Spatio-Seasonal Variations of Salinity and Associated Chemical Properties in the Middle Section of Karnaphuli River Water, Chittagong, Bangladesh Using Laboratory Analysis and GIS Technique

Sajal Roy, Md. Akhtaruzzaman, and Biswajit Nath

***Abstract*—This research was performed to assess the concentration of cations and anions associated with salinity of different sampling locations (SL) in the middle section of Karnaphuli river (KR) water in two seasons. The mean values of pH and electrical conductivity (EC) of all the SL were found to be 7.23 and 3.74 mS/cm in pre-monsoon while 6.87 and 1.04 mS/cm in monsoon. The average values of chloride, bi-carbonate, sulfate and phosphate were found to be 3.50, 1.31, 3.85 and 1.08 folds higher in pre-monsoon compared to monsoon as confirmed through the laboratory analysis. In contrast, the mean contents of calcium, magnesium, potassium and sodium in pre-monsoon were found to be 2.16, 3.13, 2.54 and 2.84 times higher compared to monsoon period. The values of all parameters among the SL differed significantly ($p<0.05$) in the two seasons. In the ArcGIS Spatial analyst tool, Surface interpolation technique of Inverse Distance Weighted (IDW) method was further utilized to get the variations of KR water. Moreover, the results of this study will be helpful for river management planners to take early protection from further deterioration of the quality of KR water to certain extent.**

***Index Terms*—Anion, cation, Karnaphuli river, monsoon, pre-monsoon, salinity, sampling location.**

I. INTRODUCTION

Bangladesh is a riverine country which is criss-crossed by numerous rivers. Karnaphuli river (KR) is one of the largest and the most important rivers that originated from the Lushai hills in Mizoram of India and flows 270 kilometers south-west through Chittagong Hill Tracts and Chittagong into the Bay of Bengal (BOB) [1]. The coastal regions of Bangladesh (CRB) cover 32% of the country consisting of 19 districts which accommodate more than 35 million people [2]. In recent years, the south and south west parts of Bangladesh were severely affected by coastal salinity. Increased salinity from saltwater (SW) intrusion poses an imminent threat to the people of the CRB through affecting the agriculture, aquaculture, infrastructure, coastal ecosystems, and the availability of freshwater for household and commercial use [3]. Paucity of safe drinking water, scarcity of irrigation water and poor agricultural production are common problems of the coastal regions because of increasing salinity in the soil and water [4].

The KR river water has been extensively used for multiple purposes, like bathing, fishing, hydraulic power generation, irrigation etc. The KR has great importance in Chittagong [5]. The intrusion of SW in the coastal areas was identified as a major problem around the world, especially in the low-lying regions [6]. The rate of salinity intrusion in CRB is observed to be much higher than that of previous years [7]. This intrusion of SW greatly influences the physico-chemical and biological properties of the coastal rivers [8]. Several researchers investigated the water quality of KR in terms of heavy metal pollution and some chemical perspective especially, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), etc. and found the quality of parameters highly deviated from the standard value [5], [9], [10].

Moreover, In CRB, soil salinity has been considered a major constraint to food grain production [11]. Water salinity causes an increase in soil salinity which further decreases the agricultural productivity. The excess presence of sodium in irrigation water reduces the permeability of soil, deteriorates drainage condition and ultimately affects crop production [12], [13]. Increasing intrusion of SW increases the degree and extent of saline areas and restricts normal crop production. Bangladesh is no exception from these effects. The coastal regions of Bangladesh have marked an area of 2.85 million hectares, where about 0.833 million hectares were recognized as saline soils which is now estimated to be 1.06 million hectares [14].

Salinity in aquatic ecosystem is expressed by the total amount of such dissolved cations as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), and such anions as chloride (Cl^-), carbonate (CO_3^{2-}) bicarbonate (HCO_3^-) and sulfate (SO_4^{2-}) which can be measured by determining total dissolved solids (TDS) or electrical conductivity (EC) [15], [16]. In recent time, adjoining to KR, the research on water quality of river Halda, Bangladesh was assessed by [17]. However, there is no previous research work available in the context of combination of laboratory and modern geographical information (GIS) system in the KR. By observing the lack of research concerning the present theme and objectives in the study area, it is utmost important to conduct this study in the MSKR water. It is worth mentioning that, the middle section of it was identified as a polluted area by the direct influence of several industries located along the

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bank of KR. Therefore, it is necessary to investigate the parameters of water associated with salinity that affect the KR water at different locations in two different seasons. Moreover, it is also important to investigate the nature and changing pattern of multiple parameters of SW of MSKR in the spatial and seasonal context.

Therefore, the objectives of this study are to determine the pH, EC, concentrations of cations (e.g., Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions (e.g., $Cl^–$, $SO_4^{2–}$, $CO_3^{2–}$, $HCO_3^–$ and PO_4^{3-}) from the MSKR water collected from different SL in two different seasons (pre-monsoon and monsoon) of the year 2018.

II. Materials and Methods

A. Study Area

The KR is strongly influenced by the tidal action in its estuary part which meets with the BOB in the south. The KR is recognized as the most important and largest river in Chittagong. The total length of KR is 270 km, where its mouth meets with the Bay of Bengal and its source location is in Saitah, Mizoram, India. Karnaphuli or Khawthlangtuipui (in Mizo, meaning “western river”), is the largest and considered as the most important river in Chittagong and the Chittagong Hill Tracts. The KR divides the Chittagong district into two parts, one is confined with the city and port in the meandering section of the KR and another is the heavy industrial area. The Chittagong city is mostly concentrated with urban areas located in the western bank of KR with a population estimated over 5.02 million [18] and predominantly they depend on the KR water. The maximum and minimum temperature is above 35℃ and 24.5℃ from February to November. The Chittagong division is situated in the eastern parts of Bangladesh which is covered by hills with north-south trending folded mountain range. The surface geology of the area consists of beach and dune sand formation and valley alluvium and colluvium type.

In the present study, very specific area is considered which is middle section of KR and is referred to MSKR, because of its being directly influenced by the several heavy industrial wastes and nearby agricultural runoff into the water. The aquatic life of the KR is under threat due to the pollution and oil spill leakage by the tankers in different times that caused several environmental degradation.

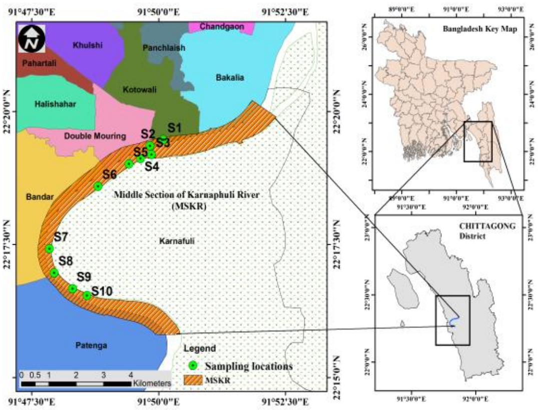


Fig. 1. Location of the study area (MSKR) and its sampling sites (green dot symbol represents sampling sites from S1 to S10).

