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Assessment of coastal surface water quality for irrigation purpose

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Abstract

The study aimed to assess the coastal surface water quality for irrigation purposes through the analysis of the water samples of some selected estuaries, rivers, and ponds. The analysis results showed that the mean value of typical water quality parameters like electrical conductivity (EC), total dissolved solids (TDS), sodium (Na^+), and chloride (Cl^-) ions exceeded the permissible limit of the Department of Environment (DoE), Bangladesh 2010, and FAO, 1985 for the pre- and post-monsoon seasons. The Piper diagram indicated a Na-Cl water type, especially during the pre- and post-monsoon seasons. The water quality parameters in the areas showed a higher amount than the standard permissible limits, indicating that the quality is deteriorating. The water quality index values for domestic uses showed very poorly to unsuitable in most of the surface waters except pond water, especially during the pre- and post-monsoon periods. The surface water quality index for irrigation purpose usages was found to be high and/ or severely restricted (score: 0–55) during the pre- and post-monsoon seasons. The study observed that due to saline water intrusion, the water quality deterioration started from post-monsoon and reached its highest level during the pre-monsoon season, which gradually depreciates the water quality in coastal watersheds of Bangladesh.

Key words: coastal, deterioration, salinity, surface water, water quality, watersheds

Highlights

- Characterization of the coastal surface water quality.
- Exploration of the present status of the coastal water quality of Bangladesh.
- Analysis of the coastal surface waters and comparison with standard permissible limits offered by different organizations.
- Irrigation water quality indexing to observe the status for irrigation purposes with seasonal variations.

INTRODUCTION

Bangladesh is geographically a low-lying deltaic land, with a flat topography, and gradually sloping down to the Bay of Bengal, enriched with vast coastal areas. The coastal areas of Bangladesh cover an area of 47,201 km^2, which is about 32% of the total area that encompasses the landmass of 19 districts (Ahmad 2019). The coastal zone and offshore islands in Bangladesh are very flat with heights of less than 3 m above Mean Sea Level (Baten *et al.* 2015), unique physical characteristics, gifted with vast floodplain lands, overlapped with numerous estuaries, tidal rivers, creeks, and their tributaries.

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The river systems of the coastal areas in Bangladesh have tidal influence from the Bay of Bengal as well as having freshwater flows from the upstream. Throughout the rainy season, local rainfall upsurges with freshwater flow preserving the water quality as good, but in the dry season the pressure of that flow decreases due to insufficient rainfall and human-induced settlements. As a result, a consequential backwater effect forms, and thus the surface water quality deteriorates due to the increase of salinity. Water quality mainly depends on several factors, including general geology, the degree of chemical weathering of various rock types, recharge water, and upstream water flows (Albarède 2003; Mostafa *et al.* 2017).

The coastal belt of the country is facing enormous challenges in meeting freshwater demand due to limited water supply from the groundwater and surface water sources as they are affected by the various degrees of salinity and other water quality problems (Chowdhury *et al.* 2014). Reports showed that about 53% of the coastal watersheds of Bangladesh are affected by various degrees of salinity (Minar *et al.* 2013; Rahman *et al.* 2015). The problem becomes intensified due to some climate change-associated hazards like sea-level rise, riverbank erosion, land accretion, insufficient and irregular rainfall, cyclones, tidal surges, and so on. Due to sea-level rise, over-extraction of groundwater, upstream diversion of surface water, and shrimp farming, the coastal Ganges-Brahmaputra delta has been experiencing a relatively rapid measure in groundwater, river and soil salinity (Dasgupta *et al.* 2014).

The tide of the sea and the sweet water pressure from the upstream has a considerable influence to form a unique brackish water ecosystem (Mondal *et al.* 2013). Salinity hazards in coastal areas of Bangladesh affect different uses of water including irrigation, drinking, household, fisheries, and so on. (Mahtab & Zahid 2018). Therefore, the irrigated waters can affect plant growth through toxicity, nutrient deficiency, or altering plant availability of nutrients (Ayers & Westcot 1985). A few studies have revealed that Kalapara is one of the vulnerable mid-coastal watersheds of Bangladesh with high to moderate degrees of salinity (Rahman *et al.* 2015). These studies mainly focused on seasonal variations of salinity, the impact of salinity on agriculture, fisheries, land uses, crop production, and so on. Concerning the impacts of salinity on water quality in the coastal watersheds of Bangladesh, a detailed study was conducted in Kalapara Upazila during the pre-monsoon, monsoon, and post-monsoon seasons of 2016 and 2017. The suitability of surface water sources for irrigation and domestic consumption was assessed in terms of suitable water quality index. The irrigation and domestic water quality index method classified the water quality according to the degree of usability by using some prescribed water quality parameters (Khalaf & Hassan 2013; Tyagi *et al.* 2013; Krishnan *et al.* 2016). Water quality index, an important water quality measuring tool, is generally used to express the overall water quality at a certain location, which is based on several water quality parameters (Khalaf & Hassan 2013). In the study, weighted arithmetic water quality index (WAWQI) and Irrigation Water Quality Index (IWQI) methods were followed to apprehend the existing water quality considering the domestic and irrigation purpose uses. The objective of the study was to investigate the suitability of the mid-south coastal watersheds for irrigation purposes in Bangladesh. The findings would contribute to sustainable water management in coastal watersheds of Bangladesh.

