Journal of Geoscience and Environment Protection, 2019, 7, 131-151
http://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Assessment of Groundwater Quality in a Tidal River Basin of the Ganges Delta in Bangladesh

Sadhon Chandra Swarnokar[1*], Nazia Hassan[1], Masudur Rahman[1], Md. Muhyminul Islam[2], Mosummath Hosna Ara[3]

[1]Environmental Science Discipline, Life Science School, Khulna University, Khulna, Bangladesh
[2]Department of Environmental Science and Disaster Management, Bangabandhu Sheikh Mujibur Rahman Science & Technology University, Gopalganj, Bangladesh
[3]Chemistry Discipline, Science, Engineering and Technology School, Khulna University, Khulna, Bangladesh
Email: *skswarnokar.es10@gmail.com, munnazia_ku@yahoo.com, gkm.buet@gmail.com, muhyminul24@gmail.com, hosnaara1@gmail.com

How to cite this paper: Swarnokar, S. C., Hassan, N., Rahman, M., Islam, M. M., & Ara, M. H. (2019). Assessment of Groundwater Quality in a Tidal River Basin of the Ganges Delta in Bangladesh. *Journal of Geoscience and Environment Protection, 7,* 131-151.
https://doi.org/10.4236/gep.2019.75013

Received: April 9, 2019
Accepted: May 27, 2019
Published: May 30, 2019

Abstract

At Shailmari River basin, located in the central Ganges Delta and the south-western coastal Bangladesh, groundwater is the only potable source for water supply due to incompatible surface water sources. However, salinity degradation along with arsenic and iron contamination poses a serious health threat to the basin community. Considering this, an investigation was carried out along both banks of the river to assess groundwater vulnerability and its quality for drinking by conducting multi-seasonal water sampling campaigns from 20 domestic wells and analyses (both in-situ and laboratory) for several physico-chemical (pH, EC, TDS and major ions) and biological (coliforms) parameters. The results show slightly alkaline groundwater in the study area with largely variable chemical composition, i.e. EC varies from around 1900 to 2700 μS/cm. The abundance of major ions indicates as $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ for cations and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$ for anions. As per the Canadian water quality index (CCMEWQI), almost all groundwater samples concentrate in the marginal category meaning that groundwater is frequently threatened. Besides, it is not fully safe for drinking as revealed from comparison of geochemical data with national and WHO water quality standards.

Keywords

Groundwater Quality, Hydrogeochemistry, Major Ions, CCME WQI, Tidal Delta, Geochemical Process, Bangladesh

1. Introduction

The quality and quantity of ground water reflects the life and health issues of any region that sustain the ripple of drinking and domestic uses in coastal environment worldwide (Banks et al., 1998). In developing countries, anthropogenic factors, geological structure and mineralogy of both watersheds and aquifers play a substantial role in controlling the ground water quality (Drever, 1988; Apello & Postma, 2005; Bahar & Reza, 2010). Being an agro based country, Bangladesh possesses 5,049,785 ha agro-arable land which depends on adequate water supply from both groundwater (80.60%) and surface water (19.40%) of usable quality (Shahid et al., 2006; Hasan et al., 2007; Vyas and Jethoo, 2015; Islam et al., 2016). Usually, ground water is a critical concern in coastal Bangladesh as the people in this region are highly reliant on it for sustaining their livelihoods (Hasan et al., 2013). More than 50 million inhabitants of coastal area depend on ground water for encountering their drinking, domestic and irrigation uses, directly related to poor drinking water quality attributed by water borne pathogens, fecal coli forms and various toxic pollutants (UNESCO, 2007; Kumar et al., 2009; Chitradevi & Sridhar, 2011; Pethick & Orford, 2013). Coupled with low socio-economic condition, people in the this region are the worst sufferers due to fresh and safe water crisis in both shallow and deep tubewells as a function of geochemical interactions, coastal hazards, salinity intrusion and major anthropological activities (sewage disposal, over withdrawal of fresh water, agricultural application etc.) (Rahman et al., 2000; Chidambaram et al., 2009; ADB, 2011; Sappa et al., 2015). Batiaghata is a part of south-western coastal region under Khulna division where subsequent encroachment of saline water is the most severe (Karim et al., 1990; Bahar & Reza, 2010). During dry season, almost 80% people rest on ground water fed irrigation and approximately 97% people depend on drinking water supplies that come from groundwater via hand-operated tubewells (Shamsudduha et al., 2009). Agriculture is the dominant governing occupational practice with shrimp farming throughout the year in this region where ground water executes a persistent threat with risk of salinity intrusion in ground water (Karim et al., 1990; Mondal et al., 2006; Bahar & Reza, 2010). The situation becomes worse in prolonged dry period. Therefore, befitting ground water sources can provide guarantee for the safe water both for domestic uses and irrigation practices. Studies on the surface water quality of Shailmari River System of this area has been already done, but information on ground water is unrevealed yet (Islam et al., 2016). Hence, a detailed investigation of shallow and deep tubewells along the bank of Shailmari River connected with Rupsha-Kazibacha River system could be a very realistic study to assess the quality of groundwater through hydro-chemical investigation and water quality indexing.