The MSKR extents from $22^0 15^/ 45^{//}$ N to $22^0 20^/ 20^{//}$ N latitude and $91^0 47^/ 35^{//}$ E to $91^0 52^/ 15^{//}$ E longitude approximately with area of only 9.53 km^2. Fig. 1 shows location of MSKR along with locations of WS used in this study.

B. Water Sample Collection, Measurement Process and Laboratory Analysis

The present study was carried out in the MSKR where a total of 60 WS were collected from ten SL (See Table S1). From each station, three samples were collected by simple random sampling method and considered to get the mean values. All the SL are represented in Fig. 1. The first SL was started from the locality called Avoymitra ghat and continued toward the confluence of sea which ended beside Super Petro Chemical Private Ltd. industry at SL 10. The WS were collected in plastic bottles in two different seasons of the year including GPS measurements of the same points, one in pre-monsoon (April) and another in monsoon (July). Thereafter, WS were transported to the laboratory of Department of Soil Science, University of Chittagong, Bangladesh for immediate analysis for pH and EC. For the purposes of chemical analysis, all samples were filtered with Whatman No. 42 filter paper to remove suspended particles. After determination of $Cl^–$, few drops of concentrated hydrochloric acid (HCl) was added and stored in refrigerator (4℃) to avoid any microbial growth [19]. The preserved water samples were analyzed for the determination of associated chemical properties such as cations and anions. The average monthly rainfall data of the particular year (2018) from January to December [20] is shown in Fig. 2.

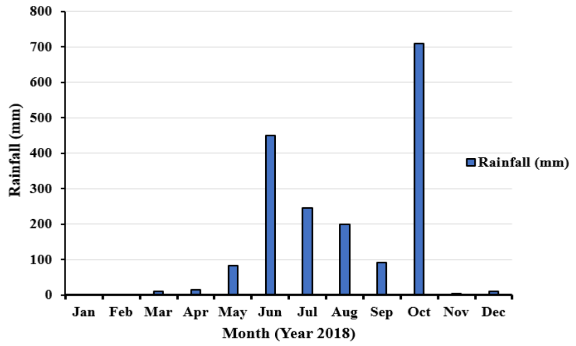


Fig. 2. Average monthly rainfall of the year 2018 (January–December) in Chittagong station [20].

pH and EC were determined by glass electrode pH (Seven CompactTM pH/Ion S220) meter and EC meter (Adwa AD 330) by following standard method. The salinity hazard (EC) classification was described following the guidelines provided by [21]. The determination of Cl^- was performed by titrimetric method where 5 ml water sample was titrated against standard 0.05 N silver nitrate after adding 2-3 drops of $K_2Cr_2O_4$ with water. The concentration of $CO_3^{2–}$ and $HCO_3^–$ were determined individually by titration of 5 ml water sample with standard 0.05 N H_2SO_4 acid after adding 2-3 drops of phenolphthalein and 2-3 drops of methyl orange indicators respectively for $CO_3^{2–}$ and $HCO_3^–$. The concentration of PO_4^{3-} and $SO_4^{2–}$ were determined by spectrophotometer (SP 3000 nano Optima) at the spectral lines of 880 nm and 420 nm wavelengths, by following the ascorbic acid blue color and turbidimetric methods using Tween-80, respectively. The determination curves coefficients obtained from spectrophotometer for PO_4^{3-} and SO_4^{2-} are y= 0.6700x (RSQ= 0.9994) and y= 0.0240x (RSQ= 0.9896), respectively. The above analyses were performed by following the method described in [22]. The concentration of major cations like Na^+, K^+, Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrometer (AAS) (Agilent Technologies 200 Series AA). The concentration of all cations was measured using curves of standard solutions of analytical grade that prepared from stock solution supplied by Scharlab S.L, Spain.

C. Statistical Data Analysis, Interpretation and GIS Mapping

To determine the specific differences between pairs of means of the obtained results, the Duncan's Multiple Range Test (DMRT) method [23] was performed by using statistical packages for social sciences (SPSS version 16). The standard deviation and correlation analyses were then performed in the same software. In addition to our present results, we have computed the percentage of specific cations and anions out of total concentrations of cations and anions in two different seasons using the following formula:

$$PSI = \frac{Xi}{\sum X} \times 100$$

where, *PSI* is the percentage of specific ion either cation or anion, and *Xi* is the concentration of individual ion, and $\sum X$ is the sum of either cations or anions.

In the later stage, to further illustrate the data, based on the values found from laboratory analysis, most important parameters related to salinity such as pH, EC, Na^+, Cl^- were considered for GIS map visualization. More specifically, to monitor the MSKR water status, first we considered the MSKR boundary as a shapefile which masked out from the world river database, later modified and matched with the Google earth (GE) for validation and finally used for masking operation. The map of individual parameter was prepared to visualize the changes of the MSKR in two different seasons by the inverse distance weighted (IDW) method of spatial analyst tool box of ArcGIS 10.6 software. The IDW method is found better to know the water quality (WQ) of the MSKR. To determine the status of MSKR, four distinct maps of pH, EC, Na^+, Cl^- were prepared by considering natural breaks (Jenks) method during image classification and then data values were rounded in two decimal places. For map visualization, similar color code index gradient was applied on each classified image starting with low values (brick red) to high values (deep blue).

Finally, the samples sites were categorized into different classes indicating whether water is suitable or not for irrigation purposes based on the standard ranges of pH [24], salinity hazard [21], percent sodium (% Na) [21] and magnesium ratio (MR) [25].

