Spatio-temporal assessment and trend analysis of surface water salinity in the coastal region of Bangladesh

Mashura Shammi[1,2], Md. Mostafizur Rahman[1,3*], Md. Atikul Islam[4], Md. Bodrud-Doza[1], Anwar Zahid[5], Yeasmin Akter[6], Samia Quaiyum[7], Masaaki Kurasaki[3]

[1]Department of Environmental Sciences, Jahangirnagar University, Dhaka-1342, Bangladesh

[2]Department of Environmental Pollution and Process Control, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi-830011, Xinjiang, PR China

[3]Graduate School of Environmental Science, Hokkaido University, Sapporo 060-0810, Japan

[4]Department of Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh

[5]Ground Water Hydrology, Bangladesh Water Development Board, 72 Green Road, Dhaka 1205, Bangladesh

[6]Department of Chemistry, University of Chittagong, Chittagong-4331, Bangladesh

[7] Dept. of Natural History and Science Faculty of Science, Hokkaido University, Sapporo, Japan

[*]Corresponding Author: rahmanmm@juniv.edu Graduate School of Environmental Science, Hokkaido University, Sapporo 060-0810, Japan

Abstract

The study was designed to collect water samples over two seasons- wet-monsoon season (n=96) (March-April) and dry-monsoon season (n=44) (September-October) to understand the seasonal variation in anion and cation hydrochemistry of the coastal rivers and estuaries contributing in the spatial trend in salinity. Hydrochemical examination of wet-monsoon season primarily revealed Ca–Mg–HCO_3 type (66%) and followed by Na–Cl type (17.70%) water. In the dry-monsoon season the scenario reversed with primary water being Na-Cl type (52.27%) followed by Ca–Mg–HCO_3 type (31.81%). Analysis of Cl/Br molar ratio vs. Cl (mg/L) depicted sampling area affected by seawater intrusion (SWI). Spatial analysis by Ordinary Kriging method confirmed approximately 77% sample in the dry-monsoon and 34% of the wet-monsoon season had shown SWI. The most saline intruded areas in the wet-monsoon seasons were extreme south-west coastal zone of Bangladesh, lower Meghna River floodplain and Meghna estuarine floodplain and South-eastern part of Chittagong coastal plains containing the districts of Chittagong and Cox's Bazar adjacent to Bay of Bengal. In addition, mid-south zone is also affected slightly in the dry-monsoon season. From the analyses of data, this study could further help to comprehend seasonal trends in the hydrochemistry and water quality of the coastal and estuarine rivers. In addition, it can help policy makers to obligate some important implications for the future initiatives taken for the management of land, water, fishery, agriculture and environment of coastal rivers and estuaries of Bangladesh.

Keywords: seawater intrusion (SWI), estuary**,** spatial salinity trend, non-parametric test, electric conductivity (EC), Na/Cl molar ratio, Cl/Br molar ratio.

1. Introduction

Coastal zones are transition environments, forming the interface between continent and ocean. The effects of human activity on coastal water resources usually reduce the flows of freshwater to estuaries; modifying estuarine mixing processes and extending marine influences further inland (Loitzenbauer and Mendes 2012). Bangladesh is considered as one of the most climate vulnerable countries in the world. In the southern part, it has approximately 710 km coastal line with highly susceptible areas to sea level rise. The coastal area in the southern part covers about 32% of total land area of the country (MoWR 2005) and are particularly vulnerable to climate change effects (Bhuiyan and Dutta 2012). Water salinity is regular hazards for many parts of southern Bangladesh. For example, Batiaghata Upazila, Khulna District in south-west coastal region of Bangladesh is the mostly saline affected area, where agriculture activities are mainly dependent on rainfall (Shammi et al. 2016). Previous study on groundwater in south-west part of Bangladesh confirmed the area was dominantly of Na–Cl type brackish water (Halim et al. 2010) due to the seawater influence and hydrogeochemical processes (Bahar and Reza 2010). Anthropogenic and bio-physical factors (e.g., upstream withdrawal of freshwater, cyclones) operating outside the geographical boundary of coastal region of Bangladesh contribute to increasing salinization in the southwest coastal area (Shameem et al. 2014).

Nevertheless, it is very difficult to get the actual scenario of hydrochemistry of the coastal river and estuaries due to dynamic mixing. Estuary provides a unique experimental site to understand the effect of monsoonal river discharge on freshwater and seawater mixing (Ghosh et al. 2013). The estuaries that are typically characterized by gradients of ionic strength, pH and concentrations of the suspended particulate matter; provide an ideal environment to study the nature and extent of solute-particle interaction, and the resultant modification of the elemental and isotopic fluxes from the rivers to the oceans (Samanta and Dalai 2016). Seawater intrusion (SWI) is a global issue (Werner et al. 2013) in coastal aquifers all over the world and predisposed to the influences of sea level rise and climate change. Surface water such as rivers and canals are impacted similarly by intruding seawater. Here, salinity refers to the total concentration of dissolved inorganic ions in water (Williams and Sherwood 1994) and often measured as electrical conductivity (EC) siemens/meter (Canedo-Arguelles et al. 2013). Temporal and spatial status of water salinity condition in Kumar-Modhumoti River in Gopalganj district showed that during the start of wet-monsoon months (March–April), the conductivity of river water was high due to low rainfall and upstream discharge. Conductivity ranged from 3.5 dS/m to 4.0 dS/m, while in the late wet-monsoon months (August−September), the conductivity of river water decreased (0.3–0.4 dS/m) (Shammi et al. 2012). Correlation of river discharge data of Gorai-Madhumati and conductivity of Madhumati River confirmed that salinity level was higher when upstream river inflow was below 500 m^3/S (Shammi et al. 2012).

In addition, trend analysis provides a view for meteorological, hydrological and climatological variables in past and future time's changes (Kisi and Ay 2014). The main idea of trend analysis is to detect whether values of data are increasing, decreasing or stable over time. Detection of trend is a complex subject because of characteristics of data (Kisi and Ay 2014). In general, there are different parametric and nonparametric statistical techniques to check the existence or absence of trend in time series analysis and climate change studies but the nonparametric methods are used relatively wider in hydro-meteorological studies (Takeuchi et al. 2003). Nonparametric methods are appropriate for the series that have a significant skew and cannot be fitted with statistical distributions (Niazi et al. 2014). Since then, many nonparametric statistical tests have been developed to determine trends in data series. Mann–Kendall (Mann 1945;

Kendall 1975) test is one of the best trend detecting methods. This method is suitable for the nonnormal and is not sensitive to observed values. This test has been recommended for detecting trends in environmental time series data by the World Meteorological Organization (Niazi et al. 2014). On the otherhand, the Sen's slope method (Sen 1968) uses a linear model to estimate the slope of the trend (Salmi et al. 2002) with the extent of magnitude at a satisfactory significant level.

It is important to determine the possible impacts of sea level rise on salinity to devise suitable adaptation and mitigation measures and reduce impacts of salinity intrusion in coastal cities (Bhuiyan and Dutta 2012). Nevertheless, till to date, there are no studies depicting the actual hydrochemistry related to the salinity condition in the coastal rivers and estuarine waters of Bangladesh. Therefore, this study was designed to collect water samples over two seasons- wet-monsoon season and dry-monsoon season, to understand the seasonal variation in anions and cations hydrochemistry of the coastal rivers and esutaries contributing in the spatial trend in salinity. The study was further trailed by time-series analysis of salinity data using Mann–Kendall and Sen's slope test for 13 south-west zone rivers to find salinity trend in of southern regions of Bangladesh followed by existing policy analysis for the management of salinity affected areas.

2. Landform and hydromorphological settings

Bangladesh occupies an area of 143,998 km^2 and has a subtropical humid climate. Geographically, it extends from 20°34′N to 26°38′N latitude and from 88°01′E to 92°41′E longitude. Except the hilly southeast, most of the country is a low-lying plain land (Shahid 2010). The topography of the region is rather flat, and gently sloping towards the Bay of Bengal (Bhuiyan and Dutta 2012). The original morphology and hydrogeology of many low-lying coastlands worldwide have been significantly modified over the last century through river diversion, embankment built-up, and large-scale land reclamation projects. This led to a progressive shifting of the groundwater–surface water exchanges from naturally to anthropogenically driven (Da Lio et al. 2015). Hydrology of the coastal plains of Bangladesh presents a complicated interaction of fresh water flow from the upstream, the tides and tidal flows from the Bay of Bengal, tropical cyclones, storm surge and other meteorological effect from the sea and the physiography of the coastal plains (FAO 1985). Understanding the mixing between salt/fresh surface water and groundwater in coastlands is an issue of paramount importance considering the ecological, cultural, and socio-economic relevance of the coastal plains (Da Lio et al. 2015). Low-lying parts of four regions further inland Ganges River floodplain, Old River floodplain comprising Arial Bil and Gopalganj Bil (low-lying lakes), lower Meghna River floodplain and Meghna estuarine floodplain lie sufficiently close to the coast that they could be affected by a rising sea-level at an early date (Brammer 2014a).

The physical geography of Bangladesh's coastal area is more diverse and dynamic than is generally recognised. Failure to recognise this has led to serious misconceptions about the potential impacts of a rising sea-level on Bangladesh with global warming (Brammer 2014b). Estuaries are a transition zone between continental and marine environments and record the complex interaction of these two discrete environments in terms of physical phenomena (e.g. mixing of fresh and saline water, tidal and wave action, sediment transport) and chemistry. They play an important role in understanding the continental input via rivers to the oceans (Ghosh et al. 2013). Sea salinity intrusion is a major concern in the southern part of the river system, as the rivers are affected by tides and is an important issue in these rivers. Most of the area is protected with polders against river flooding (Bhuiyan and Dutta 2012). The coastal zone is exposed to the risk of tropical cyclones in the wet-monsoon and dry-monsoon seasons, with the associated risk of storm surges in areas close to the coast (Brammer 2014b).

3. Methodology

3.1. Study area

The study area for surface water encompasses the coastal south part of the Bengal Basin. The sampling area were selected in the southern part of Bangladesh taking into account the south-east coastal zone to south-west zone of Bangladesh. Geographically, sampling points extended from 20°34'N to 23°40'N latitude and from 88°01'E to 92°41'E longitude (Figure 1). Most part of the sampling points lied on the Ganges and Meghna River and their many tributaries and distributaries except south-east part of Chittagong coastal plains and Bay of Bengal.