2. Materials and Methods

2.1. Salient Features of the Study Area

The study area is a part of Rupsha-Kazibacha River system of the Shailmari River under Khulna districtis confined between the longitude 89˚31'18.6" and 89˚28'31.9" East and the latitude 22˚44'45.1" and 22˚46'23.8" North (**Figure 1**) of

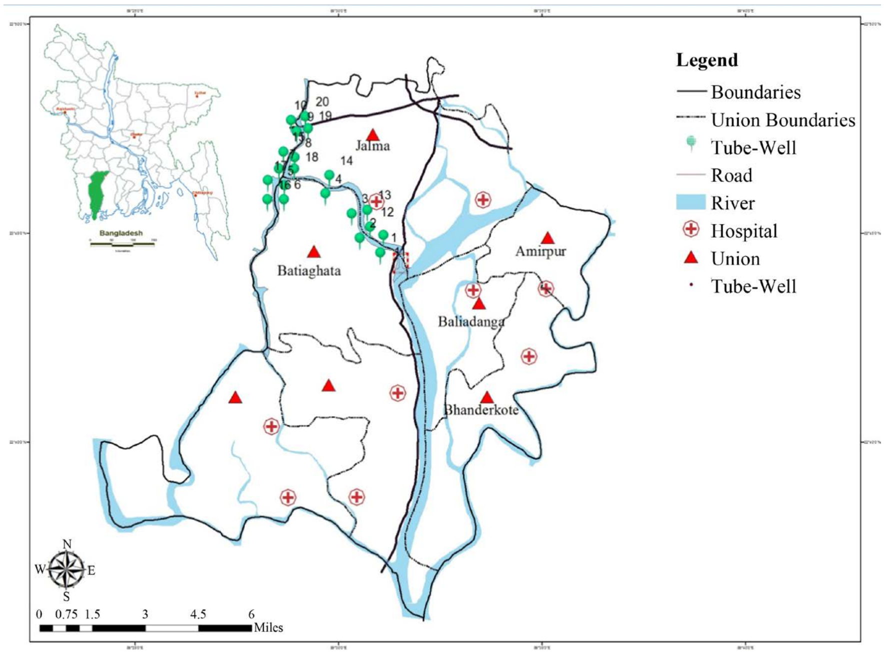


Figure 1. Location of the sampling stations in the study area.

which 607.80 km^2 is riverine and 2028.22 km^2 is under forest (Roy et al., 2005). The present study was conducted particularly on three riverine unions i.e. Jalma on the left bank, Batiaghata and Dumuria on the right bank of the river in the context of its hydro-geochemical characterization and suitability evaluation. The hydro chemical characteristics of this river system are mostly controlled by unique climatic variation, local geologic and anthropogenic structure. It is highly attributed by widespread shrimp farming, agro farming, livestock, poultry industries, brick kiln and other industries (Islam et al., 2016).

2.2. Geology and Hydrology of the Study Area

The study area is characterized by the Quaternary alluvial sequence marking the Halocene to Recent Alluvium deposits (Alam, 1990). Hydrogeological properties of this area are therefore, largely governed by the litho-stratigraphy and prevailing tectonic features of this region (ADB, 2011). The present study involves the deep hydrogeology of Batiaghata, which consists of a confined and deep Pleistocene aquifer where deposition of sediments helped the formation of aquifers with high transmissivity and storage in this region (Rahman et al., 2011). The hydrogeology of the Khulna region has generally been marked as a three aquifer systems separated by aquitards composed of clay minerals (**Figure 2**) (ADB, 2011; DPHE-JICA, 2015). The upper or first aquifer is semi-confined, shallow Holocene aquifer type and occurs at a depth of 50 to 100 m from the surface which consists of gray fine to very fine sand and overlain by 5 - 45 m thick silty clay aquitard (ADB, 2011). The second aquifer encounters at depth around 150 to 270 m below the surface and extends up to 350 m in places which is confined to leaky confined in nature and serves as the main aquifer in most parts of the