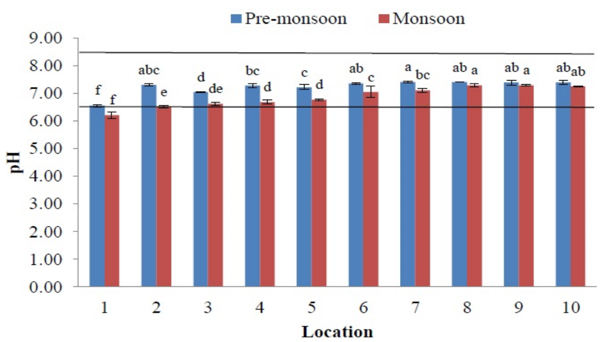
III. Results and Discussion

Based on the aforementioned analytical procedures the following results have been found:

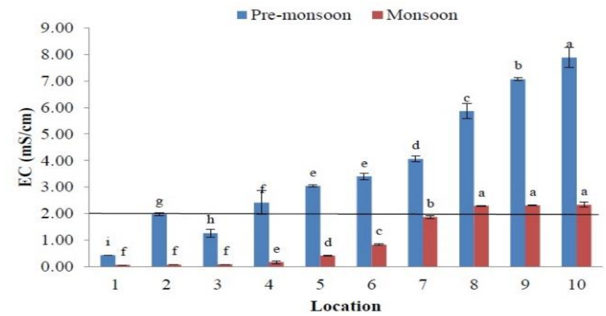
A. pH and EC

Fig. 3 shows the mean values of pH and EC of WS collected from different SL at two different seasons. pH of the WS ranged from 6.50 to 7.40 with an average value of 7.23 in pre-monsoon and 6.20 to 7.29 with a mean value of 6.87 in monsoon, respectively (Fig. 3a) indicating slightly acidic to slightly alkaline in nature. In pre-monsoon, the lowest pH was recorded in SL-1 and highest in SL-7. On the other hand, the lowest and highest pH values were found in SL-1 and SL-9 respectively. The values of pH among the SL varied significantly ($p<0.00$) at 5% level of significance in both pre-monsoon and monsoon.

In pre-monsoon, EC of WS varied between 0.45 to 7.88 mS/cm (Fig. 3b) and the mean value of all the SL was 3.74 mS/cm. The maximum EC was recorded at SL-10 whereas the minimum EC was found at SL-1. The EC of SL-5 and SL-6 did not differ significantly. On the other hand, during monsoon the value of EC ranged from 0.06 to 2.33 mS/cm with a mean of 1.04 mS/cm. Similar to pre-monsoon, the highest EC value was observed at SL-10 and lowest at SL-1 respectively. In monsoon, no significant differences in EC values were observed among SL-1, 2, 3, and SL-8, 9, 10. However, in both seasons the mean values of EC among all SL significantly varied ($p<0.00$) at 5% level of significance. The mean value of EC was observed to 3.60 folds higher in pre-monsoon compare to monsoon. However, in pre-monsoon season, 30% of the WS possess EC less than 2.0 mS/cm, 30% posses 2.0-4.0 mS/cm and 40% possess greater than 4.0 mS/cm. On the contrary, 70% of the WS were less than 2.0 mS/cm, whereas, 30% were observed within the range of 2.0-4.0 mS/cm during monsoon.



(a)

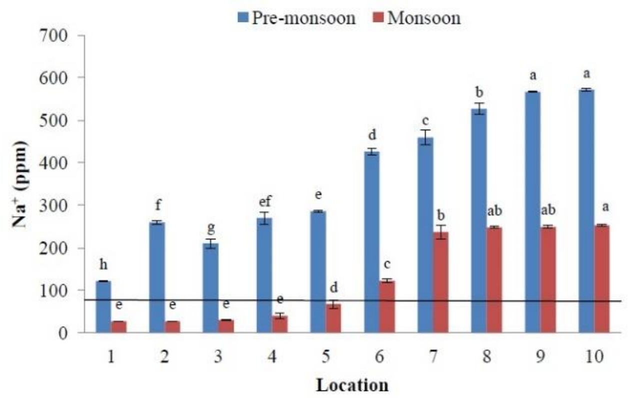


(b)

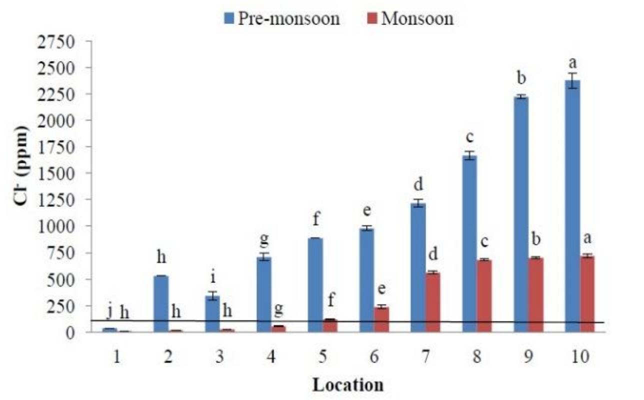
Fig. 3. pH and EC (mS/cm) measurement based on WS collected from different SL in two different seasons. Means followed by the same letter (s) in both (a and b) do not differ significantly from each other at 5% level of significance. The horizontal lines in Fig. 3(a) indicate the range of suitability of water and in Fig. 3(b) indicate maximum permissible limit for irrigation purposes, respectively.B. Concentration of $Na^+$and Cl^-

The minimum concentration of Na^+ was detected in SL-1 and maximum in SL-10 in both pre-monsoon and monsoon seasons. In pre-monsoon period, the concentration of Na^+ ranged from 121.87 to 571.91 ppm with an average of 369.9 ppm whereas in monsoon, it ranged from 27.13 to 252.87 ppm with a mean content of 130.2 ppm (Fig. 4a). WS collected from SL-10 contained 4.69 and 9.32-folds more Na^+ than SL-1 in both pre-monsoon and monsoon seasons. However, the average content of sodium of all the sampling locations in pre-monsoon was 2.84 times higher in comparison to monsoon.

It is evident from Fig. 4b that the concentration of Cl^- varied from 35.5 to 2378.5 ppm with an average concentration of 1098.13 ppm during pre-monsoon and 8.88 to 718.88 ppm during monsoon season having an average value of 313.32 ppm. The concentration of Cl^- at SP-10 was observed to 67- folds higher than SP-1 in pre-monsoon, while it was 81- folds higher at SP-10 compared to SL-1 in monsoon. In monsoon, SL 1-4 did not differ significantly though there was significant differences among rest of the SL ($p<0.00$). Similarly, in pre-monsoon there was significant differences ($p<0.00$) among all the SL at 5% level of significance. The mean content of Cl^- of all samples was observed to 3.50 times higher in pre-monsoon compared to monsoon.



(a)



(b)

Fig. 4. Concentration of Na^+ (ppm) and Cl^- (ppm) of WS collected from different SL in two different seasons. Means followed by the same letter (s) in both (a and b) do not differ significantly from each other at 5% level of significance. The horizontal lines in Fig. 4a and Fig. 4b indicate the standard limits [26] (70 ppm and 100 ppm for Na^+ and Cl^-, respectively) of water for irrigation purposes.