MATERIALS AND METHODS

Study area

The study was conducted with surface water (i.e. estuaries, rivers and ponds) at Kalapara Upazila in Patuakhali district, the mid coastal watersheds of Bangladesh. The area is about 483.08 km^2 located at 21.9861°N 90.2422°E crossed with numerous channels, rivers, and their tributaries (Wikipedia, July 2020). The southern part of this area is opened with the Bay of Bengal. Ten experimental locations (spots) were selected randomly considering the exposed and interior coast (Figure 1).

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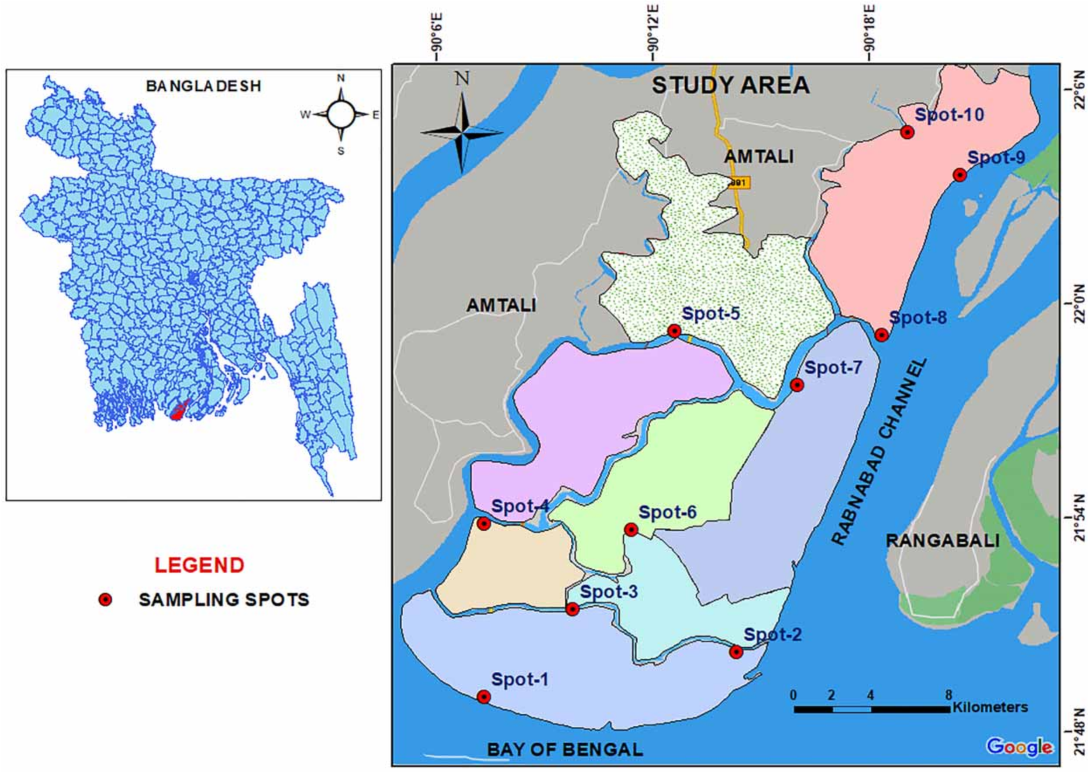

Figure 1 | Study area and sampling spots.

Sampling

The water samples were collected seasonally, such as the pre-monsoon, monsoon, and post-monsoon seasons during April, August, and December, respectively, of 2016 and 2017. In the course of the high tide period, samples were collected in the selected locations of the estuaries, rivers, canals, and ponds. The sampling locations are indicated as spots 1–10 in Figure 1. The sampling location spot-1 was marked at the open shoreline of Kuakata beach, which is an estuary area, and spots 2–10 were marked in the different estuaries, rivers, and ponds of the study area approximately at a distance of about 35 kilometers from the shoreline. A detailed description of the sampling locations, areas, and water sources is stated in Table 1.

Table 1 | Description of sampling location and source

Spot No.	Area	Latitude	Longitude	Water source
Spot-1	Kuakata sea spot, Union Latachapli	21.816	90.122	Estuary and pond
Spot-2	[a]Vill.- Tettrish kani Union : Latachapli	21.837	90.239	Estuary and pond
Spot-3	Vill- Laksmi bazar Union : Latachapli	21.857	90.163	River and pond
Spot-4	Vill- Hazipur Union : Nilgang	21.897	90.122	River and pond
Spot-5	Vill- Nashnapar Union : Tiakhali	21.987	90.21	River and pond
Spot-6	Vill- East Madhukhali Union: Mithagang,	21.894	90.19	River and pond
Spot-7	Vill- Charipara Union: Lalua	21.962	90.267	River and pond
Spot-8	Vill- Tiakhali Union : Tiakhali	21.985	90.306	River and pond
Spot-9	Vill- Dhankhali Union : Dhankhali	22.06	90.342	River and pond
Spot-10	Vill- Rajapara Union : Taikhali	22.08	90.318	River and pond

[a]Vill.: Village; Union: an adminstrative area consisting of some villages.