3.2. Description of the available data

A various multidisciplinary data are highly needed for the study of sea water intrusion (SWI) to provide reliable results (Trabelsi et al. 2016). Surface water samples were collected in 500 ml plastic bottle for two different seasons March-April 2012, wet-monsoon season (n=96) and September-October 2012, dry-monsoon (n=44) to broadly cover the seasonal variation following the standard guidelines (APHA, 1998). However, due to seasonal drying up of the rivers, similar points that were covered in the wet-monsoon season could not be covered in the dry-monsoon season due to inaccessibility by waterways. The chemical analysis was carried out following the procedure as described by Islam et al. (2016). The samples were collected followed by filtering through 0.45 μm membranes. Temperature (°C), pH, electrical conductivity (EC) and total dissolved solid (TDS) were measured in-situ by Portable Multi-Meter (Hach, sensION+

MM150). Chemical components such as EC, TDS, major cations and anions were used to identify seawater intrusion (Trabelsi et al. 2016).

Major anions such as chloride (Cl^-), nitrate (NO_3^-), sulfate (SO_4^{2-}), phosphate (PO_4^{3-}) and fluoride (F^-) were measured by ion chromatography. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) were determined by titration with HCl. Major cations, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+), were determined by using AAS (Varian 680FS). The trace elements, manganese (Mn), iron (Fe), boron (B), iodine (I), bromine (Br), and silicon dioxide (SiO_2) were determined by using Spectrophotometer (DR 2800). Overall data reproducibility for ions was within ±10 %. Cation and anion charge balance (<10 %) was an added proof for the precision of the data. Chemical analyses were carried out in Bangladesh Council of Scientific and Industrial Research (BCSIR) and Bangladesh University of Engineering and Technology (BUET) laboratory, Dhaka.

3.3. Geostatistical modelling of EC of the study area

To understand the area-wide distribution of salinity occurrences over two seasons in the study area ordinary Kriging (OK) method for spatial analysis of EC were adopted. The OK method, which is referred to as partial spatial estimation or interpolation, is a method to estimate the value of regionalized variables at unsampled location based on the available data of regionalized variables and structural features of a variogram (Webster and Oliver 2001). The OK estimates are determined by Eq. (i).

$$\hat{z}(x_0) = \sum_{i=1}^{n} \lambda_i z(x_i) \quad \ldots\ldots \text{(i)}$$

where $\hat{z}$ is the estimated value of an attribute at the point of interest x_0, z is the observed value at the sampled point x_i, λ_i is the weight assigned to the sampled point, and n represent the number of sampled points used for the estimation (Webster and Oliver 2001). The attribute is usually called the primary variable, especially in geostatistics. To ensure that the estimates are unbiased, the sum of the weights λ_i must be equal to one. The spatial distribution maps of EC and Na/Cl ratio in surface water was done by ArcGIS version 10.1.

3.4. Statistical analysis

Pearson Correlation matrix was performed with 2-tailed test of significance at standard α = 0.05. Principal component analysis (PCA) is one of the most commonly used multivariate statistical methods in natural sciences, which was developed by Hotelling (1933) in the thirties from original work of Pearson Correlation matrix (Jiang et al. 2015). The main objective of this method is to simplify data structure by reducing the dimension of the data (Jiang et al., 2015). Total 13 variables containing pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, CO_3^{2-}, HCO_3^{-}, NO_3^{-}, SO_4^{2-} and PO_4^{3-} were chosen for Correlation matrix and PCA analysis mainly because of their contribution to salinity and dominance in natural waters. The statistical analysis was done by Origin 9.0 software package of OriginLab (USA) and also used for subsequent calculations. After the application of PCA, a varimax normalized rotation was applied to minimize the variances of the factor loadings across variables for each factor. In this study, all principal factors with eigen values which are greater than 1 were taken into account. The first three factors were able to account for were.

3.5. Hydrochemistry analysis

To understand the hydrochemistry of the sampling water, GW Chart Software (USGS) was used and to classify water types in both seasons the Piper trilinear analysis was done *via* generating the Piper diagram (Piper 1953).

3.6. Historical Trend analysis by Mann-Kendall

The nonparametric MK test (Mann 1945; Kendall 1975) has been commonly used to assess the significance of monotonic trends in climatological, meteorological and hydrological data time series (Kisi and Ay 2014). The rank-based non-parametric Mann-Kendall method is adopted to study trends in the annual series. The choice of this method is based on the fact that it has the advantage of being less sensitive to outliers over the parametric method (Otache et al., 2008). The MK test statistic (S) is calculated in the following Eqs

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

… … …(ii)

$$sgn(x_j - x_i) = \begin{cases} +1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases}$$

… … …(iii)

Where, where x_i and x_j are the data values at times i and j, and n indicates the length of the data set. While a positive value of s indicates an increasing trend, negative of s indicates a decreasing trend. The following expression, as an assumption, is used for the series where the data length n>10 and data are approximately normally distributed (variance ($\sigma^2 = 1$) and mean (l = 0) value) .

$$Var\ (S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)}{18}$$

… … …(iv)

In this equation, P is the number of tied groups, and the summary sign (Σ) indicates the summation over all tied groups. t_i is the number of data values in the Pth group. If there are not the tied groups, this summary process can be ignored. After the calculation of the variance of time series data with Eq. (ii), the standard Z value is calculated according to the following Eq. (v).

$$Z = \begin{cases} \frac{s-1}{\sqrt{var(s)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{s-1}{\sqrt{var(s)}}, & if\ S < 0 \end{cases}$$

… … …(v)

The calculated standard Z value is compared with the standard normal distribution table with two-tailed confidence levels (α = 10%, α = 5% and α = 1%). If the calculated Z is greater |Z| > $|Z_{1-\alpha}|$, then the null hypothesis (H0) is invalid. Therefore, the trend is statistically significant. Otherwise, the H0 hypothesis is accepted that the trend is not statistically significant, and there is no trend in the time series (trendless time series) (Kisi and Ay 2014).

3.7. Trend analysis by Sen's Test

True slope in time series data (change per unit time) is estimated by procedure described by Sen (1968) in case the trend is linear. The method requires a time series of equally spaced data (Shahid 2010). The magnitude of trend is predicted by the Sen's slope estimator (Q_i). The magnitude of trend is predicted by the Sen's slope estimator (Qi).

$$(Q_i) = \frac{x_j - x_k}{J - K}$$

For i=1, 2, …..N… … …(vi)

Where, x_j and x_k are data values at times j and k (j > k) respectively. The median of these N values of Q_i is represented as Sen's estimator. $Q_{med} = \frac{Q(N+1)}{2}$ if N is odd, And $Q_{med} = \left[\frac{QN}{2} + \frac{Q(N+2)}{2}\right]/2$ if N is even. Positive value of Q_i indicates an increasing trend and negative value of Q_i shows decreasing trend in time series.

3.8. Toolkit used for Mann-Kendall and Sen's slope test

To investigate the salinity trend of coastal rivers of Bangladesh annual data series of 13 rivers of Gorai-Madhumati River networks were taken into justification. Average salinity data of each months EC data were calculated following the annual average of the calender year (2004-2011). Missing value were calculated using interpolation techniques. To analyse historical trend of river salinity, two freeware tool kits were used. One is GSI Mann-Kendall excel tool kit developed by GSI Environmental Inc. based on the methodology of Aziz et al (2003) and was used for constituent salinity trend analysis of the southern rivers of Bangladesh over a period of times. Annual average value was calculated from the monthly data of the rivers. The Mann-Kendall test for trend analysis, as coded in GSI Toolkit, relies on three statistical metrics (Aziz et al. 2003): The 'S' Statistic: Indicates whether concentration trend of salinity vs. time is generally decreasing (negative S value) or increasing (positive S value). The Confidence Factor (CF): The CF value modifies the S Statistic calculation to indicate the degree of confidence in the trend result, as in 'Decreasing" vs. "Probably Decreasing" or "Increasing" vs. "Probably Increasing." Additionally, if the confidence factor is quite low, due either to considerable variability in concentrations vs. time or little change in concentrations vs. time, the CF is used to apply a preliminary "No Trend" classification, pending consideration of the Coefficient of Variation (COV). The COV is used to distinguish between a "No Trend" result (significant scatter in concentration trend vs. time) and a "Stable" result (limited variability in concentration vs. time) for datasets with no significant increasing or decreasing trend (e.g. low CF). 2nd toolkit used in this study was the MAKESENS 1.0 Excel template freeware program developed by Finnish Meteorological Institute, Helsinki, Finland (Salmi et al. 2002). Mann–Kendall test and Sen's slope estimating trends in the time series of annual values were calculated following equations described in section 3.5 and 3.6.

4. Results

4.1. Physico-chemical properties of coastal rivers and estuarine waters in the study area

Summary of the hydro-chemical properties of coastal rivers and estuarine waters collected from of the study areas during wet-monsoon and dry-monsoon period are given in Table 1. It is revealed from the table that wide ranges and large standard deviations were observed for most parameters, indicating chemical composition of coastal river water was affected by various processes. During wet-monsoon pH of the water ranged from minimum 6.20 to maximum 8.24 with an average value of 7.72±0.58. The dry-monsoon pH value ranged from a minimum of 7.20 to maximum of 11.00 with an average value of 8.24±0.82. These results suggested that during wet-monsoon the water was slightly acidic to slightly alkaline, while during dry-monsoon the water pH fell in neutral to more alkaline. Nevertheless, the average pH revealed that the water was overall slightly alkaline in both seasons due to the variation of mixing river water and seawater, which was typical to estuary. However, to this date there are no previous reports on downstream estuarine river condition in Bangladesh.

The ocean's influence on continental waters can be monitored by their salinity, since where this influence is greater, so is the salinity. Similarly, the effects of freshwater discharged from hydrographic basins can be observed in the ocean in terms of reduced salinity through dilution (Loitzenbauer and Mendes, 2012). EC values during wet-monsoon and dry-monsoon range from 65.90 to 34,800 µS/cm with an average value of 2,168.59±5,753.56 µS/cm and 228 to 57,300 µS/cm with an average value of 11083.27±17573.81 µS/cm. EC is directly related to the values of TDS in both seasons. TDS values varied from the minimum value of 25.20 to the maximum value of 18,440 mg/L in wet-monsoon season. On the other hand in dry-monsoon the value varied from 114 mg/L to 28600 mg/L with an average value of 5,716±8,921.83 mg/L. To mention here, 15 samples which had exceeded the value of TDS>1,000 mg/L indicating brackish sea water in the wet-monsoon season of which 4 samples were actually from the Bay of Bengal. On the other hand, in dry-monsoon season approximately 56% sample had exceeded the value of TDS > 1,000 mg/L indicating brackish sea water, of which 5 were from Bay of Bengal. While in the wet-monsoon season the contribution of TDS and EC was from seawater, in the dry-monsoon season it was due to the heavy river discharge carrying sediments and industrial pollutants from upstream and mixing with brackish seawater.