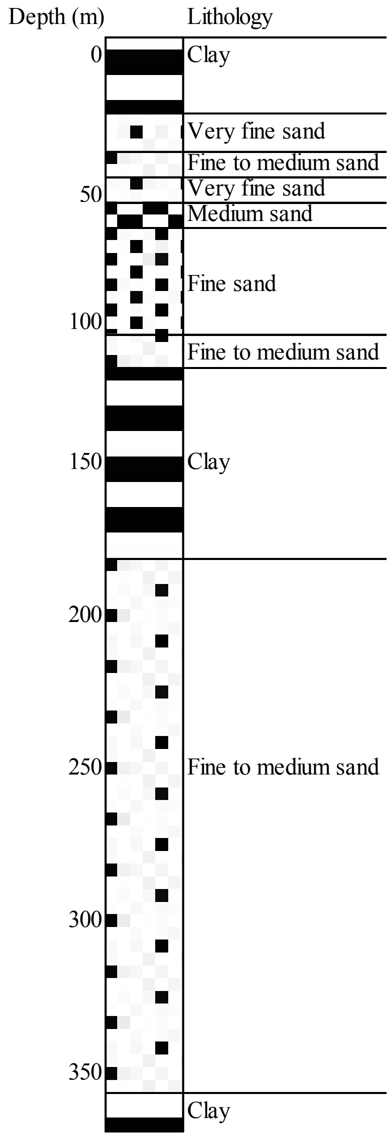


Figure 2. Lithological cross section of the aquifer system in the study area (adapted from ADB, 2011; DPHE-JICA, 2015).

study area. The aquifer is dominated by gray very fine to medium sand, underlain by gray clay aquitard and is separated from the upper shallow aquifer by a thick clay aquitard. The third aquifer is the deepest aquifer and occurs below 350 m from the ground surface (ADB, 2011; DPHE-JICA, 2015). The study area is also governed by sub-tropical and humid climatic pattern which experiences hot summer in pre-monsoon from March to May, while receives 80% of total annual rainfall during monsoon from June to September. The pre-monsoon and winter is fed by lesser precipitation with coastal hazards and livelihood extremes (FAO, 2011).

2.3. Water Sample Collection and Preparation

A well suited reconnaissance survey was performed prior to select the sampling station to optimize the consumption pattern of the people. The number tubewells were selected through the purposive (Non -probability) sampling technique from both bank of the Shailmari river basin. Water samples were collected for four successive seasons from each sampling locations following the guidelines of standard methods APHA, 1999 throughout the study period. For cationic and anionic analyses samples were collected in 500 ml PET bottles and preserved by adding HCl (to pH ~ 2) for cationic samples. Then samples were carried to the laboratory and conserved at 4˚C prior to laboratory analysis (APHA, 1999; Huang et al., 2014). The number of samples in total 80 regarding four consecutive seasons namely, Pre-monsoon (May, 2014), Monsoon (August, 2014), Post-monsoon (October, 2014) and winter season (March, 2015) [10 from left bank and 10 from right bank for each season] (**Figure 1**). The sample station ID, owner of the tubewells, depth and number of households depend on those tubewells are listed in **Table 1**.

Table 1. Sampling location of the study area.