B. Concentration of Associated Cations (K^+, Ca^{2+} and Mg^{2+})

The mean concentrations of K^+, Ca^{2+} and Mg^{2+} of all the SL in both seasons are given in Table I. The concentration of K^+ increased gradually from SL-1 to SP-10 with the exception of SL-3. K^+ concentration varied from 13.27 to 32.78 ppm with a mean content of 24.49 ppm in pre-monsoon and 2.08 to 18.62 ppm with a mean of 9.64 ppm in monsoon period (Table I). The average concentration of K^+ in pre-monsoon was 2.54- folds higher compared to monsoon. In SL-10, the content of potassium was 2.47 times higher compared to SL-1 in pre-monsoon and 8.95 times higher in monsoon.

From Table I, it is revealed that Ca^{2+} content of WS ranged from 15.67 to 53.33 ppm having an average value of 29.13 ppm in pre-monsoon and from 5.5 to 23.50 ppm with a mean concentration of 13.48 ppm in monsoon. The mean value of Ca^{2+} was found to be 2.16- folds more in pre-monsoon in comparison to monsoon. The lowest concentration was found in SL-2 and SL-1 in pre-monsoon and monsoon seasons respectively whereas, the highest concentration was found in SL-9 in both seasons.

Magnesium content was found to vary from 15.20 to 171.20 ppm with an average value of 83.88 ppm and 5.90 to 54.90 ppm with an average content of 26.77 ppm during pre-monsoon and monsoon periods, respectively (Table I). The concentration of Mg^{2+} in SL-10 was 11.26 and 9.25 times higher compared to SL-1 in pre-monsoon and monsoon respectively. The average concentration of Mg^{2+} was found to 3.13 times higher in pre-monsoon compared to monsoon.

C. Concentration of Associated Anions (HCO_3^-, SO_4^{2-} and PO_4^{3-})

The mean concentrations of HCO_3^-, SO_4^{2-} and PO_4^{3-} of all the SL in both seasons are given in Table II. The concentration of HCO_3^- varied from 146.40 to 185.03 ppm during pre-monsoon and 78.30 to 162.70 ppm during monsoon with average values of 158.40 ppm and 121.19 ppm respectively. The average concentration of HCO_3^- was found to 1.31- folds greater in pre-monsoon in comparison to monsoon. Similar to Cl^-, HCO_3^- concentration gradually increased which was 1.26 times higher in SL-10 compared to SL-1 in pre-monsoon season.

In monsoon, the concentration of HCO_3^- also found to 2.08 times higher in SL-10 compared to SL-1. Moreover, the concentration of CO_3^{2-} was also studied but had not been detected in WS collected from all SL both in pre-monsoon and monsoon seasons.

The concentration of SO_4^{2-} ranged from 18.82 to 40.55 ppm with an average content of 29.82 ppm and 0.79 to 15.20 ppm with an average concentration of 7.74 ppm during pre-monsoon and monsoon seasons, respectively. The concentrations of SO_4^{2-} also gradually increased from SP-1 to SP-10 except SP-3 in pre-monsoon. The water sample collected from SL-10 contained 2.15 times more SO_4^{2-} compared to SL-1 in pre-monsoon, whereas in monsoon, the concentration was 17.70 times greater in SL-10 in comparison to SL-1. The average concentration of SO_4^{2-} of all the samples in pre-monsoon was 3.85-folds greater compared to monsoon.

TABLE I: CONCENTRATION OF ASSOCIATED CATIONS (PPM) IN WS OF DIFFERENT SAMPLING POINTS IN TWO DIFFERENT SEASONS

Location	Potassium (K^+)		Calcium (Ca^{2+})		Magnesium (Mg^{2+})	
	Pre-monsoon	Monsoon	Pre-monsoon	Monsoon	Pre-monsoon	Monsoon
Site-1	13.27^{f}±0.12	2.08^{e}±0.09	22.00^{f}±1.00	5.50^{h}±0.50	15.20^{h}±0.92	5.90^{h}±0.46
Site-2	19.23^{e}±0.78	2.22^{e}±0.05	15.67^{h}±0.58	6.00^{gh}±0.00	46.20^{f}±2.40	7.50^{g}±0.30
Site-3	13.70^{f}±1.09	2.38^{e}±0.09	16.33^{gh}±1.53	6.50^{fg}±0.00	37.20^{g}±2.67	8.30^{g}±0.35
Site-4	21.77^{d}±2.36	3.06^{e}±0.39	26.67^{e}±3.21	7.00^{f}±0.50	51.00^{f}±2.16	10.70^{f}±0.96
Site-5	25.02^{c}±0.28	4.22^{d}±0.12	18.67^{g}±1.53	8.67^{e}±0.29	70.40^{e}±2.11	15.40^{e}±0.46
Site-6	26.28^{c}±0.25	10.62^{c}±0.46	25.33^{e}±0.58	13.17^{d}±0.58	75.00^{e}±3.65	21.40^{d}±1.14
Site-7	28.87^{b}±0.47	16.06^{b}±0.88	32.00^{d}±0.00	19.83^{c}±0.58	90.20^{d}±1.93	41.10^{c}±1.08
Site-8	31.48^{a}±0.24	18.89^{a}±0.61	35.67^{c}±0.58	22.33^{b}±0.76	122.60^{c}±2.27	50.80^{b}±0.75
Site-9	32.53^{a}±0.12	18.25^{a}±0.63	53.33^{a}±3.06	23.50^{a}±0.50	159.80^{b}±7.41	52.00^{b}±0.46
Site-10	32.78^{a}±0.61	18.62^{a}±0.41	45.67^{b}±0.58	22.33^{b}±0.29	171.20^{a}±8.32	54.60^{a}±1.31
p value	0.00	0.00	0.00	0.00	0.00	0.00
Drinking water quality standards [27]	12		100		150	

Note: Means followed by the same letter (s) do not differ significantly from each other at 5% level of significance

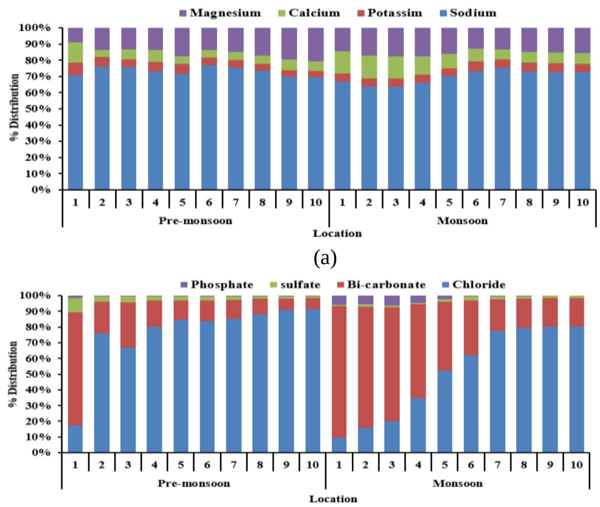
TABLE II: CONCENTRATION OF ASSOCIATED ANIONS (PPM) IN WS OF DIFFERENT SAMPLING POINTS IN TWO DIFFERENT SEASONS