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Samples analysis

The temperature, dissolved oxygen (DO), pH, and electrical conductivity (EC) of surface waters were recorded in-situ from the spots. Total Dissolved Solids (TDS) were measured using the gravimetric method. The major cations – that is, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) ions – were measured using atomic absorption spectrophotometer (AAS). The anionic concentration in the water samples was determined using an Ultraviolet (UV) spectrophotometer.

Irrigation water quality index (IWQI)

The irrigation water quality index (IWQI) method was used to apprehend the existing water quality for irrigation purpose uses. It is a customary and frequently used method for irrigation water quality assessment, initially developed by Meireles *et al.* (2010) and followed by several researchers. The model was developed according to the proposal of the University of California Committee of Consultants (UCCC) and the criteria established by Ayers and Westcott in 1985. The model included the most variable parameters of irrigation water quality, such as EC, Na^+, Cl-, HCO_3- and Sodium Absorption Ratio (SAR) (Table 2).

Table 2 | Parameter limiting values for quality measurement (q_i)

q_i	EC (ds/cm)	SAR $(meq/L)^{1/2}$	Na^+ (meq/L)	Cl^- (meq/L)	HCO_3^- (meq/L)
85–100	$0.2 \leq EC < 0.75$	$2 \leq SAR < 3$	$2 \leq Na < 3$	$1 \leq Cl < 4$	$1 \leq HCO_3 < 1.5$
60–85	$0.75 \leq EC < 1.5$	$3 \leq SAR < 6$	$3 \leq Na < 6$	$4 \leq Cl < 7$	$1.5 \leq HCO_3 < 4.5$
35–60	$1.5 \leq EC < 3.0$	$6 \leq SAR < 12$	$6 \leq Na < 9$	$7 \leq Cl < 10$	$4.5 \leq HCO_3 < 8.5$
0–35	$EC < 0.2$ or $EC \geq 3.0$	$SAR < 2$ or $SAR \geq 12$	$Na < 2$ or $Na \geq 9$	$Cl < 1$ or $Cl \geq 10$	$HCO_3 < 1$or $HCO_3 \geq 8.5$

Then, the water quality measurement parameter value (q_i), and aggregation weights (w_i) were established according to the following equations.

$$q_i = q_{imax} - \frac{(X_{ij} - X_{inf}) \times q_{iamp}}{X_{amp}} \tag{1}$$

Here, q_{imax} is the maximum value of q_i for each class; x_{ij} represents the observed value for the parameter; x_{inf} indicates the lower limit of the class to which the parameters belong; q_{iamp} represents the class amplitude of q_i and x_{amp} corresponds to class amplitude to which the parameter belongs. To evaluate x_{amp} for the last class of each parameter, the upper limit was considered to be the highest value determined in the analysis.

Each parameter weight used in the WQI was obtained from principal components and factor analysis as described in SPSS (Statistical Package for the Social Science v.13) (Table 3)

$$W_i = \sum_{j=1}^{k} F_j A_{ij} / \sum_{j=1}^{k} F_j \sum_{i=1}^{n} A_{ij} \tag{2}$$

where,

$$W_i = \frac{\sum_{j=1}^{k} F_j A_{ij}}{\sum_{j=1}^{k} F_j \sum_{i=1}^{n} A_{ij}}$$

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Table 3 | Weights of IWQI parameters

Parameters	w_i
EC	0.211
Na^+	0.204
HCO_3^-	0.202
Cl^-	0.194
SAR	0.189
Total	1.000

Here, W_i is the weight of the parameter for the WQI; F is component 1 auto value; A_{ij} is the explainability for parameter i by factor j; i is the number of physico-chemical parameters selected by the model, ranging from 1 to n; j is the number of factors selected in the model, varying from 1 to k. (Meireles *et al.* 2010).

The final equation:

$$WQI = \sum W_i q_i \tag{3}$$

The index values were classified considering the risk of salinity and toxicity to plants as observed in the classifications presented by Bernardo (1995), and Holanda & Amorim (1997). Restrictions to water use classes were characterized as shown in Table 4.

Table 4 | Restriction in water use

WQI	Water use restriction	Recommendation for plants
$85 \leq 100$	No restriction (NR)	No toxicity risk for most plants
$70 \leq 85$	Low restriction (LR)	Avoid salt-sensitive plants
$55 \leq 70$	Moderate restriction (MR)	Plants with moderate tolerance to salts
$40 \leq 55$	High restriction (HR)	Plants with moderate to high tolerance to salts
$0 \leq 40$	Severe restriction (NR)	Plants with high salt tolerance

Weighted arithmetic water quality index (WAWQI)

Weighted arithmetic water quality index method was used to assess the existing water quality for domestic (bathing, washing, etc.) purpose uses. The method was developed by Brown *et al.* (1970) and followed by several researchers such as Bora & Goswami (2017), Chowdhury *et al.* (2012) and so on. The model was developed using the equation:

$$WQI = \frac{\sum Q_n W_n}{\sum W_n} \tag{4}$$

The quality rating scale (Q_n) for each parameter was calculated using the equation:

$$Q_n = 100 \frac{V_n - V_i}{V_s - V_i} \tag{5}$$

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Here, V_n is the estimated concentration of the ith parameter of analyzed water, V_i is the ideal value of this parameter in pure water, $V_i = 0$ (except pH = 7.0 and DO = 14.6 mg/l), Vs is the recommended standard value of the ith parameter.