SS	R.B	Location	Owner	Coordinate		Age (yrs.)	Depth (feet)	HH
				Longitude (N)	Latitude (E)			
1	LB	Hatibaty Govt. Primary School	Public	22˚44'30.7"	89˚31'02.8"	5	480	10
	RB	Guptomari Govt. Primary School	Public	22˚44'52.9"	89˚31'04.1"	12	470	20
2	LB	Hugolbunia	Unicef	22˚44'48.5"	89˚30'29.2"	3	450	20
	RB	Soighoria Biswas Bari	Unicef	23˚45'02.4"	89˚30'32.9"	4	430	10
3	LB	Hugolbunia	Unicef	22˚45'23.3"	89˚30'13.1"	6	470	25
	RB	Bodnakhali Rishi Bari	NGO	22˚45'20.2"	89˚30'29.1"	6	440	16
4	LB	Balabari	Union council	22˚45'53.6"	89˚29'39.9"	14	450	22
	RB	Hugolbunia Mali Bai	Public	22˚46'06.0"	89˚29'39.9"	19	470	35
5	LB	Sardarbari	Unicef	22˚46'05.5"	89˚28'32.0"	7	470	30
	RB	Uttor Sailomari Kheaghat	Unicef	22˚46'19.6"	89˚28'38.2"	11	420	25
6	LB	Kasari Bari	Invidual	22˚45'51.1"	89˚28'39.2"	18	480	15
	RB	Dhanibunia Moholder Bari	Individual	22˚45'44.0"	89˚28'13.0"	8	440	20
7	LB	Dumuria brick yield	Individual	22˚46'27.7"	89˚28'35.7"	8	490	15
	RB	Dumuria brick yield	Individual	22˚46'20.4"	89˚28'29.9"	14	500	50
8	LB	Labubunia	Public	22˚46'44.8"	89˚28'48.5"	13	500	12
	RB	Tiabunia	Individual	22˚47'00.2"	89˚28'48.3"	11	470	20
9	LB	East Jhiledanga	WDB	22˚47'24.9"	89˚29'02.3"	14	700	10
	RB	Kaiya Bazar	Public	22˚47'22.3"	89˚28'53.3"	16	480	40
10	LB	Jelermor	Individual	22˚47'34.6"	89˚28'55.0"	10	450	20
	RB	Shima Sreti Primary School	Public	22˚47'28.6"	89˚28'51.6"	6	450	10

Note: Here LB_1 to LB_{10} and RB_1 to RB_{10} represent the left bank and right bank sampling station respectively and HH represent House Hold number depends on these tubewells.

2.4. Laboratory Measurement and Hydro-Chemical Investigation

In-situ and laboratory measurement were conducted following the rules prescribed in American Public Health Association and Standard Methods (APHA, 1999; Huang et al., 2014). Some field parameters such as pH, DO, Temperature and EC were conducted instantly at the sampling site by a portable pH, DO meter(HACH sensION156 portable) and EC/TDS meter (HANNA H1-9635) after calibration (APHA, 1999). In the laboratory, sodium (Na^+) and potassium (K^+) were measured using flame photometer (Model No. PEP 7) whereas titration method is used for measuring calcium (Ca^{2+}), magnesium(Mg^{2+}) and chloride (Cl^-) (Ramesh & Anbu, 1996). Bicarbonate (HCO_3^-) concentrations of the groundwater had measured by potentiometric titration method with H_2SO_4. Salinity and TDS were estimated in the laboratory by digital multi-meter (Model No. Bantee900p). Sulphate (SO_4^{2-}), ortho-phosphate (PO_4^{3-}), and nitrate (NO_3^{2-}) of the water samples were analyzed using UV–visible spectrophotometer (Model No.4802 uv/visbouble beam Spectophotometer) (APHA, 1999). Total hardness (TH) of the groundwater was calculated using the formula given by Sawyer et al. (2003). For microbiological analysis, 500 ml water samples were aseptically collected in sterile Nalgen plastic bottles. All samples were placed in an insulated box filled with ice packs (Johnny Plastic Ice; Pelton Shepherd, Stockton, CA, USA) immediately after collection and transported to the Environmental Microbiology Laboratory of Environmental Science Discipline at Khulna University. We counted the concentration of Total Coliform (TC) and Faecal Coliform (FC) using the membrane filtration technique. Membrane filters, through which water sample was passed, were aseptically placed onto m-FC and m-Endo agar base plates followed by Hi-media procedures (APHA, 1999). The m-Endo plates were incubated at 35˚C ± 0.2˚C for 24 h for enumeration of TC whereas for FC estimation, incubation was done at 44˚C - 45˚C. After incubation, characteristic pink colored colonies were counted as TC and blue colored colonies were counted as FC, expressed as colony forming units (cfu) per 100 ml.