	Bi-carbonate (HCO_3^-)		Sulfate (SO_4^{2-})		Phosphate (PO_4^{3}-)	
Location	Pre-monsoon	Monsoon	Pre-monsoon	Monsoon	Pre-monsoon	Monsoon
Site-1	146.40^{cd}±6.10	78.3^{f}±3.50	18.82^{e}±1.03	0.79^{f}±0.06	2.89^{f}±0.19	5.34^{b}±0.96
Site-2	140.30^{de}±0.00	86.4^{ef}±8.80	24.66^{d}±1.63	1.50^{ef}±0.05	3.48^{e}±0.51	6.32^{b}±0.69
Site-3	148.43^{cd}±7.04	91.5d^{ef}±0.00	20.15^{e}±0.88	1.55^{ef}±0.02	1.91^{g}±0.18	7.98^{a}±1.03
Site-4	144.37^{d}±7.04	96.6^{de}±8.80	26.00^{d}±0.88	1.82^{e}±0.12	2.30^{g}±0.20	7.36^{a}±0.59
Site-5	132.17^{e}±7.04	101.7^{d}±8.80	28.46^{c}±2.17	3.79^{d}±0.11	3.26^{ef}±0.39	5.76^{b}±0.40
Site-6	156.57^{c}±7.04	132.2^{c}±8.80	30.01^{c}±1.34	10.24^{c}±0.81	4.57^{bc}±0.16	2.07^{c}±0.02
Site-7	168.77^{b}±7.04	147.4^{b}±8.80	34.82^{b}±1.02	14.35^{b}±0.45	4.45^{cd}±0.31	2.10^{c}±0.15
Site-8	180.97^{a}±7.04	157.6^{ab}±8.80	35.62^{b}±1.17	15.20^{a}±0.29	3.99^{d}±0.29	2.02^{c}±0.03
Site-9	180.97^{a}±7.04	157.6^{ab}±8.80	39.13^{a}±0.93	14.22^{b}±0.37	5.79^{a}±0.08	0.86^{d}±0.16
Site-10	185.03^{a}±7.04	162.7^{a}±8.80	40.55^{a}±1.58	13.98^{b}±0.98	5.00^{b}±0.34	0.87^{d}±0.07
p value	0.00	0.00	0.00	0.00	0.00	0.00
Drinking water quality standards [27]	-		200		6.0	

Note: Means followed by the same letter (s) do not differ significantly from each other at 5% level of significance.

Phosphate concentrations in WS collected from first five stations were comparatively higher in monsoon season than that of the pre-monsoon period and conversely, WS of the rest five SL contained higher amount of PO_4^{3-} in pre-monsoon season. However, the average PO_4^{3-} concentration in monsoon was 1.08 times greater in comparison to pre-monsoon. The concentration of PO_4^{3-} ranged from 1.91 to 5.79 ppm during pre-monsoon, while, it varied from 0.86 to 7.98 ppm during monsoon season. The highest concentration was found in SL-3 and lowest in SL-9 in monsoon while the maximum content was found in SL-9 and lowest in SL-3 in pre-monsoon. Moreover, the mean concentration of HCO_3^-, SO_4^{2-} and PO_4^{3-} among all the SL varied significantly ($p<0.00$) in both seasons at 5% level of significance.

The concentrations of major cations and anions in the MSKR water varied both spatially and temporally. Abundance of these ions was in the following order: $Na^+ > Mg^{2+} > Ca^{2+} > K^+ = Cl^- > HCO_3^{2-} > SO_4^{2-} > PO_4^{3-}$ during both pre-monsoon and monsoon periods (Fig. 5).



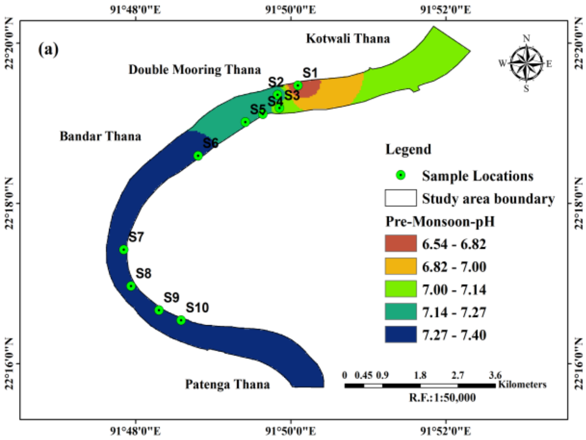
(a)

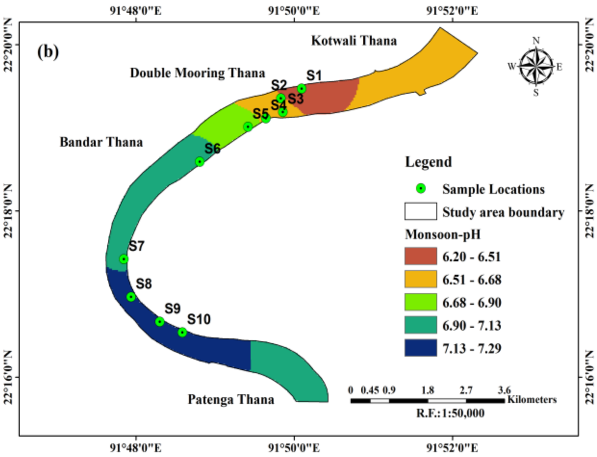
(b)

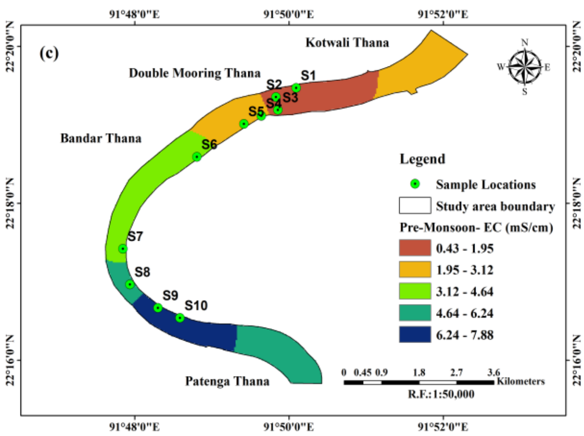
Fig. 5. Percentage (%) distribution of cations and anions in WS collected from different SL in two different seasons. Fig. 5(a) represent percentage distribution of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), and Fig. 5(b) represent percentage distribution of anions (Cl^-, HCO_3^-, SO_4^{2-}, PO_4^{3-}), respectively.