An understanding of salinity dynamics can be useful in the management of coastal water resources and for assessing possible limitations their used through salt penetration (Loitzenbauer and Mendes 2012). Therefore, on a spatial basis (Figure 2), the distribution of the EC values showed variable trends over the south regions. Based on the spatial map (a) the most saline intruded areas (sample n=96) can be listed in the wet-monsoon seasons are- (i) extreme south-west coastal zone of Bangladesh including the distrcts of Khulna, Satkhira, Bagerhat, Jessore and Gopalganj; (ii) lower Meghna River floodplain and Meghna estuarine floodplain comprising the districts of Bhola, Noakhali and Feni and (iii) south-east part of Chittagong coastal plains containing the districts of Chittagong and Cox's Bazar near Bay of Bengal; and (b)The little affected mid-south zone particularly Barisal, Jhalkathi, Patuakhali and Barguna. In the dry-monsoon season (Figure 2b), out of 44 samples, the extreme south-west districts data were not collected, except Gopalganj district. From the spatial data analysis (Figure 2b), it is witnessed that in the dry season the district was affected by salinity. The above mentioned lower Meghna River floodplain and Meghna estuarine floodplain comprising the districts of Bhola, Noakhali and Feni and South-east part of Chittagong coastal plains containing the districts of Chittagong and Cox's Bazar near Bay of Bengal showed higher salinity concentration than that was in the wet-monsoon season. Even mid-south zone particularly Barisal, Jhalkathi, Patuakhali, Pirojpur and Barguna have been found to be affected.

In principle, salinity can refer to any inorganic ions, while in practise it is mostly the result of the following major ions: Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{2-} , and HCO_3^{-} (Williams 1987). River water of the study area was clearly dominated by Na^{+}, Mg^{2+}, Ca^{2+}, Cl^{-}, HCO_3^{-}, and SO_4^{2-}during both of the seasons. During wet-monsoon and dry-monsoon seasons approximately 68.63% and 82.9% of the total cations and anions contributing to salinity were from Cl^{-} which is prevalent from the pie chart analysis (Figure 3a-b). In the wet-monsoon season the orders of salinity contributing anions and cations were in the order of $Cl^{-}>HCO_3^{-}> SO_4^{2-}>Na^{+} > Ca^{2+}>Mg^{2+}>CO_3^{2-}$. In the dry- monsoon season the order was $Cl^{-}>Na^{+}> SO_4^{2-}>HCO_3^{-}>Ca^{2+}> K^{+}>Mg^{2+}>CO_3^{2-}$. Increased load of Cl^{-}, Na^{+}, SO_4^{2-}, HCO_3^{-} in the dry-monsoon season may depict the opposite view due to landward movement of seawater. With respect to TDS and EC samples of wet-monsoon and dry-monsoon seasons had shown the abundance of the major ions is in the following order: $Na^{+}> Ca^{2+}> K^{+}> Mg^{2+}$ and $Cl^{-}> SO_4^{2-}> HCO_3^{-}> NO_3^{-}> CO_3^{2-}$. The severe anions and cations variation in the dry-monsoon season may be attributed to the reduction of flows of freshwater through increased upstream abstraction and increases of intrusion from sea to land. The greater the penetration of marine influence into the land, the lower is the availability of freshwater, which becomes brackish through its mixture with saline waters (Loitzenbauer and Mendes 2012).

It was observed from the sample analysis that mean value of NO_3^- varied with the season from 0.1 mg/L to 43 mg/L in wet-monsoon season and 0.09 mg/L to 6.95 mg/L in the dry monsoon season. The reason for seasonal nitrogen variation may be attributed to the nonpoint run off of agricultural input of fertilizers and pesticides. Rainfall-runoff increased NO_3^- load in the wet-monsoon season while in dry-monsoon the load was reduced. Variation of PO_4^{3-} remained identical in both seasons with an average value of 0.31±0.80 mg/L. In addition, fluoride, iodide and bromide all three anions were found to be higher in wet-monsoon season. In the wet-monsoon season concentration of fluoride, iodide and bromide varied from minimum 0 mg/L to 3.51 mg/L, 0 to 20.35 mg/L and 0 to 12.66 mg/L, respectively. Moreover, in the dry-monsoon season the values of fluoride, iodide and bromide varied from 0 to 2.43 mg/L, 0.02 to 3.55 mg/L and 0 to 2.24 mg/L respectively. Likewise all other anions and cations concentration, there was colossal deviation of Fe concentration in both seasons. Concentration of Fe varied from a minimum value of 0.05 to maximum value of 52.3 in the wet-monsoon season. While in the dry monsoon season the minimum value started at 0.02 mg/L to maximum value of 37.60 mg/L. Correspondingly B and Mn concentration in the wet-monsoon season accounted for 0.28 mg/L and 0.14 mg/L on an average, whereas in dry-monsoon season the values accounted for 0.51 mg/L and 0.70 mg/L, respectively. The rise in the metal concentration might be related to the upstream sediment carrying the metals rising in the dry-monsoon.

To find out more on the interrelations among various anions and cations in respect to EC and TDS, Pearson's correlation matrix was prepared for wet-monsoon season (Table 2) and dry-monsoon season (Table 3) taking into account of 13 hydrochemical variables including pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, CO_3^{2-}, HCO_3^-, NO_3^-, SO_4^{2-} and PO_4^{3-}. According to Table 2, statistically positive significant correlations were found between EC and TDS (r = 0.99).

Subsequently, TDS and EC showed strong significant correlation with K^+(r= 96 and 97), Cl^- (r=99 and 99) and SO_4^{2-} (r=95 and 96). Other strong correlation that were observed from the matrix were K^+ and Cl^- (r=97) and K^+ and SO_4^{2-}(r= 0.96). Moreover, Mg^{2+}, Ca^{2+}, Na^+, K^+, Cl^-, $CO_3{}^{2-}$ and SO_4^{2-} all had shown a weak but significant correlation with EC and TDS. The results may be attributed to the high salinity nature of coastal river water along with precipitation and heavy discharge from upstream. In addition, pH was negatively correlated with Mg^{2+} and CO_3^{2-} anion. Likewise in the dry-monsoon season **s**tatistically positive significant correlations were found between EC and TDS (r = 0.99) (Table 3). Successively, TDS and EC showed strong significant correlation with Cl^- (r=99) and K^+ (r= 96 and 97). Mg^{2+}, Ca^{2+}, Na^+, K^+, Cl^-, HCO_3^- and SO_4^{2-} all showed weak but significant correlation with EC and TDS. This was further confirmed by Principle component analysis (PCA) (Table 4, Figure 4a-b)**.**

PCA is a multivariate statistical method complementary to classical approaches of hydrogeochemical research (Morell et al. 1996). PCA provides a quick visualization and shows correlation among different water quality variables. PCA was applied by considering 13 variables containing pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, $CO_3{}^{2-}$, HCO_3^-, NO_3^-, SO_4^{2-} and PO_4^{3-}. For wet monsoon season PCA on the combined datasets provided three factors with eigen value>1 that can explain approximately 67.84% of the variability of the data (PC 1 variance of 42.11% and PC 2 variance of 15.37%) (Table 4). From the biplot analysis of PCA, when two variables are far from the centre and close to each other, then the variables are said to be significantly and positively correlated (r=1). In the wet-monsoon season coefficients of PC1 which were related to the salinity of the river water closely related to EC, TDS, Cl^-, K^+ and SO_4^{2-} (Figure 4a). PC 2 which might be related to the inorganic carbon content of the river HCO_3^- and CO_3^{2-} in a weak relation to Na^+, Mg^{2+} and Ca^{2+}. On the other hand, for dry-monsoon season PCA on the combined datasets provided four factors with eigenvalue >1 that could explain approximately 54.97% of the variability of the data (PC 1 variance of 38.40% and PC 2 variance of 16.58%) (Table 4). From the biplot analysis of PCA in dry-monsoon season, coefficients of PC1 was related to the salinity of the river water unlike wet-monsoon season. The closely related variables of EC and TDS to Cl^- and K^+ are shown in Figure 4(b). However, unlike PCA of wet-monsoon season it was challenging to find out the second set of component (PC 2) as there was not any strong relationship among the variables to support the assumptions.

4.2. Seasonal hydrochemistry of the coastal rivers of Bangladesh

The concentrations of major ions measured in the surface water samples are presented in the Piper Trilinear plot (Figure 5a-b). The high variability in major ion chemistry and their seasonal variations are shown in the analysis of two seasons. For the study area in the wet-monsoon season approximately 66 % of samples were Ca–Mg–HCO_3 and occupied the section of the diamond shape in the Piper diagram and their chemical properties dominated by alkaline earths and weak acids (Figure 5a). Second dominant category was Na–Cl type occupying 17.70% of the sample clustered near the right corner of the central diamond. These waters were from the contribution of seawater (Figure 5a). 5.20% sample fell in the category of Ca-Cl type water while 9.3% fell in mixed Na–Ca–Mg–HCO3–Cl type water probably evolved from silicate weathering or ion exchange process due to mixing of upstream water discharge and seawater (Karanth 1994). In the wet-monsoon season Ca–Mg–HCO_3 dominated in river water due to the discharge being dominated from upstream pushing off the Na–Cl type seawater towards south (Figure 5a).

Major river water in the dry-monsoon season fell into the category of Na-Cl type (52.27%) followed by Ca–Mg–HCO_3 type (31.81%) (Figure 5b). A small fraction of sample fell in the category of Ca-Cl and mixed type. In the dry-monsoon season Na–Cl type sea-water dominates over Ca–Mg–HCO_3 type due to limited river water discharge from upstream and pushing the salinity front towards north.