The unit weight,

$$W_n = \frac{k}{V_s} \tag{6}$$

and

$$k = \frac{1}{\sum\left(\frac{1}{V_s}\right)} \tag{7}$$

where, $V_s = 1, 2, 3 \ldots n$

The rating of water quality according to this WQI is given in Table 5.

Table 5 | Estimation of water quality index by Weighted Arithmetic Water Quality Index method

WQI value	Rating of water quality	Possible uses
0–25	Excellent	Domestic usages (Bathing, washing)
26–50	Good	Domestic usages (Bathing, washing
51–75	Poor	Domestic usages (Bathing, washing
76–100	Very Poor	Proper treatment required
>100	Unsuitable	Proper treatment required

RESULTS AND DISCUSSION

Characterization of physicochemical parameters

The mean values of WT, DO, pH, EC, and TDS describing the in-situ water quality of the selected study area are demonstrated in Table 6. The minimum mean water temperature was found to be 19.0 ± 0.8 °C during the post-monsoon and the maximum mean was 31 ± 1.0 °C during the pre-monsoon season. The minimum mean values of DO and EC were 7.1 ± 0.1 and 7.6 ± 0.2 mg/L, and that of the maximum mean values were 7.4 ± 0.1 and 8.1 ± 0.3 mg/L, respectively. These values were found to be within the permissible standards (Tables 6 and 7). Rahman *et al.* (2013) studied some physicochemical parameters of some coastal rivers in Khulna district during 2008–2009. The study result showed that the DO values range at four sampling stations was 4.2–7.3 mg/L, and the pH values vary from 7.0 to 8.4 for the entire year, which supports the present study as well. The DO values in estuaries, and rivers were found slightly higher than the pond water due to the tidal influence of seawaters. Several reports showed a similar observation where the DO values were found higher in the lower area of the estuaries as the marine waters influenced (Mudge *et al.* 2007; Zhang *et al.* 2010; Costa *et al.* 2018). The EC and TDS values of estuaries, and rivers showed significant fluctuations due to their distance, depth, water-volume, rainfall as well as the freshwater pressure from the upstream regions. The mean EC value ranges from 0.6 ± 0.4 to 13.1 ± 8.4 ds/cm, and the TDS values were 595 ± 41.1 to 11,295 ± 800 mg/L. Most of them were found to exceed the permissible limit of the standards (Tables 6 and 7). A study conducted by Rahman *et al.* (2013) on some physicochemical parameters of the Passur River in the Sundarbans showed that the minimum mean EC value widely

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Table 6 | Descriptive statistics of surface water quality parameters

	Estuaries, rivers and canals			Ponds		
Parameters	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	**Pre-monsoon**	**Monsoon**	**Post-monsoon**
WT °C	31 ± 1.0	30.1 ± 0.7	19.0 ± 0.8	30.2 ± 0.6	30.2 ± 0.8	19.3 ± 0.4
DO mg/L	7.1 ± 0.1	7.4 ± 0.1	7.3 ± 0.1	7.1 ± 0.1	7.3 ± 0.1	7.2 ± 0.0
pH	7.6 ± 0.2	8.1 ± 0.3	7.6 ± 0.2	7.7 ± 0.1	7.9 ± 0.6	7.6 ± 0.3
EC ds/cm	13.1 ± 8.4	1.1 ± 0.3	7.0 ± 4.8	1.2 ± 0.2	0.6 ± 0.04	0.9 ± 0.0
TDS mg/L	11,295 ± 800	978 ± 257	6,634 ± 4,356	1,076 ± 182.6	595.0 ± 41.1	852. ± 31.4
Na^+ mg/L	1,425 ± 993	114 ± 21	572 ± 320	150.1 ± 25.5	73.0 ± 4.7	87.1 ± 3.4
K^+ mg/L	37.1 ± 19	4.3 ± 1.2	23.1 ± 14	6.8 ± 0.8	4.6 ± 0.3	7.0 ± 0.3
Mg^{2+} mg/L	97.3 ± 66	14.8 ± 3.6	61.1 ± 41.6	9.6 ± 1.8	9.8 ± 0.7	10.6 ± 0.4
Ca^{2+} mg/L	45.4 ± 30	17.0 ± 4.4	29.2 ± 18.6	4.3 ± 0.7	11.4 ± 0.8	4.5 ± 0.2
Cl^- mg/L	2,435 ± 1,512	183 ± 36.7	913 ± 532	227.3 ± 38.4	111.1 ± 5.3	133.9 ± 5.2
SO_4^{-2-} mg/L	367 ± 245	21.1 ± 5.7	88.2 ± 58.4	35.6 ± 7.3	12.8 ± 0.9	10.7 ± 0.4
NO_3^-mg/L	2.2 ± 0.3	2.5 ± 0.6	1.5 ± 0.4	2.6 ± 0.3	2.3 ± 0.4	1.5 ± 0.4
HCO_3^-mg/L	187 ± 37.6	274.3 ± 12.9	122.7 ± 9.6	107.2 ± 5	200.1 ± 11.8	107.1 ± 5.8
PO_4^{-3-} mg/L	0.8 ± 0.1	1.5 ± 0.2	1.2 ± 0.2	1.5 ± 0.3	1.2 ± 0.2	0.8 ± 0.2