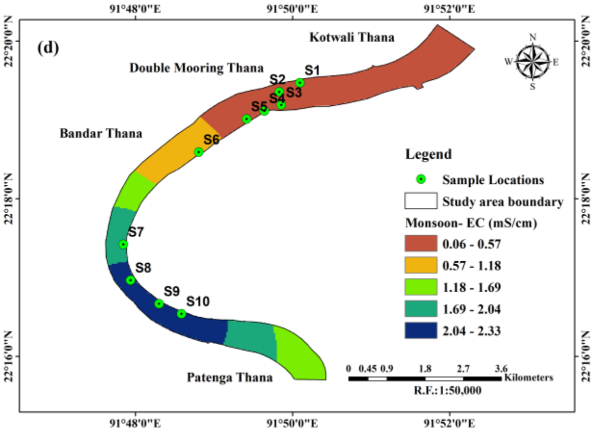
D. Spatio-Seasonal Variations of Water Quality Parameters

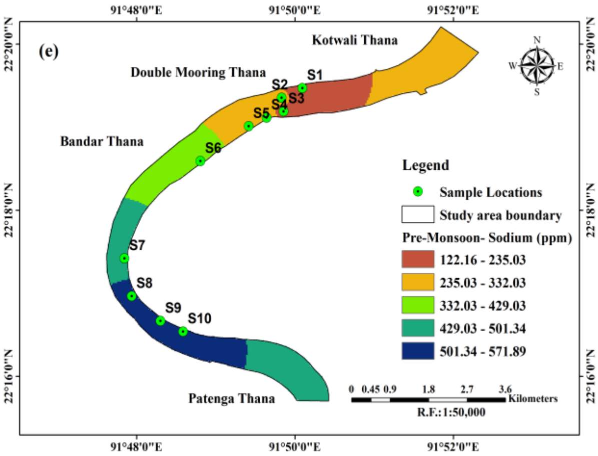
The spatio-seasonal variation of MSKR water quality represented an increase in values of parameters like pH, EC, cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) and anions (Cl^{-}, HCO_3^{-}, SO_4^{2-}, PO_4^{3-}) in pre-monsoon season compared to monsoon season. However, out of the ten SL datasets, the study further utilize only four important parameters such as pH, EC, Na^{+} and Cl^{-} in the ArcGIS 10.6 mapping environment for geospatial data visualization and rest of the parameters represented in Table I and II as concentration of cations and anions, respectively. In the mapping exercise, IDW based maps of the above mentioned parameters in both seasons are highlighted the spatio-seasonal variations of MSKR (Fig. 6a-h).

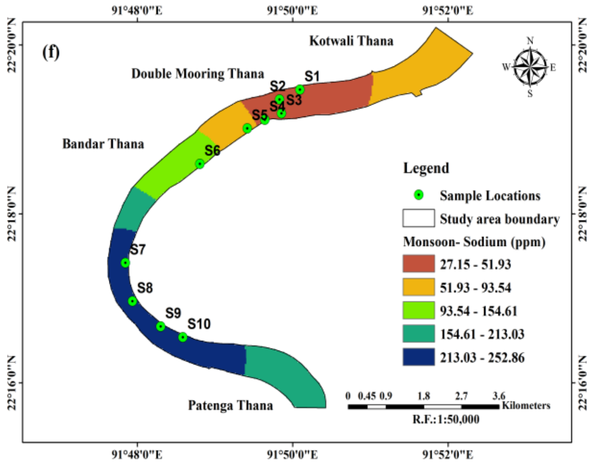


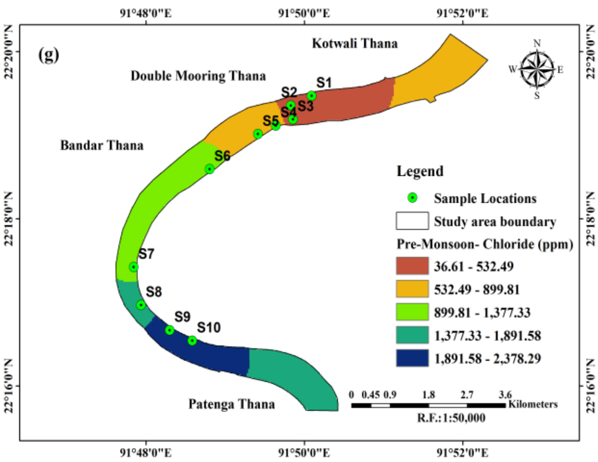












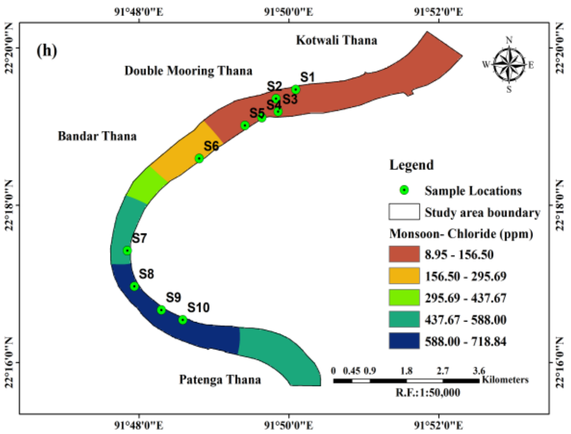


Fig. 6. Percentage (%) multi-parameters water quality assessment of MSKR in pre-monsoon and monsoon seasons based on 10 sampling sites. Fig. 6(a-h) pre-monsson and monsoon scenarios for the selective parameters are sequentially represented: (a) pH (pre-monsoon), (b) pH (monsoon), (c) EC (pre-monsoon), (d) EC (monsoon), (e) sodium (pre-monsoon), (f) sodium (monsoon), (g) chloride (pre-monsoon), and (h) chloride (monsoon).

Moreover, the classified maps were representing the spatio-seasonal variations based on the highest and lowest concentrations of values of individual parameters. The individual parameter based classified maps were prepared in five class ranges by following natural breaks (Jenks) method available in the classification window of ArcGIS 10.6 software which represents with the low to high values (brick red to deep blue color) (Fig. 6a-h). In Fig. 6a pH in pre-monsoon have mixing nature before meeting at SL-1, then the value sharply increased even after SL-10 towards the confluence area. On the contrary, in monsoon season due to influence of rainfall and dilution effects of water, pH value sharply reduced from SL-1 to SL-7 (Fig. 6b) compared to pre-monsoon. The EC values were gradually increasing from SL-1 to SL-10 in pre-monsoon (Fig. 6c), whereas it was 3.5 fold lower than pre-monsoon as observed from SL-1 and it continued beyond SL-10 (Fig. 6d). In connection with, Na^+ values were found in mixing condition in pre-monsoon before met at SL-1, which further gradually increased till SL-10 and then slightly decreased near to Patenga area (Fig. 6e). The scenario has been different in monsoon (highest Na^+ values observed within the range of 213.03-252.86 ppm) (Fig. 6f) compared to pre-monsoon season (value observed from 501.34-571.89 ppm (Fig. 6e). The Cl^- values of the first five stations (SL 1-5) had mixing behavior compare to rest of the stations (SL 6-10), which gradually increased from 899.1 to till 2378.29 ppm (Fig. 6g). Conversely, the scenarios have been different in monsoon season throughout the entire MSKR (Fig. 6h) approximately 3.5 folds lower than pre-monsoon season. Thus, large scale changing phenomena of each parameter was clearly distinguished in the MSKR before its meeting point in the BOB.