4.3. Analysis of molar ratio to identify seawater intrusion

Constant records of pre and dry-monsoon hydrochemistry are important to study the coastal river water salinity and its fluctuation trends. Moreover ionic ratios reveal information about processes in water bodies more visibly than concentrations (Siebert et al. 2014). In this paper Cl/Br molar ratio, Na/Cl molar ratio, K/Cl molar ratio, Mg/Ca molar ratio were used to distinguish seawater intrusion. The Cl/Br molar ratio can be obtained by multiplying mass ratio by 2.254. The variation in Cl/Br molar ratio in sea water is about 290±4 (Katz et al. 2011). A Cl/Br molar ratio vs. Cl (mg/L) depicts the sample affected by seawater intrusion (Figure 6). Approximately 77% sample in the dry-monsoon had crossed the Cl/Br molar ratio of sea water at 290 compared to the wet-monsoon season affected by approximately 34% sample. From Figure 6 it is clear that seawater was affecting the salinity trend of the river water more in dry-monsoon compared to the wet-monsoon season. In the wet-monsoon season Na/Cl molar ratio varied from minimum value of 0 to 39.42 with average value 1.28±4.09. On the other hand, dry-monsoon season it varied from 0.01 to 3.83 with average value 0.76±0.75 (Table 5). Approximately 23% sample collected in the wet-monsoon season and 40% sample collected in the dry-monsoon had Na/Cl ratio above 0.86 indicating seawater intrusions. The spatial distribution of Na/Cl ratio for both seasons is depicted in Figures 7a-b by utilizing ordinary kriging (OK) method. It was clear from the spatial distribution map that dry-monsoon season was highly saline affected in the common sampling points in the sapling point areas. Moreover, from Br/Cl molar ratio, it was found that in the wet-monsoon season approximately 62% and in dry-monsoon approximately 90% sample had molar ratio above >0.0015 (Table 5). In wet-monsoon season Mg/Ca molar ratio varied from minimum value of 0.001 to 32.36 with an average value of 1.69 while in dry-monsoon season it varied from 0.08 to 93.66 with an average value of 4.37. However, only 3 samples in wet-monsoon and dry-monsoon seasons had shown Mg/Ca molar ratio >5. Therefore, from the above data analysis it was perceived that the existence of seasonal variation in anions and cations over time in respect to salinity occurrences due to seawater intrusion and low upstream water flow in the river.

4.4. Fluctuation of salinity trends in the coastal rivers of Bangladesh

Understanding the dynamics of salinity gives a useful instrument for environmental monitoring in an estuarine zone (Loitzenbauer and Mendes 2012). Therefore, it is also very important to understand annual trends of time-series data of salinity in the rivers. In this context, trends of salinity variation are very important for the surface water quality of coastal Bangladesh which was investigated by traditional hydrochemistry parameter electrical conductivity (EC) data of different rivers using Mann–Kendall and Sen's slope test statistics. The results obtained from the Mann-Kendall test was used to establish the trends in time series of annual salinity trends in the 13 river stations belonging to the Gorai River network of south-west zone of Bangladesh whether they were increasing, decreasing, stable or trendless over time. Sen's slope test was also used to identify the significant level of increasing or decreasing trend and a comparison of their value is presented in Table 6.

Findings from Mann-Kendall test also obtained the annual trend of salinity rising in the Madhumati River significantly (confidence factor 98.9%). Other rivers which showed increasing trend of salinity are Rupsa River, Khulna; Kakshiali River, Satkhira; Morichan River, Satkhira;

and Shibsha River, Khulna with confidence factor 96.9− 99.9%. The result is also in agreement with the spatial analysis of EC (Figure 2). Similar result of increasing salinity trend has been found in the MAKESENS tool kit for Madhumati River at 0.1 level of significance; Kakshiali River, Satkhira at 0.001 level of significance; Morichan River, Satkhira at 0.01 level of significance and Shibsha river, Khulna at 0.05 level of significance (Table 6). However, one river Panguchi River, Bagerhat found to be decreasing in salinity trend in both tool kit analyses at 0.1 level of significance in MAKESENS and 98.9% confidence factor in GSI toolkit analysis. Two rivers Pasur River, Bagerhat and Vadra River, Khulna showed "Probably increasing" trend with confidence interval 91.1% and 94.6%, respectively in GSI tool kit analysis. Although seasonal variations in the EC was found higher during trend analysis, overall annual analysis of the salinity trend was found to be "stable" over time for Kapotaksha River, Satkhira. Moreover, five rivers showed "no trend" in the analysis. The rivers are Daratana River, Bagerhat; Shailmari River, Khulna; Betna River, Satkhira; Kazibachha River, Khulna and Shibsha Rivers, Khulna. The causes of the variability in salinity trends in the above mentioned rivers are likely related to the local hydrogeologic condition, tidal effects from the Bay of Bengal, local rainfall-runoff condition, and climatic events. Besides these extreme western parts of rivers are actually parts of the moribund Ganges Delta.

5. Discussions

It is evident from our result that there is a marked seasonal variation exists in the hydrochemistry of coastal rivers in Bangladesh. There is a significant variation in anions and cations contributing to the salinity variation may be associated to at the Ganges-Brahmaputra-Meghna (GBM) River discharge as well as inland rainfall-runoff. Seasonal variation of anions and cations were significantly marked from the results. It was particularly evident in the nitrate variation in the surface water. In Bangladesh the rainfed aman rice cultivation is widespread along the coastal areas (Shelley et al. 2016). It was apparent that wet-monsoon season NO_3^- indicated agricultural source and fertilizers application of transplanted aman (t. aman) production. NO_3^- containing fertilizer such as urea is applied 24 kg/3330m² in t. aman production (FAO 2017). Seeding time of aman rice is between March and April and transplanted between July and August during wet-monsoon period. The crop is harvested from November through December (Shelley et al. 2016) during the start of dry-monsoon period.

The up scaled monthly discharge of GBM river mouths produced for oceanographic investigations exhibited a marked seasonal and inter annual variability (Papa et al. 2012). The impact of Farakka Dam on the Lower Ganges River flow was calculated by comparing threshold parameters for the pre-Farakka period (from 1934 to 1974) and the post-Farakka period (1975–2005). In a normal hydrological cycle, rivers in Bangladesh suffer from low flow conditions when there is no appreciable rainfall runoff. The discharge of river is 80,684 m^3/s during the flood or wet-monsoon season while during the dry-monsoon season when the inflow is very low, discharge can be as low as 6041 m^3/s (Ahmed and Alam 1999). The results demonstrate that due to water diversion by the Farakka Dam, various threshold parameters, including the monthly mean of the dry season (December–May) and yearly minimum flows have been altered significantly. The ecological consequences of such hydrologic alterations include the increase of salinity in the southwest coastal region of Bangladesh (Gain and Giupponi 2014).

This further validates the seasonal shifting of Na-Cl dominated salinity front and molar ratio of Na/Cl, Br/Cl Mg/Ca. Seawater has distinct ionic and isotopic ratios such as Na/Cl=0.86, Br/Cl=0.0015, Mg/Ca=5.2 (Vengosh et al. 1999; Vengosh and Rosenthal 1994). A Na/Cl ratio of 0.86 was thought to indicate sea water intrusion (Bear et al. 1999). The Na/Cl molar ratio could reach unity due to the mixing of seawater and freshwater, which had a Na/Cl ratio greater than unity (Vengosh and Rosenthal 1994). Mg/Ca molar ratio greater than 5 is a direct indicator of seawater intrusion (Vengosh and Ben-Zvi 1994). Significant variation was observed during wet-monsoon season and dry-monsoon season from the molar ratio study of Na/Cl, Br/Cl Mg/Ca indicating seawater intrusion. Chloride and bromide ions have been used to differentiate among various sources of anthropogenic and naturally occurring contaminants in groundwater (Katz et al. 2011). The elements in the estuaries are typically assessed by making plots of their dissolved concentrations vs. salinity. Several elements are removed from the dissolved phase whereas some elements are also released from the suspended particles (Samanta and Dalai 2016). In the present study significant changes in the values of Cl/Br molar ratio, Na/Cl molar ratio, K/Cl molar ratio, Mg/Ca molar ratio in the dry-monsoon compared to the wet-monsoon season indicate saline water intrusion in the coastal rivers. To support the scenario a similar seasonal changes in $\delta^{18}O$ from Hooghly Estuary (India) was observed. The study had identified low salinity and depleted $\delta^{18}O$ during monsoon was consistent with increased river discharge as well as high rainfall. This was driven by composition of the freshwater source which was dominated by rainwater during monsoon and rivers during non-monsoon months (Ghosh et al. 2013). Furthermore, presence of seawater was found maximum (31–37%) during February till July and lowest (less than or equal to 6%) from September till November. A temporal offset between Ganges River discharge farther upstream at Farakka and salinity variation at the Hooghly Estuary was observed (Ghosh et al. 2013). Similar situation has been observed from the seasonal changes in hydrochemistry of anions, cations, Na-Cl dominated salinity front and molar ratio study of different anions and cations.

The results obtained from the Mann-Kendall and Sen's slope test (Table 4) along with spatial analysis of EC (Figure 2) established the trends in time series of annual trend of salinity rising in the Gorai-Madhumati River network. These results are in agreement with the previous hydrodynamic modelling studies of Bhuiyan and Dutta (2012) and temporal and spatial analysis of salinity occurrences in Kumar-Madhumati River by the study of Shammi et al. (2012). Madhumati River is actually within the network of Gorai-Madhumati. Dry-season flow in the Gorai-Madhumati, the main river carrying fresh water into western parts of the region, has decreased over time. That was mainly due to reduced flow from the Ganges river into the Gorai following construction of the Farakka barrage across the Ganges in India in 1975, but abstraction of river water and groundwater for dry-season irrigation on the Ganges River Floodplain (Region D) through which the Gorai-Madhumati passes has also reduced river flow (Brammer 2014a). Due to the reduced flow of the rivers in this area in dry season, salinity intrudes into the river systems (Bhuiyan and Dutta 2012).

According to Brammer (2014b), in the moribund Ganges delta, rivers have been cut off from the Ganges for several centuries, making conditions in the extreme south-west region of Bangladesh naturally saline in the dry season. Similar scenario has been observed from spatial distribution of EC analysis from Figure 2 which is in agreement with the time series analysis. Immediately adjacent to the Meghna River estuary and the Ganges Tidal Floodplain are five low-lying regions/subregions (Ganges River floodplain, Gopalganj Bils, lower Meghna River floodplain, and two sub regions of Meghna Estuarine floodplains in low and western outliers) might be affected by a rising sea-level as early as the coastal regions. These regions/subregions include a wide diversity of environmental conditions that need to be taken into account in assessing potential impacts of sea-level rise and in considering appropriate mitigation measures (Brammer

2014b). A salinity flux model integrated with an existing hydrodynamic model was applied in order to simulate flood and salinity in the complex waterways in the coastal zone of Gorai river basin with sea level rise (SLR) scenario (Bhuiyan and Dutta 2012). The results of salinity model obtained had indicated the risk and changes in salinity due to sea level rise with increased river salinity as well as the salinity intrusion length in the river. Sea level rise of 59 cm produced a change of 0.9 ppt at a distance of 80 km upstream of river mouth, corresponding to a climatic effect of 1.5 ppt per meter SLR (Bhuiyan and Dutta 2012). The SLR depends not only on changes in the mass and volume of sea water but also on other factors, such as local subsidence, river discharge, sediment and the effects of vegetation (Lee 2013). Moreover, the SLR trend obtained from ensemble empirical mode decomposition (EEMD) was 4.46 mm/yr over April 1990 to March 2009, which was larger than the recent altimetry-based global rate of 3.360.4 mm/yr over the period from 1993 to 2007 (Lee 2013). It is, therefore, important to determine the impacts of SLR on salinity to devise suitable adaptation and mitigation measures and reduce impacts of salinity intrusion in coastal cities (Bhuiyan and Dutta 2012).