2.5. Ground Water Quality Monitoring Methods

Water quality monitoring is a vital part of any environmental monitoring program owing to reporting the results in both from societal and environmental point of view. The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) produces a number between 0 (worst water quality) and 100 (best water quality) while numbers are divided into 5 descriptive categories: Excellent (CCME WQI Value 95 - 100), Good (CCME WQI Value 80 - 94), Fair (CCME WQI Value 65 - 79), Marginal (CCME WQI Value 45 - 64) and Poor (CCME WQI Value 0 - 44) in a mathematical framework (CCME, 2001). For assessing ambient water quality conditions in respective water quality objectives, water samples were ranked to simplify the degree of vulnerability. Three vital elements are incorporated in this index: scope (F_1)—the number of variables not meeting water quality objectives; frequency (F_2)—the number of times these objectives are not met; and amplitude (F_3)—the amount by which the objectives are not met was calculated using the formula demonstrated in Table 2 (CCME, 2001; Rocchini & Swain, 1995). To evaluate the suitability of water samples for drinking and domestic purposes were compared with both WHO (World Health Organization) and Bangladesh Drinking Water Quality standards corresponding the determined values of the physico-chemical parameters of the water samples (Ahmed & Rahman, 2000; WHO, 2011).

3. Results and Discussions

3.1. Groundwater Hydrochemistry

To achieve the analytical insights and accuracy during the study period, the charge balance between cations and anions were found within ±10% by repetitive analysis after calculating the ionic balance errors (Vyas & Jethoo, 2015; Hounslow, 1995). The analytical results exhibited inclusive hydrochemical variation among the seasons throughout the study period. Figure 3 shows the spatial and temporal variation, while Table 3 shows mean, the standard deviation, and the coefficient of variation between the left and right banks as well as within the seasons. The pH values range from 6.45 to 8.08 with a mean value 7.33 for left bank and range from 6.36 to 7.92 for right bank of Shailmari River. The lowest value is observed in winter and the highest value in monsoon season.

The observed average concentrations of Na^+ and Cl^- were 225.76 ± 39.44 and 284.90 ± 68.00 for left bank and 218.36 ± 54.85 and 256.79 ± 57.58 for right bank respectively. The highest concentration of Na^+ was found 298.35 mg/l in winter and for Cl^- 406.30 mg/l in pre-monsoon season that exhibits the increased salt concentration in the study area. The EC ranges from 1681 µS/cm (monsoon) to 2515 (winter) µS/cm with an average value of 2091.60 µS/cm for right bank. In case of left bank the average concentration of EC was 2121.30 ± 216.40 µS/cm while 2091.60 ± 240.80 µS/cm for right bank. TDS values ranges from 802 mg/l with average concentration within the range of 1106.60 ± 152.70 (Right bank) to 1598 mg/l (Left bank) with an average value of 1146.60 ± 149.90 mg/l. The lowest and highest concentration was found in monsoon and pre-monsoon season respectively. Among the anions, concentration of HCO_3^- was observed higher

Table 2. Mathematical steps followed for CCME WQI.

Scope (F_1)	Frequency (F_2)	Amplitude (F_3)	CCME WQI index
$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variable}}\right) \times 100$	$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right) \times 100$	$F_3 = \left(\frac{\text{nse}}{0.01\,\text{nse} + 0.01}\right)$ where, $\text{excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_j}\right) - 1$ $\text{excursion}_i = \left(\frac{\text{Objective}_j}{\text{Failed test value}_i}\right) - 1$ $\text{nse} = \frac{\sum_i^n \text{excursion}_i}{\#\text{ of tests}}$	$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$

