 31: 273-278.

Praveena SM and Aris AZ (2013) A baseline study of tropical coastal water quality in Port Dickson, Strait of Malacca, Malaysia. Marine Pollution Bulletin 67: 196-199.

Raj VM, Sivakumar S and Padma S (2013) Comparative study near coastal zone of Muttukadu, Tamil Nadu, India. Journal of Environmental Biology 3(4): 147-150.

Rajasegar M (2003) Physicochemical characteristics of the vellar estuary in relation to shrimp farming. Journal of Environmental Biology 24(1):95 -101.

Raju C, Sridharan G, Mariappan P and Chelladurai G (2015) Physico-chemical parameters and Ichthyofauna diversity of Arasalar estuary in southeast coast of India. Applied Water Science. DOI: 10.1007/s13201-014-0260-0

Ravaniah G, Kumari PG and Murthy NCV (2010). Water quality analysis of the pennar estuary, Nellore. Journal of Current Science 15 (2): 321-334.

Reddi KR, Jayaraju N, Suriyakumar I and Sreenivas K (1993) Tidal fluctuation in relation in relation to certain physico-chemical parameters in Swarnamukhi river estuary: East coast of India. Indian Journal of Marine Sciences 22: 223-234.

Saravanakumar A, Rajkumar M, Sesh J and Thivakaran GA (2008) Seasonal variations in physic-chemical characteristics of water, sediment and soil texture in arid zone mangrove of Kachchh-Gujarat. Journal of Environmental Biology 29(5): 725-732.

Shoko AP, Limbu SM, Mrosso HDJ and Mgaya YD (2014) A comparison of diurnal dynamics of water quality parameters in Nile tilapia (*Oreochromis niloticus*, Linnaeus, 1758) monoculture and polyculture with African sharp tooth catfish (*Clarias gariepinus*, Burchell, 1822) in earthen ponds. International Aquatic Research 6(1): 56. DOI: 10.1007/s40071-014-0056-8

Singare PU, Mishra RM and Trivedi MP (2011) Assessing the Health of Sediment Ecosystem of Mithi River of Mumbai: Use of Physico-Chemical Measurements. Resources and Environment 1(1): 32-41.

Sridhar R, Thangarajan T, Kumar SS and Kannan L (2006) Water quality and phytoplankton characteristics in the Palk Bay, southeast coast of Indian Journal of Environmental Biology 27(3): 561-566.

Srilatha G, Thilagavathi B and Varadharajan D (2012) Studies on the physico-chemical status of muthupettai mangrove, south east coast of India. Advances in Applied Science Research 3(1): 201-207.

Sun L and Gui H (2015) Hydro-chemical evolution of groundwater and mixing between aquifers: a statistical approach based on major ions. Applied Water Science 5(1): 97-104. DOI: 10.1007/s13201-014-0169-7

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