Considering the concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} in meq/l, the % Na^+ values for different SL were computed whereas MR was calculated by using the contents of Ca^{2+} and Mg^{2+} in meq/l. The % Na^+ ranged from 65.80 in SL-5 to 71.88 in SL-6 with an average value of 67.76 in pre-monsoon, whereas it varied from 57.39 in SL-3 to 70.78 in SL-7 with an average of 64.26 in monsoon. The value of MR ranged from 53.51 to 86.20 with an average value of 79.89 in pre-monsoon and from 64.12 to 80.29 with the mean value of 73.49 in monsoon period. The highest and lowest values of MR were found in SL-1 and SL-10 respectively both in pre-monsoon and monsoon. Further, on the basis of pH, salinity hazard (EC), % Na^+ and MR, WS were categorized into different suitability classes used for irrigation purposes (Table III). Based on salinity hazard, first seven WS from starting point during monsoon season were found within the permissible limit (2.0 mS/cm) and the rest three WS were identified as doubtful (2.0-3.0 mS/cm) for irrigation purposes. On the contrary, during pre-monsoon season, only three WS from starting point were within the permissible limit (2.0 mS/cm), and the last six WS were unsuitable (>3.0 mS/cm) for irrigation. Considering the % Na^+, all the WS were found in the category of doubtful (60-80) in pre-monsoon. On the other hand, SL-2, 3 and 4 were within the permissible limit (40-60) whereas SL-1 and SL-5 to 10 were found in doubtful category (60-80).

TABLE III: CLASSIFICATION OF THE WS BASED ON THE SUITABILITY CLASSES FOR IRRIGATION

Parameters	Range	Classification	Number of samples	
			Pre-monsoon	Monsoon
pH (DoE, 2008)	6.5-8.5		All samples	All samples except site- 1
Salinity hazard (EC) (mS/cm) (Wilcox, 1955)	<0.250	Excellent		Sites- 1, 2, 3 and 4
	0.25-0.75	Good	Site- 1	Site- 5
	0.75-2.0	Permissible	Site- 2 and 3	Site- 6 and 7
	2.0-3.0	Doubtful	Site- 4	Site- 8, 9 and 10
	>3.0	Unsuitable	Site- 5, 6, 7, 8, 9 and 10	
Percent sodium (%Na) (Wilcox, 1955)	<20	Excellent		
	20-40	Good		
	40-60	Permissible		Site- 2, 3 and 4
	60-80	Doubtful	All samples	Site- 1, 5, 6, 7, 8, 9 and 10
	>80	Unsuitable		
Magnesium ratio (MR) (Palliwal, 1972)	>50%	Suitable	All samples	All samples
	<50%	Unsuitable		

From the statistical analysis, it was found that the correlation between EC with all cations and anions in pre-monsoon were significant and positive (Table IV). The correlations between cations and anions in both seasons were also found highly significant and positive with the exception of PO_4^{3-}. The correlations of PO_4^{3-} with other parameters were found to be negative and significant (Table V).

The dominance of Na^+ and Cl^- in MSKR water plays an important role in controlling river water salinity. The pH of KR water under study in both seasons was within the permissible limit of 6.0-8.5 for irrigation purposes set by [24] and also within the standard pH of 6.5-9.0 for aquatic life [27]. Depending on EC, water is classified as non-saline: <0.7 mS/cm, slightly saline: 0.7-2.0 mS/cm, moderately saline: 2-10 mS/cm, highly saline: 10-25 mS/cm and very highly saline: 25-45 mS/cm [28]. Accordingly, 10% of the WS were found to be non-saline, 20% were in the category of slightly saline and 70% were in the group of moderately saline in pre-monsoon period.

TABLE IV: CORRELATION AMONG THE PARAMETERS OF WS FOR ALL STATIONS IN PRE-MONSOON

	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	PO_4^{3-}
pH	1									
EC	0.692*	1								
Na^+	0.784**	0.959**	1							
K^+	0.796**	0.937**	0.692**	1						
Ca^{2+}	0.462	0.903**	0.855**	0.809**	1					
Mg^{2+}	0.673*	0.997**	0.951**	0.921**	0.909**	1				
Cl^-	0.696*	0.998**	0.956**	0.933**	0.913**	0.998**	1			
HCO_3^-	0.475	0.867**	0.882**	0.765**	0.890**	0.865**	0.859**	1		
SO_4^{2-}	0.764**	0.973**	0.978**	0.983**	0.869**	0.965**	0.972**	0.834**	1	
PO_4^{3-}	0.556*	0.826**	0.862**	0.838**	0.809**	0.833**	0.832**	0.746**	0.865**	1

** Correlation is significant at the 0.01 level 1-tailed Pearson correlation)
* Correlation is significant at the 0.05 level 1-tailed Pearson correlation)

TABLE V: CORRELATION AMONG THE PARAMETERS OF WS FOR ALL STATIONS IN MONSOON

	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	PO_4^{3-}
pH	1									
EC	0.914**	1								
Na^+	0.921**	0.995**	1							
K^+	0.932**	0.992**	0.995**	1						
Ca^{2+}	0.934**	0.997**	0.996**	0.996**	1					
Mg^{2+}	0.919**	0.998**	0.989**	0.986**	0.993**	1				
Cl^-	0.914**	1.000**	0.994**	0.990**	0.996**	0.999**	1			
HCO_3^-	0.970**	0.975**	0.981**	0.989**	0.985**	0.973**	0.974**	1		
SO_4^{2-}	0.941**	0.969**	0.984**	0.990**	0.980**	0.957**	0.965**	0.987**	1	
PO_4^{3-}	-0.826**	-0.905**	-0.916**	-0.931**	-0.915**	-0.890**	-0.899**	-0.916**	-0.936**	1

** Correlation is significant at the 0.01 level 1-tailed Pearson correlation)
* Correlation is significant at the 0.05 level 1-tailed Pearson correlation)

On the other hand, in monsoon, half of the collected WS were found within the group of non-saline, 20% as slightly saline and 30% as moderately saline. According to [29], water is classified on the basis of EC into different suitability groups as suitable: <2.0 mS/cm, marginally suitable: 2.0-4.0 mS/cm and unsuitable: >4.0 mS/cm. The study [30] stated that water with EC less than 0.7 mS/cm can be used for irrigation without any restriction, whereas EC within the range of 0.7-3.0 mS/cm has slight to moderate restriction and EC greater than 3.0 mS/cm has severe restriction on use for irrigation. The study showed that WS in maximum sites at monsoon period were considered suitable for irrigation.