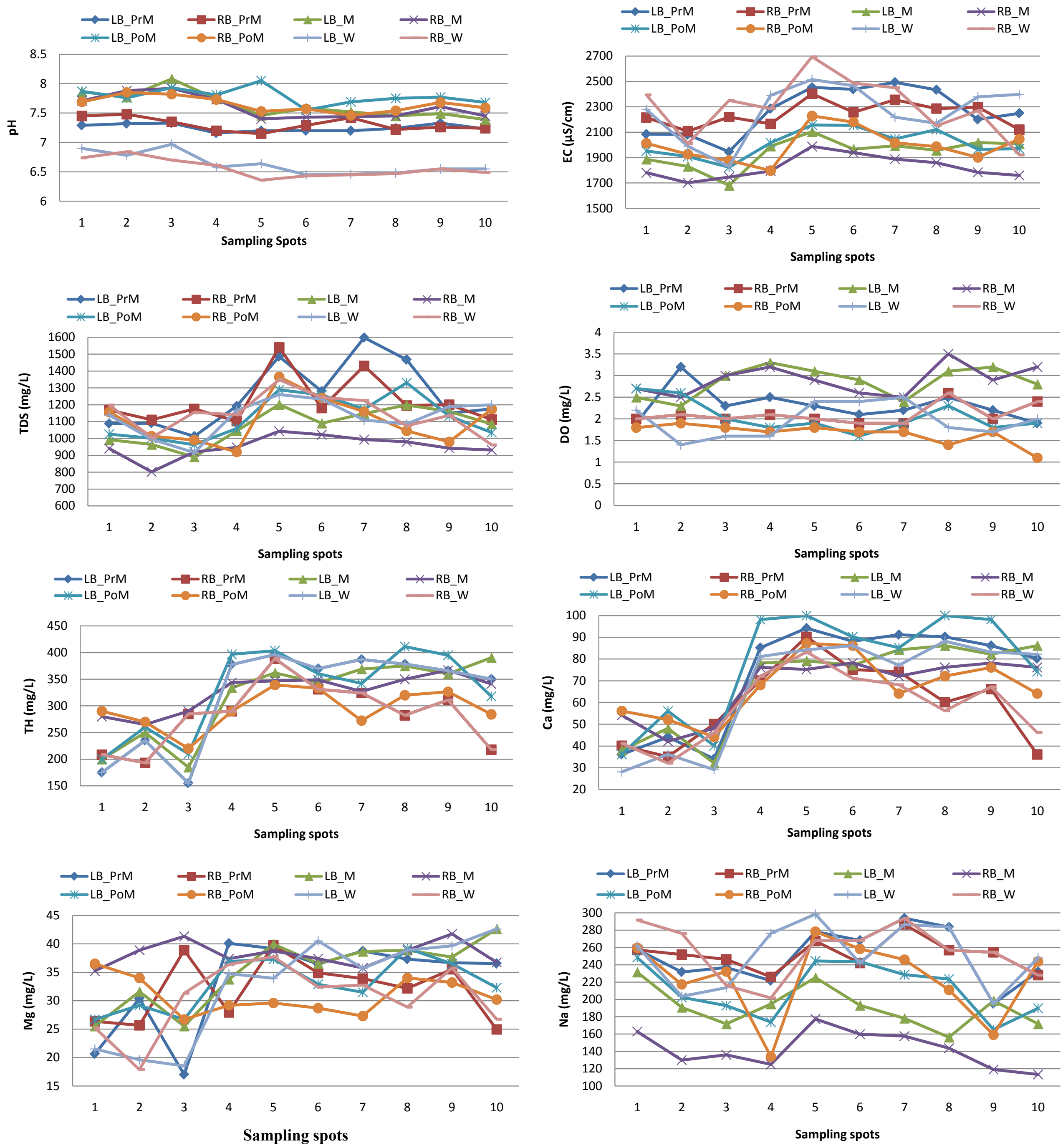
Table 3. Physicochemical parameters of groundwater samples in tidal delta, Bangladesh.