The progressive inland movement of the dry-season salt-water limit in south-western rivers has had adverse impacts on soil salinity, crop production and availability of potable domestic water supplies in affected areas (Brammer 2014b). Increased salinity possesses a risk of secondary soil salinization. Secondary soil salinization occurs when surface soil salinity has increased from non-saline to a saline level as a consequence of irrigation or other agricultural practices (Peck and Hatton 2003). The seasonal variation of using drinking water sources in the study area is influenced by the monsoonal precipitation and the success of tube well installation factors (Sarkar and Vogt 2015). Increased salinity of drinking water is likely to have a range of health effects, including increased hypertension rates. Large numbers of pregnant women in the coastal areas are being diagnosed with pre-eclampsia, eclampsia, and hyper tension (Khan et al. 2008). The main drinking water sources used in the study area are the tube well, with an average depth of 200 m, and pond, with or without the adjacent filtration facility known as PSF (pond sand filter) (Sarkar and Vogt 2015).

Nevertheless, the coastal area of the country is known as one of the highly productive areas of the world (Afroz and Alam 2013). With increasing levels of salinity in the land and freshwater resources, the brackish water aquaculture flourished rapidly on agricultural land. The change in land-use from agriculture to brackish water shrimp aquaculture has further increased the soil and water salinization across the landscape (Shameem et al. 2014). Salinity increases may affect survival of some mangroves and wetland plants, especially in dry season (Suen and Lai 2013). Integrated Coastal Zone Management (ICZM) involves an integrated planning process to address the complex management issues in the coastal area of Bangladesh (Afroz and Alam 2013). It is a blueprint for sustainable coastal development (Afroz and Alam 2013) which is made up of three broad categories of integration: (i) policy integration, (ii) functional integration and (iii) system integration (Thia-Eng 1993). Despite increasing recognition of the need for ICZM strategies, the initiation of the Coastal Zone Policy and ICZM has not contributed any significant improvement in the coastal areas (Rahman and Rahman 2015) of Bangladesh. Introduction of advanced coastal protection models must incorporate the complexity of natural environmental variation, including the influence of both the biotic and abiotic ecosystem (Spalding et al. 2014). A model should be synthesized to optimize conjunctive uses of the water in the affected area based on two questions: "Which water resources to use?" and "When to use which water source?" for the best management of water resources. Introducing water resources information system aims to build a data-bank of water resources and factors influencing their management (Loitzenbauer and

Mendes 2012). This data bank will provide information of existing and potential water resources for optimum uses of water without compromising the quality of water.

The salinity balance of each coastal river basins, including that of the Ganges, Gorai-Madhumati, Meghna, Karnafuli and other river networks should form part of this data-bank, together with the results from modeling the salinity distribution which requires regular trend analysis to combat not only salinity intrusion in the coastal areas but may help to combat other problems including, agricultural-non-point nutrient pollution, hypoxia, eutrophication, sewage pollution, industrial pollution and other problems. It is important to understand and communicate the economic, environmental and social costs of river salinization in order to guide management and restoration efforts. Impacts need to be anticipated and mitigated, and future scenarios of climate change and increasing water demand have to be integrated into the ecological impact assessment (Canedo-Arguelles et al. 2013). Consequently, for sustaining the ecosystem integrity of coastal rivers and estuaries, it is very important to restore and maintain minimum environmental flow assessment (EFA) of the major shared rivers with India. In the “Bangladesh: National Programme of Action for Protection of the Coastal and Marine Environment from Land-Based Activities” (DoE/MOEF/GOB 2006) strategy 5 clearly stated assessment of environmental flow requirement and salinity intrusion in the Integrated Coastal Zone Management Plan (ICZMP). In this regard a complete regional water management plan for the Ganges-Brahmaputra-Meghna catchment area is needed along with minimum EFA in the lower estuarine and coastal regions of Bangladesh to maintain ecological integrity of the region. However, to-date, India has not prepared any EFA of the joint rivers to support such a plan or to share hydrological data with Bangladesh (Brammer 2004). Moreover, this plan should be carried out with other countries of shared river including Nepal and China.

6. Conclusions and remarks

Trend analysis is one of the most important issues in any regional hydrological variables taking into account the spatial and temporal variable and providing result for present conditions and future scenario from past data analysis. In this context, spatial records of wet- and dry-monsoon salinity levels in the southern coastal rivers and estuary are important to study the level of salinity fluctuation trends of coastal areas of Bangladesh. The differences between wet- and dry-monsoon salinity levels, represents the combined effect of salinity scenario in the southern region. The results obtained from the historical trend analysis by Mann-Kendall test and Sen's slope was used to establish the trends in time series. In this framework, the conclusions and remarks, which can be significant from this study, are:

a) EC and TDS is the principal component of salinity along with K^+, Cl^- and SO_4^{2-} as observed from both wet-monsoon and dry-monsoon seasonal analysis in relation to the other anions and cations. Moreover, on a spatial basis the distribution of the EC values showed variable trends over the south regions. The most saline intruded areas in the wet-monsoon season is

(i) Extreme south-west coastal zone of Bangladesh comprising the distrcts of Khulna, Satkhira, Bagerhat, Jessore and Gopalganj;

(ii) Lower Meghna River floodplain and Meghna estuarine floodplain comprising the districts of Bhola, Noakhali and Feni;

(iii) South-east part of Chittagong coastal plains containing the districts of Chittagong and Cox's Bazar near Bay of Bengal;

(iv) The little affected mid-south zone particularly Barisal, Jhalkathi, Patuakhali and Barguna which are also being affected in the dry-monsoon season

b) From the hydrochemistry analysis of piper diagram in the wet-monsoon season approximately 66% of samples were Ca–Mg–HCO_3 type and second prevailing category was Na–Cl type subjugating 17.70% samples. In the dry-monsoon season foremost water type fell into the category of Na-Cl type (52.27%) followed by Ca–Mg–HCO_3 type (31.81%).

c) Seawater intrusion was also confirmed by calculated ionic ratios. It was found from Cl/Br molar ratio vs. Cl^- that about 42.7% of the collected sample water was affected by salinity in wet-monsoon season compared to the 27% collected in dry-monsoon. Moreover roughly 33.33% sample collected in the wet-monsoon season and 38.63% sample collected in the dry-monsoon had Na/Cl ratio above 0.86 indicating sea-water-intrusion.

d) From Mann-Kendall and Sen's slope test analysis it was prevalent that among the 13 river time series analysis of salinity trend, four rivers had shown significantly increasing trend of salinity in the extreme south-west zone of Bangladesh. This also signify the future work analysis of other major rivers affected by salinity particularly in other major rivers particularly in Meghna river estuary and eastern Chittagong coastal plains zones. These outcomes deliver the following perceptions for future mechanisms.

On equilibrium, the result of this study proves the extent of seawater intrusion in the coastal rivers by using an interdisciplinary approach. Moreover, the hydrochemical data in conjunction with the remote sensing and GIS and statistical methods identified the spatial extent of salinity occurrences in a seasonal basis. With the application of Mann-Kendall and Sen's slope this research further assessed salinity rising trend in south-west coastal zones of Bangladesh. In order to predict future trends in other rivers, the same method can be utilized to predict future trends of seawater intrusion. This method can be further applied to study other environmental processes to assess. The results of this study can also provide important information and a priori assessment to water resource managers, engineers, practitioners and policy makers and environmental scientists of the country to implement structures for the management of important water resources. This study could further help to comprehend seasonal trends in the hydrochemistry and water quality of the coastal and estuarine rivers, and help policy makers to obligate some important implications for the future initiatives taken for the management of land, water, fishery, agriculture and environment of coastal rivers and estuaries of Bangladesh.

Conflicts of Interest

All authors have read the manuscript and declared no conflict of interests. All authors discussed the results and implications and commented on the manuscript at all stages.

Acknowledgements

This work has been supported by the project entitled "Establishment of monitoring network and mathematical model study to assess salinity intrusion in groundwater in the coastal area of Bangladesh due to climate change" implemented by Bangladesh Water Development Board and sponsored by Bangladesh Climate Change Trust Fund, Ministry of Environment and Forest.

References

Afroz T, Alam S (2013) Sustainable shrimp farming in Bangladesh: A quest for an Integrated Coastal Zone Management. Ocean Coast Manage 71: 275-283

Ahamed AU, Alam M (1999) Development of Climate Change Scenarios with General Circulation Models. in: Saleemul Huq, Z. Karim, M. Asaduzzaman, and F. Mahtab (eds.)

Vulnerability and Adaptation to Climate Change for Bangladesh.Kluwer Academic Publishers, Dordrecht, the Netherlands. pp. 13-20.

Aziz JJ, Ling M, Rifai HS, Newell CJ, Gonzales JR (2003) MAROS: A decision support system for optimizing monitoring plans. Ground Water 41(3): 355-367

Bahar MM, Reza MS (2010) Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of Southwest Bangladesh. Environ Earth Sci 61(5): 1065-1073

Bear J (1999) Seawater intrusion in coastal aquifers: concepts, methods and practices. Boston. Mass: Kluwer Academic.

Bhuiyan MJAN, Dutta D (2012) Assessing impacts of sea level rise on river salinity in the Gorai river network, Bangladesh. Estuar Coast Shelf Sci 96: 219-227

Brammer H (2004) Can Bangladesh be Protected from Floods? University Press Ltd, Dhaka.

Brammer H (2014a) Climate Change, Sea-level Rise and Development in Bangladesh, University Press Ltd, Dhaka.

Brammer H (2014b) Bangladesh's dynamic coastal regions and sea-level rise. Climate Risk Manage 1: 51-62

Canedo-Arguelles M, Kefford BJ, Piscart C, Prat N, Schafer RB, Schulz CJ (2013) Salinisation of rivers: an urgent ecological issue. Environ Pollut 173: 157-67

DoE/MOEF/GOB (2006)Bangladesh, national programme of action for protection of the coastal and marine environment from land-based activities. Department of Environment, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka.