According to the classification method of the researcher [30], the concentrations of $HCO_3^{2-}$and SO_4^{2-} in WS were found to be lower than the permissible limit of 600 ppm and 900 ppm set for irrigation water, respectively. On the other hand, the concentration of Cl^- in WS of all SL (except SL-1) in pre-monsoon season and the WS collected from SL-6 to10 in monsoon exceeded the standard limit of 142 ppm. In pre-monsoon, PO_4^{3-} content increased from upward to downward while in monsoon season, it decreased from upward to downward direction of the MSKR. However, the concentration in all WS was within the standard level of 10 ppm for irrigation water set by [24]. But the PO_4^{3-} value in the MSKR under present study was found to be higher than that of other rivers of Bangladesh. In Bangladesh, the average PO_4^{3-} concentration of WS in Gorai river was between 0.34 ppm and 0.40 ppm in post monsoon and pre monsoon, respectively [31]. On the contrary, in major river systems of Sundarbans, it ranged between 0.33-0.41 ppm and 0.09-0.37 ppm in post monsoon and winter seasons respectively [32]. Excessive use of PO_4^{3-} fertilizer in the nearby agricultural lands in the region seems to be an important anthropogenic source of phosphorus in MSKR water samples under study. The researcher [5] reported that waste water from soap and detergent industries on the bank of KR tends to increase phosphorus concentration in water. Phosphorus is one of the major limiting nutrients in maintaining water quality and also a pollutant leading to eutrophication [33], [34]. Therefore, the findings on eutrophication in KR need more study in future.

The values of Ca^{2+} of all WS were within the acceptable limits of 400 ppm, whereas Mg^{2+}contents of first four WS in pre-monsoon and all water samples in monsoon period were below the permissible limits of 60 ppm for irrigation [30]. From the data it was obvious that the concentrations of Ca^{2+} and Mg^{2+} in water of MSKR under the present study were found higher than that of the other rivers of Bangladesh. The study [31] reported that the concentrations of Ca^{2+} and Mg^{2+} in Gorai river of Bangladesh varied between 40.8 ppm and 7.32 ppm in post monsoon and between 45.6 ppm and 8.4 ppm in pre-monsoon periods. Higher levels of Ca^{2+} and Mg^{2+} in the river water under study are possibly associated with runoff of waste water from cement industries along the river bank where limestone, dolomites, calcite, gypsum etc. are used. The author [35] reported that the discharge of untreated effluents from different industries into the KR contribute to higher levels of metals in water. The higher levels of Mg^{2+} in comparison to Ca^{2+} in WS in both seasons under present study may be due to differences in solubility of Mg^{2+} and Ca^{2+}. The study [36] also reported that sea water contribute to the increase of Mg^{2+} content in river water near coastal areas because of its abundance next to Na^+ in sea water. The concentrations of Na^+ and K^+ in WS under study area were found to be higher in both seasons compared to the standard value of 6.5 and 1.2 ppm, respectively for Na^+ and K^+ in river water [22]. Based on the %Na^+, the results showed that all the WS in pre-monsoon season, seven of them fall in doubtful category (60-80) and three samples were found within the permissible limit of 40-60 during monsoon period [21]. Naturally, Ca^{2+} and Mg^{2+} maintains an equilibrium state in fresh water body. Soil quality and crop yield are adversely affected if Mg^{2+} content is high in water by causing alkaline nature of water [37]. All the samples of river water under study were found to be unsuitable for irrigation during both seasons when considered maximum allowable limit (50) of the MR [25].

In the coastal areas, the contents of cations and anions associated with salinity of the rivers are higher in the dry season compared to the monsoon because of lack of freshwater input from upstream. From October (post-monsoon) to late May (pre-monsoon), salinity generally increases with the gradual reduction in the freshwater flow. The salinity level drops in the wet season, usually during September or early October as a result of rainfall and increased upstream flow of freshwater [38]. The study [39] reported higher levels of EC, TDS, salinity, cations and anions in pre-monsoon compared to the other seasons which may be attributed to the reduced upstream freshwater inflow because of low rainfall during this period. The author [40] also reported that increased concentration of electrolyte because of relatively high rate of evaporation during dry season. Besides, lower levels of EC, TDS and other metal have been reported due to dilution effect of the ionic composition of the water resulting from precipitation during monsoon season [41], [42]. The spatio-seasonal variation in EC as well as cations and anions of MSKR water indicates that there is a significant increase in concentrations of these parameters from upper section to downward direction under the present study in both seasons reflecting the influences of anthropogenic and natural activities, sea water-freshwater interactions. Research [43] stated that the salinity of coastal regions of Bangladesh vary from place to place due to variation in the fluctuation of groundwater and seasonal variation.

IV. Conclusion

It was evident from the present study that the salinity level as well as the concentration of cations and anions except phosphate in MSKR water increased with the progressing of distance towards the confluence of the river where it meets with the sea (BOB). The two different season based major parameters maps including other associated cations and anions results clearly represent the spatio-seasonal variation of MSKR water. The concentrations of major cations and anions varied significantly and it was observed in the descending order of concentration: $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and $Cl^- > HCO_3^{2-} > SO_4^{2-} > PO_4^{3-}$ in both pre-monsoon and monsoon seasons. The higher concentration of these parameters in pre- monsoon compared to monsoon season was also clearly evident which may be due to the dilution effect of the river water in monsoon period. Moreover, statistical analyses also support the salinity and its associated cations and anions which were found strongly correlated (1-tailed 0.05 level and 0.01 level significant) each other. The present study further suggests more SL points consideration, multi-seasonal and multi-year investigation as well as the study of entire KR channel in future to know the KR water variability in detail with the aid of GIS and remote sensing techniques.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Sajal Roy contributed in research design, sample collection, sample analysis, statistical analysis and manuscript preparation. Md. Akhtaruzzaman contributed in writing and reviewing the manuscript. Biswajit Nath contributed in IDW interpolation, GIS mapping and its methodological description, statistical analysis, and contributing in initial manuscript writing. Sajal Roy and Biswajit Nath both have later contributed in the revision of the manuscript in final form.

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