Table 7 | Organizational standard for physicochemical parameters for irrigation and domestic purposes

	Standards		
Parameters	**[a]DoE, 2010**	**WHO, 2010**	**FAO, 1985**
DO mg/L	6–8		
pH	6.5–8.5	<8	6–8.5
EC ms/m	0.75		<3.0
TDS mg/L	1,000	1,000	2,000
Na^+ mg/L	200	200	920
K^+ mg/L	12		15
Mg^{2+}mg/L	30–35		60
Ca^{2+} mg/L	75		400
Cl^- mg/L	150–600	250	1,065
SO_4^{2-} mg/L	400	250	960
NO_3^- mg/L	10		<10
HCO_3^- mg/L	200–500		610

[a]Department of Environment, Bangladesh.

varied from 4.11 to 33.2 dS/m and the maximum mean value was found in the pre-monsoon season, which supports the present study findings.

The mean values of chemical parameters (e.g. Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^-, HCO_3^- and PO_4^{3-}, etc.) describing the actual impression of surface water quality are shown in Table 6. The minimum mean concentration of major ions – that is, Na+ and Cl^- – was found to be 73.0 ± 4.7 and 111.1 ± 5.3 mg/L, whereas the maximum mean was 1,425 ± 993 and 2,435 ± 1,512, respectively. The values of Na^+ and Cl^- during the pre- and post-monsoon seasons were found to exceed the permissible limit of WHO, FAO and the DoE standards. The values of pond water samples were found to be within the permissible limit of domestic and agriculture standards and showed good quality throughout the three seasons (Tables 6 and 7). Rahman *et al.* (2013) reported that the concentration

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of sodium (Na^+) ranges from 329–398 mg/L, 899.05–915.9 mg/L, 7,948–8,839 mg/L, respectively during the rainy, winter, and summer seasons. It also showed that the chloride ion concentration was 13–4,381 mg/L in Mongla, 13–4,381 mg/L in Dangmari, 12.5–4,672 mg/L in Koromjol Rivers, and 11.99–4,422 mg/L in Koromjol Creek. These findings support the present study results.

The mean values of other cationic parameters such as K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, HCO_3^- and PO_4^{3-}, etc. are shown in Table 6. The study results found that the concentration of such chemical ions was found to be within the permissible limit of the standards (Tables 6 and 7). The concentration of nitrate and phosphate ions in the estuaries, rivers, and pond water was found in a lower extent. Srinivasan *et al.* (2013) studied the coastal rivers of the southeast coast of India and showed that the variations of the nitrate values ranged from 0.17 to 6 μmol/L. However, the nitrite concentration fluctuated between 0.02 and 0.55 μmol/L. The present study also found a lower concentration as well as seasonal fluctuation. The study results showed that the obtained values were found within the permissible limit of the DoE, WHO, and FAO standards (Tables 6 and 7), indicating that the coastal water quality is lower, influenced by nitrate and phosphate ions.

The values of predominant parameters such as EC, TDS, Na^+ and Cl^- of selected estuaries, and rivers followed the order: pre-monsoon > post-monsoon > monsoon season, respectively. The salinity related values were found to exceed the permissible limit of the DoE and FAO standards during the pre- and post-monsoon seasons. These values were found to be within the permissible limit of the FAO standard during the monsoon season, though it considerably exceeded the DoE standard (Table 7). The study found that surface waters of the area were highly affected by salinity; nevertheless, the salinity was found to be normal during the monsoon period. The values of pond water samples were found to be within the permissible limit of domestic and agriculture standards, describing a good year-round quality.

WATER TYPE

The mean concentration of the cations and anions of the estuaries, and river water samples of the pre- and post-monsoon seasons are plotted in a Piper trilinear diagram (Figure 2). The cation diagram shows that the major water samples contained higher Na^+ and K^+ than Ca^{2+} and Mg^{2+}. The concentration of Na^+ was found to be higher in all samples compared to K^+, hence Na^+ was the dominant cation. The anion diagram shows that the major water samples contained higher Cl^- than SO_4^{2-} and HCO_3^- and so the dominance of Na^+ and Cl^- indicates Na-Cl water type in surface waters during the pre-monsoon season. Water type can be varied according to the location, geology, elevation, upstream water pressure, intrusion of saline water and so on. A report showed the groundwater in Rajshahi City, Bangladesh, was found to be a Ca-HCO_3 water type using the Piper diagram (Helal *et al.* 2011).