Da Lio C, Carol E, Kruse E, Teatini P, Tosi L (2015) Saltwater contamination in the man aged low-lying farmland of the Venice coast, Italy: An assessment of vulnerability. Sci Total Environ 533: 356-69

FAO (1985) FAO report on tidal area study. Fisheries resources survey system. FAO/UNDP-BGD/79/015.http://www.fao.org/docrep/field/003/ac352e/AC352E00.htm#TOC. Accessed on 15th March 2016

FAO (2017) Applying flexible cropping schedules for rice (t. aman) production in Bangladesh. http://teca.fao.org/read/6853. Accessed 30thJanuary 2017

Ghabayen SMS, McKee M, Kemblowski M (2006) Ionic and isotopic ratios for identification of salinity sources and missing data in the Gaza aquifer. J Hydrol 318(1-4): 360-373

Gain A, Giupponi C (2014) Impact of the Farakka Dam on thresholds of the hydrologic flow regime in the lower Ganges River basin (Bangladesh). Water6(8): 2501-2518

Ghosh P, Chakrabarti R, Bhattacharya SK (2013) Short- and long-term temporal variations in salinity and the oxygen, carbon and hydrogen isotopic compositions of the Hooghly Estuary water, India. Chem Geol 335: 118-127

Halim MA, Majumder RK, Nessa SA, Hiroshiro Y, Sasaki K, Saha BB, Saepuloh A, Jinno K (2010) Evaluation of processes controlling the geochemical constituents in deep groundwater in Bangladesh: spatial variability on arsenic and boron enrichment. J Hazard Mater 180(1-3): 50-62

Islam MA, Zahid A, Rahman MM, Rahman MS, Islam MJ, Akter Y, Shammi M, Bodrud-Doza M, Roy B (2016) Investigation of Groundwater Quality and Its Suitability for Drinking and Agricultural Use in the South Central Part of the Coastal Region in Bangladesh. Expo Health. Doi: 10.1007/s12403-016-0220-z

Jiang Y, Guo H, Jia Y, Cao Y, Hu C (2015) Principal component analysis and hierarchical cluster analyses of arsenic groundwater geochemistry in the Hetao basin, Inner Mongolia. Chem Erde Geochem 75(2): 197-205

Karanth KR (1994) Groundwater Assessment Development and Management, Tata McGraw-Hill Publishing Company Limited, New Delhi, (third reprint).

Katz BG, Eberts SM, Kauffman LJ (2011) Using Cl/Br ratios and other indicators to assess potential impacts on groundwater quality from septic systems: A review and examples from principal aquifers in the United States. J Hydrol 397(3-4): 151-166

Kendall MG (1975) Rank correlation methods. Griffin, London

Khan A, Mojumder SK, Kovats S, Vineis P (2008) Saline contamination of drinking water in Bangladesh. Lancet 371(9610): 385

Kisi O, Ay M (2014) Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey. J Hydrol 513: 362-375

Lee HS (2013) Estimation of extreme sea levels along the Bangladesh coast due to storm surge and sea level rise using EEMD and EVA. J Geophys Res: Oceans 118(9): 4273-4285

Loitzenbauer E, Mendes CAB (2012) Salinity dynamics as a tool for water resources management in coastal zones: An application in the Tramandaí River basin, southern Brazil. Ocean Coast Manage 55: 52-62

Mann HB (1945) Nonparametric tests against trend. Econometrica 13:245–259

MoWR (2005)Coastal Zone Policy (CZPo), Ministry of Water Resources (MoWR)

Niazi F, Mofid H, Modares FN (2014) Trend analysis of temporal changes of discharge and water quality parameters of Ajichay River in four recent decades. Water Qual Exp Health 6(1-2): 89-95

Otache M, Bakir M, Zhijia L (2008) Analysis of stochastic characteristics of the Benue River flow process. Chin J Oceanol Limn 26(2): 142-151

Papa F, Bala SK, Pandey RK, Durand F, Gopalakrishna VV, Rahman A, Rossow WB (2012) Ganga-Brahmaputra river discharge from Jason-2 radar altimetry: An update to the long-term satellite-derived estimates of continental freshwater forcing flux into the Bay of Bengal. J Geophys Res: Oceans117: C11021

Peck AJ, Hatton T (2003) Salinity and the discharge of salts from catchments in Australia. J Hydrol 272: 191-202.

Piper AM (1944) A graphic procedure in the geochemical interpretation of water analyses. Am Geoph Union Trans 25: 914-923

Rahman AM, Rahman S (2015) Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh. Weather Climate Extremes 7: 84-95

Salmi T, Maata A, Antilla P, Ruoho-Airola T, Amnell T (2002) Detecting trends of annual values of atmospheric pollutants by the Mann–Kendall test and Sen's slope estimates-the Excel template application MAKESENS. Finnish Meteorological Institute, Helsinki, Finland.

Samanta S, Dalai T (2016) Dissolved and particulate Barium in the Ganga (Hooghly) River estuary, India: solute-particle interactions and the enhanced dissolved flux to the oceans. Geochim Cosmochim Acta 195: 1-28

Sarkar R, Vogt J (2015) Drinking water vulnerability in rural coastal areas of Bangladesh during and after natural extreme events. Int J Disaster Risk Reduct 14: 411-423

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 63:1379–1389

Shahid S (2010) Trends in extreme rainfall events of Bangladesh. Theor Appl Climatol 104(3-4): 489-499

Shameem MIM, Momtaz S,Rauscher R (2014) Vulnerability of rural livelihoods to multiple stressors: A case study from the southwest coastal region of Bangladesh. Ocean Coast Manage 102: 79-87.

Shammi M, Bhuiya G, Ibne Kamal A, Rahman M, Rahman M, Uddin M (2012) Investigation of Salinity Occurrences in Kumar-Madhumati River of Gopalganj District, Bangladesh. J Nature Sci Sustainable Technol 6(4): 299-313

Shammi M, Karmakar B, Rahman M, Islam M, Rahman R, Uddin M (2016) Assessment of salinity hazard of irrigation water quality in monsoon season of Batiaghata Upazila, Khulna District, Bangladesh and adaptation strategies. Pollution 2: 183-197

Shelley I, Takahashi-Nosaka M, Kano-Nakata M, Haque M, Inukai Y (2016) Rice cultivation in Bangladesh: present scenario, problems, and prospects. J Intl Cooper Agric Dev 14: 20-29

Siebert C, Möller P, Geyer S, Kraushaar S, Dulski P, Guttman J, Subah A, Rödiger T (2014) Thermal waters in the Lower Yarmouk Gorge and their relation to surrounding aquifers. Chem. Erde Geochem. 74(3): 425-441

Spalding MD, Ruffo S, Lacambra C, Meliane I, Hale LZ, Shepard CC, Beck MW (2014) The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. Ocean Coast Manage 90: 50-57

Suen J-P, Lai H-N (2013) A salinity projection model for determining impacts of climate change on river ecosystems in Taiwan. J Hydrol 493: 124-131

Takeuchi K, Xu ZX, Ishidiaira H (2003) Monitoring trend step changes in precipitation in Japanese precipitation. J Hydro 279:144–150

Trabelsi N, Triki I, Hentati I, Zairi M (2016) Aquifer vulnerability and seawater intrusion risk using GALDIT, GQISWI and GIS: case of a coastal aquifer in Tunisia. Environ Earth Sci 75(8): 1-19

Thia-Eng C (1993) Essential elements of integrated coastal zone management.Ocean Coast Manage 21: 81-108

Vengosh A, Heumann KG, Juraski S, Kasher R (1994) Boron isotope application for tracing sources of contamination in groundwater. Environ Sci Technol 28 (11): 1968–1974

Vengosh A, Spivack AJ, Artzi Y, Ayalon A (1999) Geochemical and Boron, Strontium, and Oxygen isotopic constraints on the origin of the salinity in groundwater from the Mediterranean coast of Israel. Water Resour Res 35(6): 1877–1894

Vengosh A, Ben-Zvi A (1994) Formation of a salt plume in the coastal plain aquifer of Israel: the Be'erToviyya region. J Hydrol 160: 21–52

Vengosh A, Rosenthal E (1994) Saline groundwater in Israel: Its bearing on the water crisis in the country. J Hydrol 156: 389–430

Webster R, Oliver M (2001) Geostatistics for environmental scientists. John Wiley & Sons, Ltd, Chichester, Sussex.

Werner AD, Bakker M, Post VEA, Vandenbohede A, Lu C, Ataie-Ashtiani B, Simmons CT, Barry DA (2013) Seawater intrusion processes, investigation and management: Recent advances and future challenges. Adv Water Resour 51: 3-26

Williams WD (1987) Salinization of Rivers and streams: an important environmental hazard. Ambio 16: 181-185

Williams WD, Sherwood J (1994) Definition and measurement of salinity in salt lakes. Int J Salt Lake Res 3(1): 53-63

Figure file

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

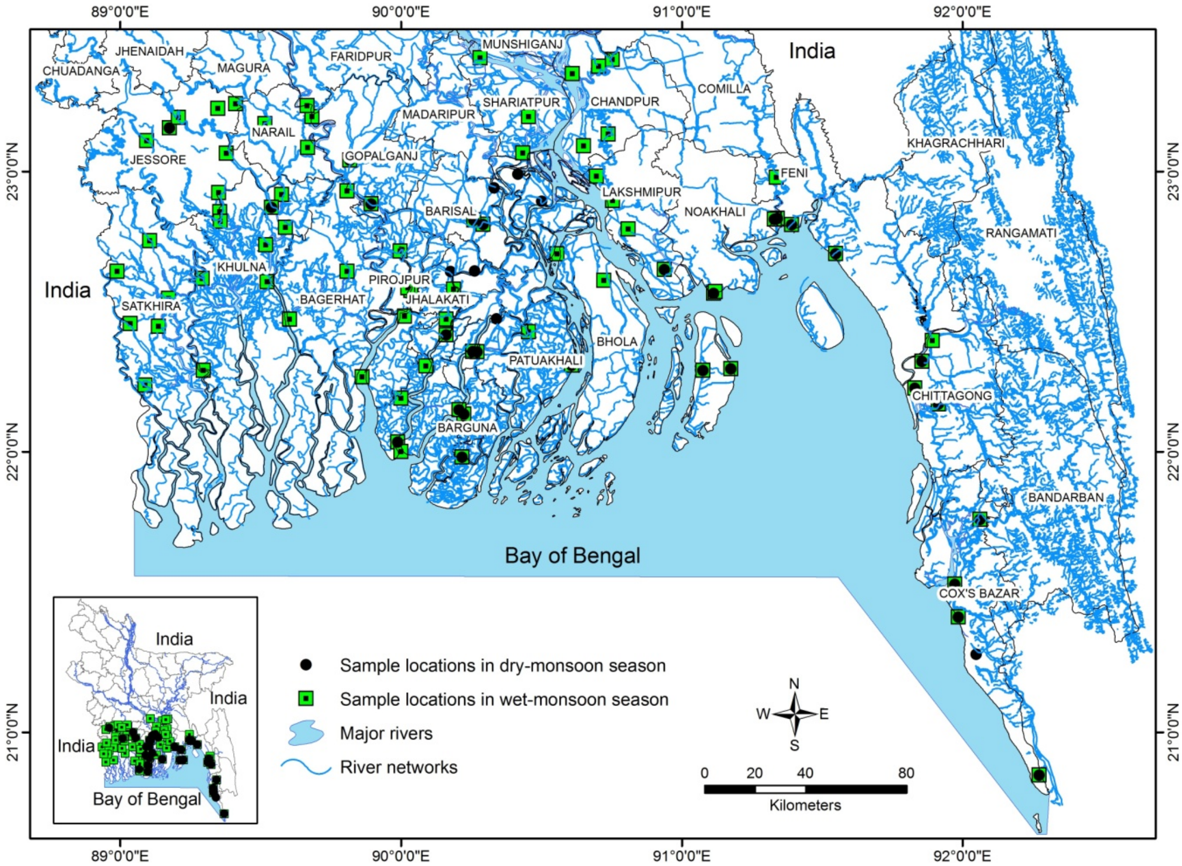

Figure 1. Location map of surface water sampling points in wet-monsoon season and dry-monsoon season along with river networks in the study area