The mean concentration of cations and anions of the estuaries, and river water samples of the monsoon season plotted in a Piper trilinear diagram (Figure 3). The cation diagram shows that the major water samples contained higher Na^+ and K^+ than Ca^{2+} and Mg^{2+}; nevertheless, the concentration of K^+ was found to be very low compared to other major cations. The anion diagram shows a mixed dominancy of anions; that is, Cl^- and HCO_3^- in water samples, and so the dominance of Na^+ in cations and $Cl^- + HCO_3^-$ in anions indicates a Na-Cl-HCO_3 water type during the monsoon season. The major cations in water samples followed the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ throughout the year but the concentration of anions was found to be slightly changed in the monsoon period compared to the other two seasons; that is, pre- and post-monsoon. The anion order followed in the pre- and post-monsoon was $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$ but it followed the order $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^- > PO_4^{3-}$ in the monsoon season.

In the pre-monsoon season, the water volumes of estuaries and rivers decreased due to the increased evapotranspiration, and decreased upstream flow, hence significantly increased salinity.

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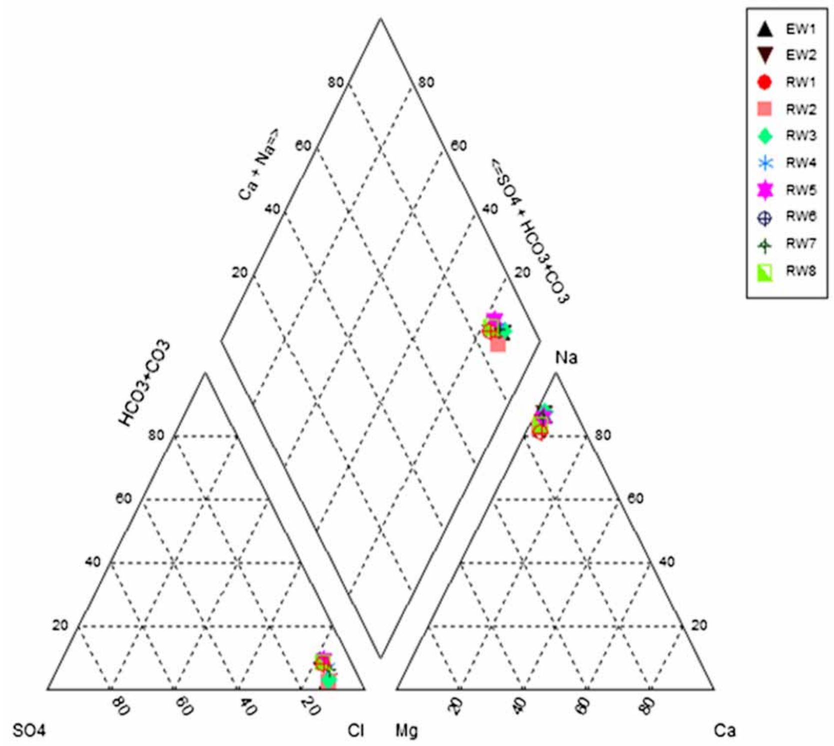

Figure 2 | Water type of estuaries and river water during pre-monsoon season.

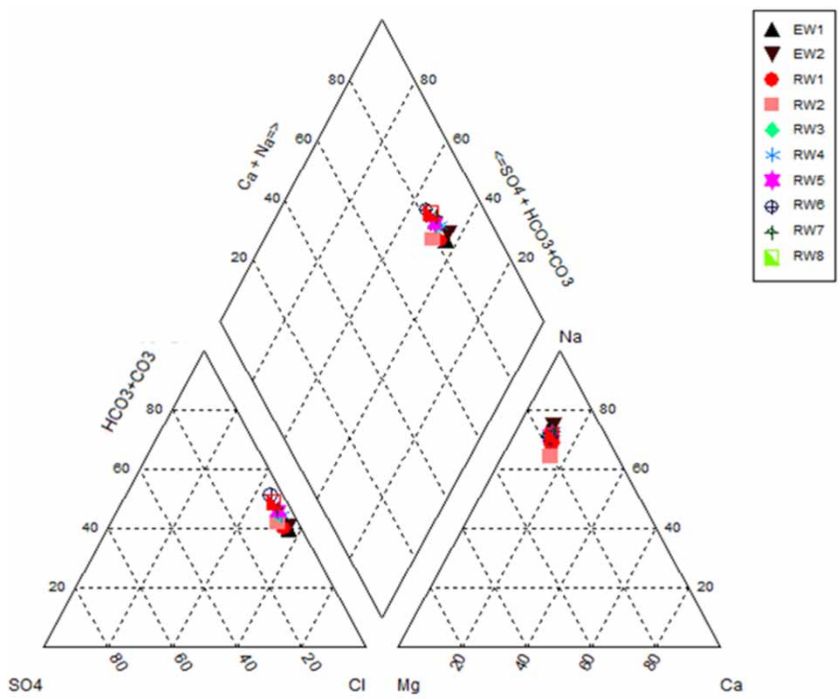

Figure 3 | Water type of estuaries and river water during monsoon season.