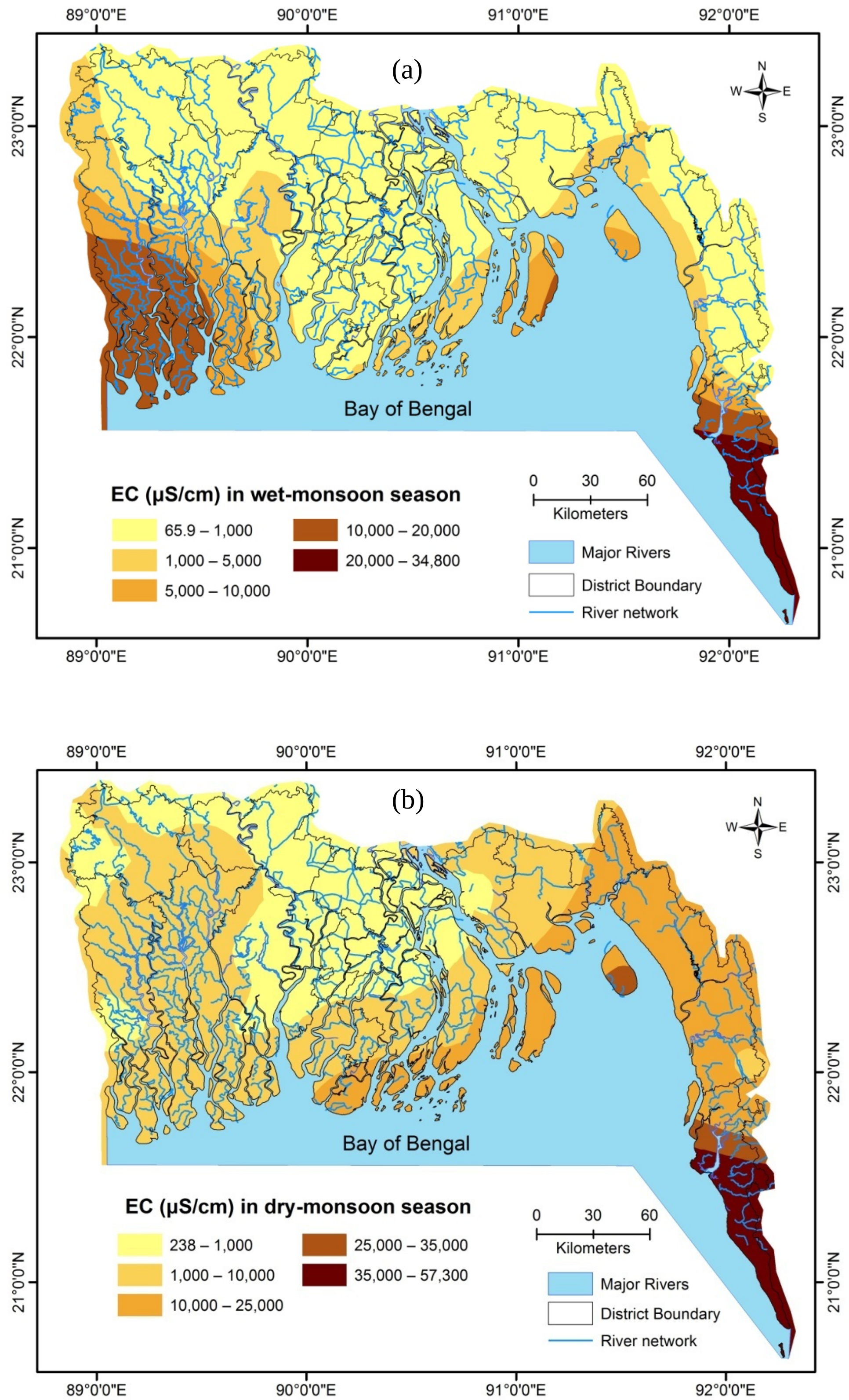

Figure 2. Spatial distribution of salinity occurrences as EC (µS/cm) in wet-monsoon season and dry-monsoon season in the coastal rivers and estuaries of Bangladesh. Sampling points in wet-monsoon (n=96) (a) and dry-monsoon (n=44) (b).

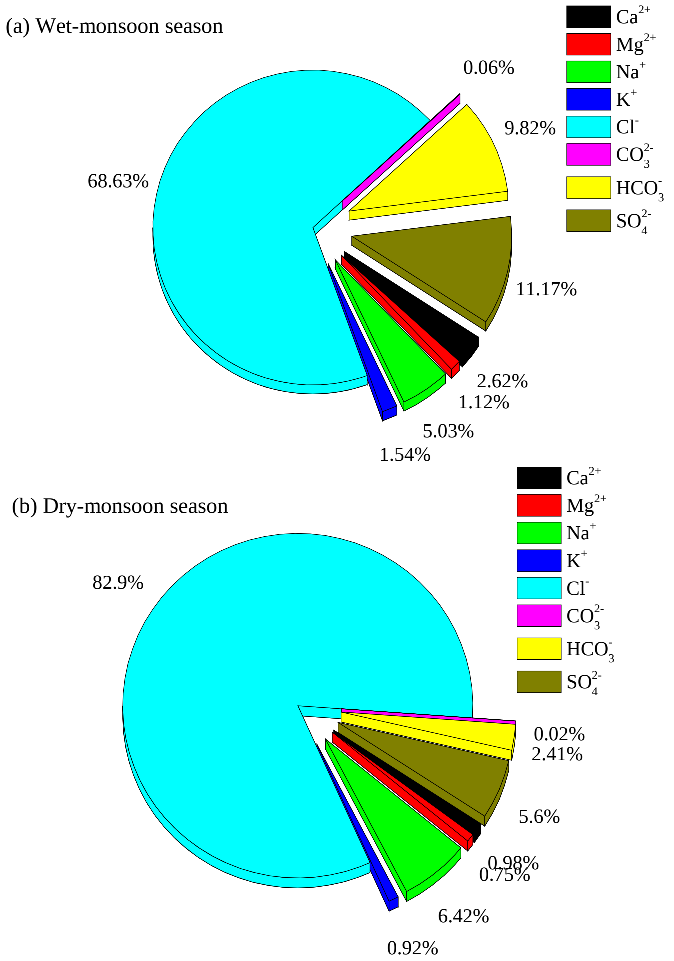

Figure 3. Seasonal variation of anions and cations contributing to salinity in the major coastal rivers and estuarine water based on average data (a) variation in wet-monsoon season (b) variation in dry-monsoon season

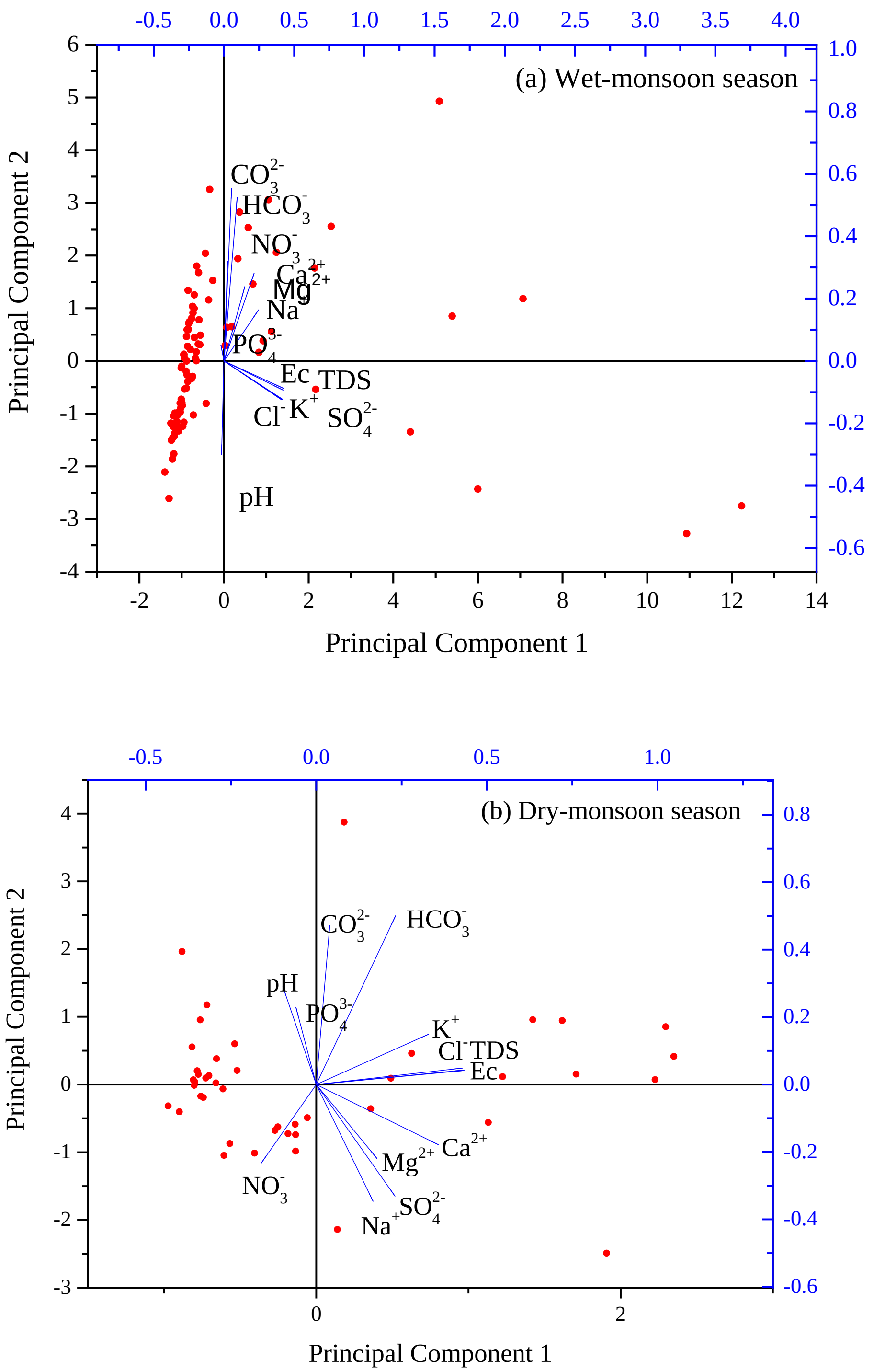

Figure 4. PCA on the combined data sets of anions and cations with other important water parameters to understand seasonal variations of river water (a) Wet-monsoon season and (b) Dry-monsoon season

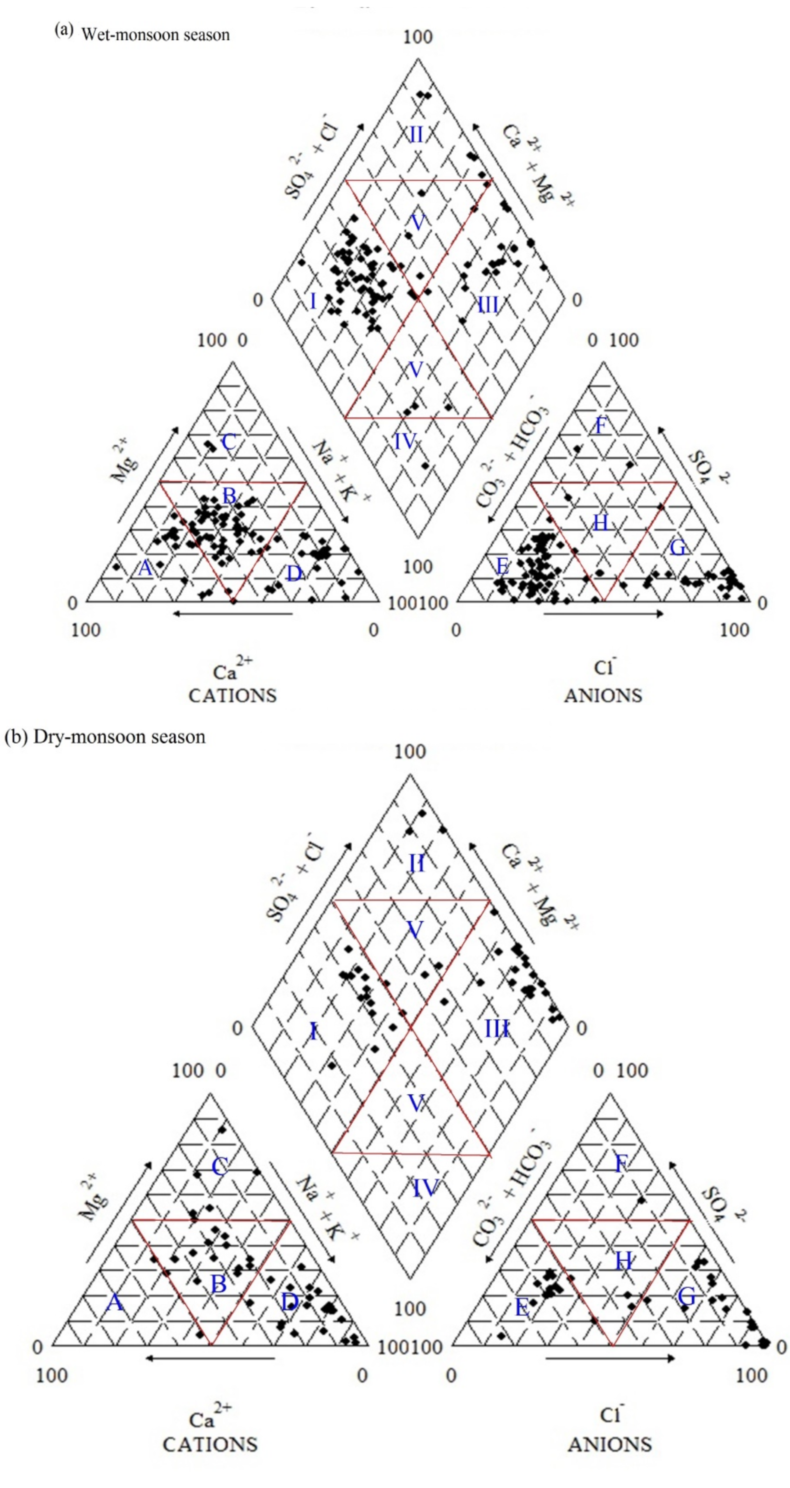

Figure 5. Piper diagram for major ion contents of surface waters of the study area to determine water types (a) wet-monsoon season and (b) dry-monsoon season. The surface waters are classified into three types; Type I: Ca–Mg–HCO_3, Type II: Ca-Cl type, Type III: Na-Cl type, Type IV: Na–HCO_3, Type V: mixed type Na–Ca–Mg–HCO_3–Cl

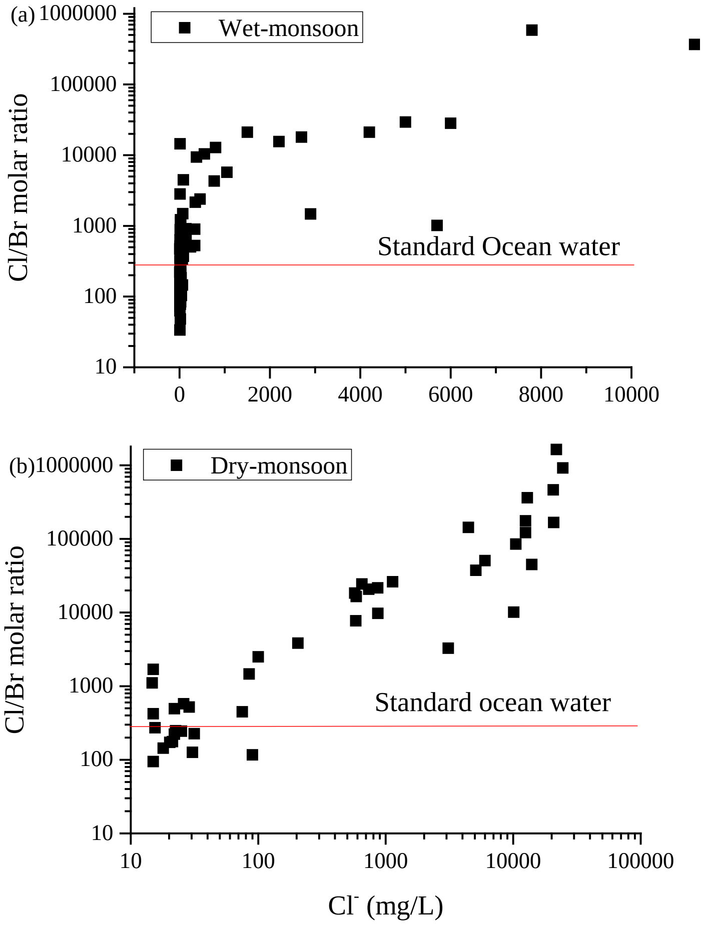

Figure 6. Cl/Br molar ratio vs. Cl^- (mg/L) for (a) Wet-monsoon and (b) Dry-monsoon season

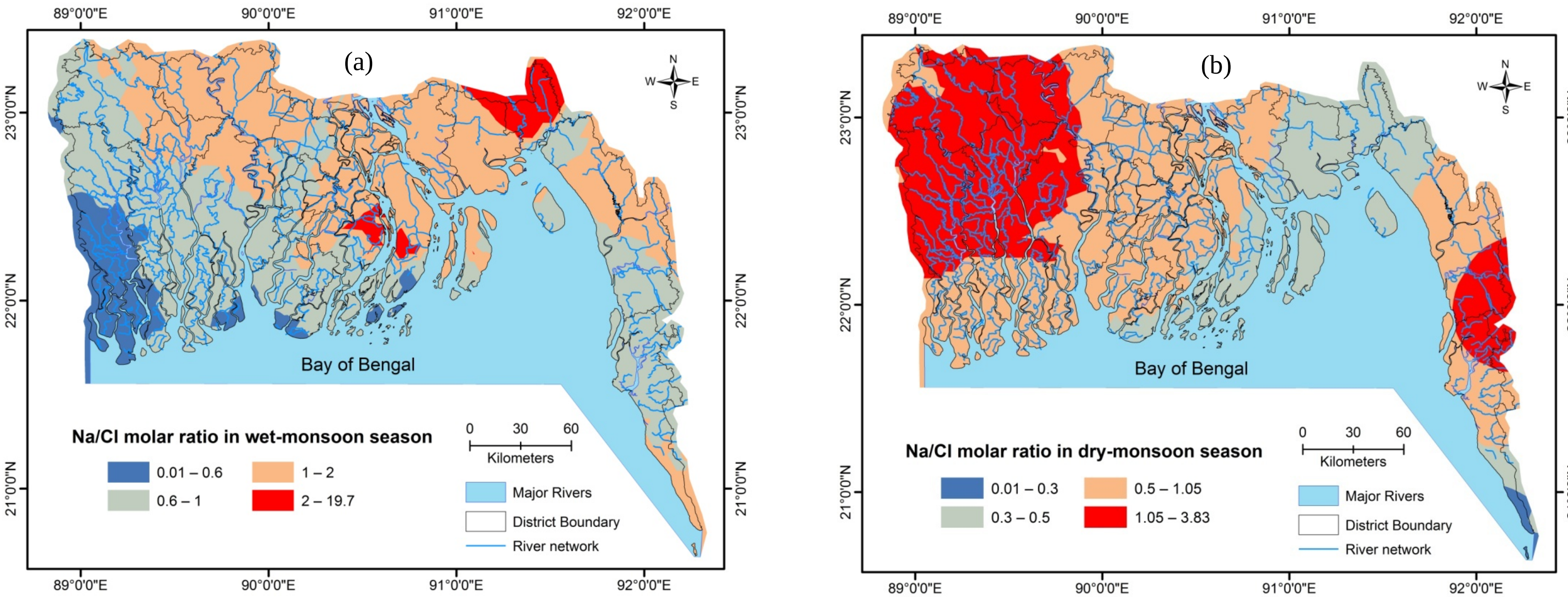

Figure 7. Spatial distribution of Na/Cl molar ratio in wet-monsoon season (a) and dry-monsoon season (b) in the coastal rivers and estuaries of Bangladesh as obtained by Ordinary Kriging method (OK). Sampling points in wet-monsoon (n=96) and dry-monsoon (n=44).