In the monsoon season, waters showed a higher bicarbonate ion concentration due to a large volume of upstream freshwater flows that flushed away the saltwater from the estuaries and rivers.

The study results found that the chloride ion concentration was substituted by higher bicarbonate during the rainy season and therefore a mixed Na-Cl-HCO_3 water type was observed.

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WATER QUALITY ASSESSMENT

The water quality index values for surface water of the study area were determined using IWQI and WAWQI methods considering the irrigation and domestic (bathing and washing, etc.) purpose uses, which are shown in Figures 4 and 5.

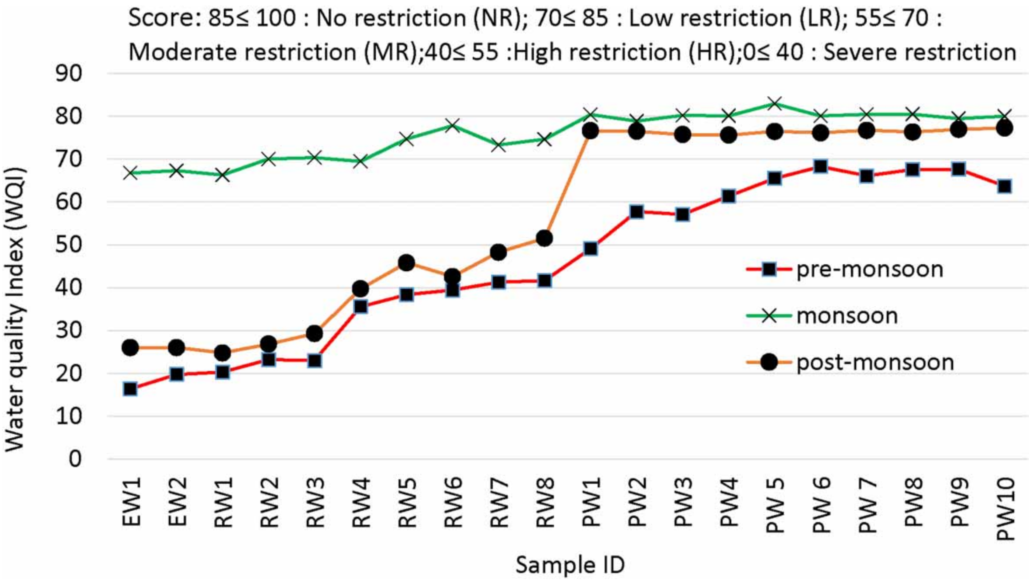

Figure 4 | WQI values of estuaries, rivers, and pond water for irrigation uses.

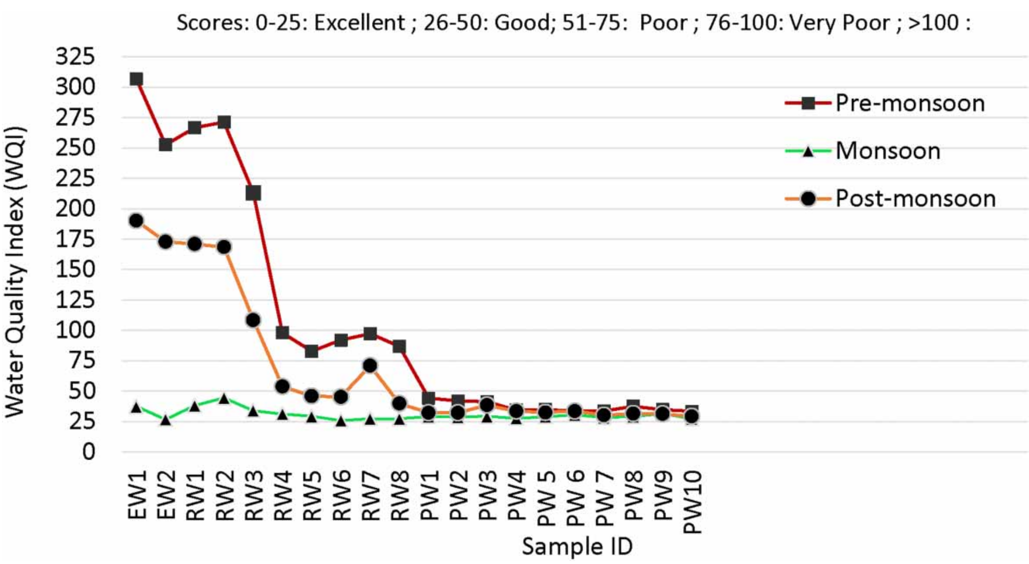

Figure 5 | WQI values of estuaries, rivers, and pond water for domestic uses.

WATER QUALITY ASSESSMENT FOR IRRIGATION PURPOSE USES

The index values showed a high and severe restrictions (scores: 0–55) for the sampling sites of EW1-EW2, RW1-RW8, PW1-PW2 during the pre- and post- monsoon seasons, respectively. The values of other sampling sites for both seasons specified low and moderate restrictions (scores: 55–85). During the monsoon season, low and moderate restrictions were also observed for all of the sampling sites, indicating a better water quality for irrigation purpose usages (Figure 4).

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WATER QUALITY ASSESSMENT FOR DOMESTIC PURPOSE USES

The index values shows an unsuitable water quality (scores $>$100) for the sampling sites of EW1- EW2 and RW1- RW4 for the period of the pre- and post- monsoon seasons, respectively. During the pre-monsoon period, the WQI values of sampling sites RW5- RW10 indicate poor to good water quality (scores: 76–100) as well. During the monsoon season, a good water quality (scores 26–50) was observed for all sampling sites. The index values of pond waters showed good quality in all seasons for the domestic purpose uses (Figure 5).

The study represents the zone-wise possible suitability of irrigation water quality during the pre-monsoon and monsoon seasons (Figure 6). The figure shows the seasonal variation of water quality in the coastal areas, which demonstrates the quality of the perspective of irrigation purpose uses.

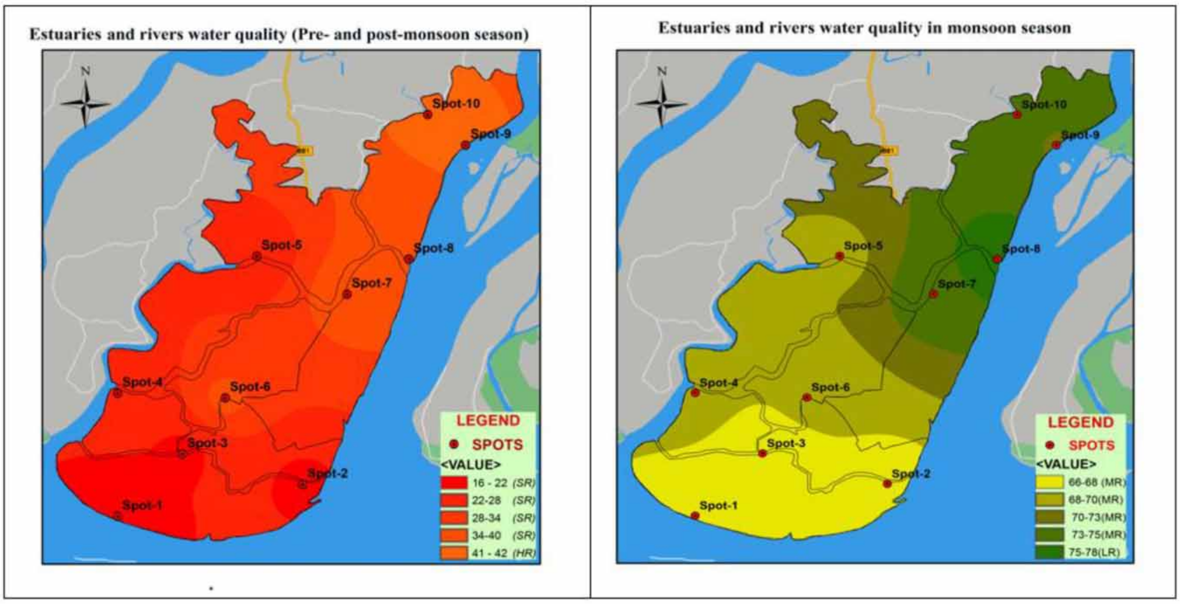

Figure 6 | Estuaries and rivers water quality map in the (a) pre- and post-monsoon, and (b) monsoon season.

CONCLUSIONS

The values of some physical parameters such as dissolved oxygen (DO) and pH were found to be within an acceptable range; however, the EC, TDS values were found to exceed the permissible limit of the DoE, WHO, and FAO standards. The predominant ions, such as Na^+ and Cl^-, were found to exceed the selected standards during the pre- and post-monsoon seasons. The mean concentration of cations in surface water followed the order $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ in order of abundance throughout all the seasons, whereas anions showed seasonal variations. The concentration of predominant anions was $Cl^- > SO_4^{2-} > HCO_3^-$ during the pre-monsoon season, and their orders were HCO_3- $> Cl^- > SO_4^{2-}$ and $Cl^- > HCO_3^- > SO_4^{2-}$, respectively, followed during the monsoon and post-monsoon period. The plentiful ions indicated a Na-Cl water type in the pre- and post-monsoon seasons; however, Na-Cl-HCO_3 water type was dominant during the monsoon season. The scores of water quality index for domestic uses showed a very poor to unsuitable quality (scores: 100 $<$ unsuitable, 76–100: very poor) in most of the surface water except pond water, especially in the pre- and post-monsoon periods. The scores of surface waters (estuaries, rivers, etc.) quality index for irrigation purpose usages was found to be high to severely restricted (score: 0–55) in the period of pre- and post-monsoon seasons. The study concluded that most of the estuary and river water quality was found to

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be unsuitable for irrigation as well as domestic purpose uses during the pre- and post-monsoon seasons in the coastal watershed of Bangladesh.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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