Bank: *Season*	Function	pH	EC	TDS	DO	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	FC	TC
		-	μS/cm	mg/L												MPN/100 ml	
Left bank: *Pre-monsoon*	Mean	7	2266	1254	2	319	72.9	33.3	249.9	5.3	456.2	336.5	1.5	0.9	0.1	4	560
	Stdev.	0.1	188.2	197.7	0.4	93.1	24.5	8.1	31.4	1.3	79.1	50.2	0.6	0.2	0.1	4.7	452.6
	CV	0.9	8.3	15.8	16.3	29.2	33.6	24.4	12.6	24.7	17.3	14.9	41.9	24.6	114.3	118.4	80.8
Left bank: *Monsoon*	Mean	8	1944	1077	3	317	69.2	35.1	191.1	7.2	502.5	231.7	1.5	0.5	0.2	5	520
	Stdev.	0.2	118.3	104.4	0.4	75.9	21.1	5.9	23.5	1.4	77.5	39.0	0.2	0.3	0.1	6.6	671.3
	CV	2.9	6.1	9.7	12.2	24.0	30.5	16.8	12.3	19.6	15.4	16.8	10.5	55.3	58.9	122.3	129.1
Left bank: *Post-monsoon*	Mean	8	2012	1127	2	330	77.8	32.9	211.2	4.7	530.2	250.1	0.5	0.5	0.2	4	290
	Stdev.	0.1	109.4	130.4	0.4	80.3	25.1	4.5	30.5	0.4	62.8	43.9	0.3	0.7	0.1	4.3	299.8
	CV	1.8	5.4	11.6	17.7	24.4	32.3	13.6	14.4	9.4	11.8	17.5	50.6	157.4	37.3	120.2	103.4
Left bank: *Winter*	Mean	7	2264	1129	2	319	67.6	32.6	250.8	6.1	440.5	321.3	0.1	1.8	1.3	0	610
	Stdev.	0.2	217.4	107.2	0.4	93.1	25.4	9.2	36.8	1.3	105.6	71.7	0.0	1.1	0.4	0.7	709.4
	CV	2.8	9.6	9.5	20.2	29.2	37.6	28.2	14.7	21.1	24.0	22.3	34.4	62.9	32.0	174.8	116.3
Right bank: *Pre-monsoon*	Mean	7	2243	1221	2	283	59.7	32.0	251.6	5.2	504.5	291.7	0.6	0.1	0.2	5	700
	Stdev.	0.1	96.3	145.8	0.2	61.4	18.8	5.5	17.9	1.0	19.9	36.3	0.2	0.1	0.1	5.0	623.6
	CV	1.6	4.3	11.9	10.8	21.7	31.4	17.1	7.1	19.3	3.9	12.5	36.1	112.3	20.9	104.3	89.1
Right bank: *Monsoon*	Mean	8	1825	952	3	326	67.6	38.2	142.4	8.1	464.8	187.0	1.5	0.5	0.2	6	910
	Stdev.	0.2	91.3	66.6	0.3	34.8	13.9	2.2	21.2	1.5	56.6	28.1	0.3	0.2	0.1	5.8	560.7
	CV	2.6	5.0	7.0	11.5	10.7	20.5	5.6	14.9	18.9	12.2	15.0	17.3	39.2	57.1	97.5	61.6
Right bank: *Post-monsoon*	Mean	8	1998	1105	2	295	67.0	30.9	223.9	5.2	505.8	254.0	0.6	0.1	0.2	4	520
	Stdev.	0.1	132.4	138.0	0.2	36.5	14.0	3.3	45.8	1.0	52.6	52.1	0.2	0.1	0.1	4.0	505.1
	CV	1.7	6.6	12.5	14.3	12.4	20.9	10.6	20.5	19.3	10.4	20.5	36.1	112.3	20.9	115.3	97.1
Right bank: *Winter*	Mean	7	2301	1149	2	283	58.3	30.5	255.5	7.7	453.2	294.4	0.2	2.8	1.0	2	890
	Stdev.	0.2	229.9	114.7	0.2	61.4	16.5	6.0	31.2	1.5	63.0	34.6	0.0	1.1	0.5	1.8	811.7
	CV	2.4	10.0	10.0	10.8	21.7	28.2	19.8	12.2	19.7	13.9	11.8	31.4	39.1	55.9	94.3	91.2
Guideline for drinking	BD	6.5 - 8.5	-	1000	6.0	500*	75	35*	200	12	-	600*	400	10	6	0	0
	WHO		1400		-		200	150		12	240	250	250		-		

Note: EC = Electrical conductivity, TDS = Total dissolved solids (TDS), DO = Dissolved oxygen, TH = Total hardness, FC = Faecal coliform, TC = Total coliform. *Maximum allowable limit for drinking in Bangladesh (BD) is used here for TH (200 - 500 mg/L), Mg^{2+} (30 - 35 mg/L) and Cl^- (150 - 600 mg/L).

in post-monsoon 590 mg/l with the variation of 482.40 ± 87.30 mg/l for left bank. For right bank the higher concentration was 594 mg/l ranges with mean variation 482.07 ± 54.30 mg/l. Variation of HCO_3^- could be recognized to the bicarbonate weathering coupled with wastewater mixing into the ground water during the sampling seasons (Chitradevi & Sridhar, 2011). Ca^{2+} and Mg^{2+} were the second and third in cationic abundance mentioned in Table 3. During the study EC, TDS, Na^+ and Cl^- were observed higher in pre-monsoon indicating potential salinization. This phenomenon might be attributed by reduced upstream freshwater inflow, geochemical interactions and presence of paleo brackish water in the river pathways while dense precipitation headed to dilute the concentrations in monsoon and consecutive post-monsoon seasons (Mondal et al., 2013). Higher load of sulfate and nitrate in dry period might be coming from weathering, erosional deposits, leaching or leakage to adjacent sewage disposal to the ground water.

Hardness is one of the significant parameters for determining the type and nature of water classified in terms of degree of hardness as 1) soft (<75 mg/l), 2)



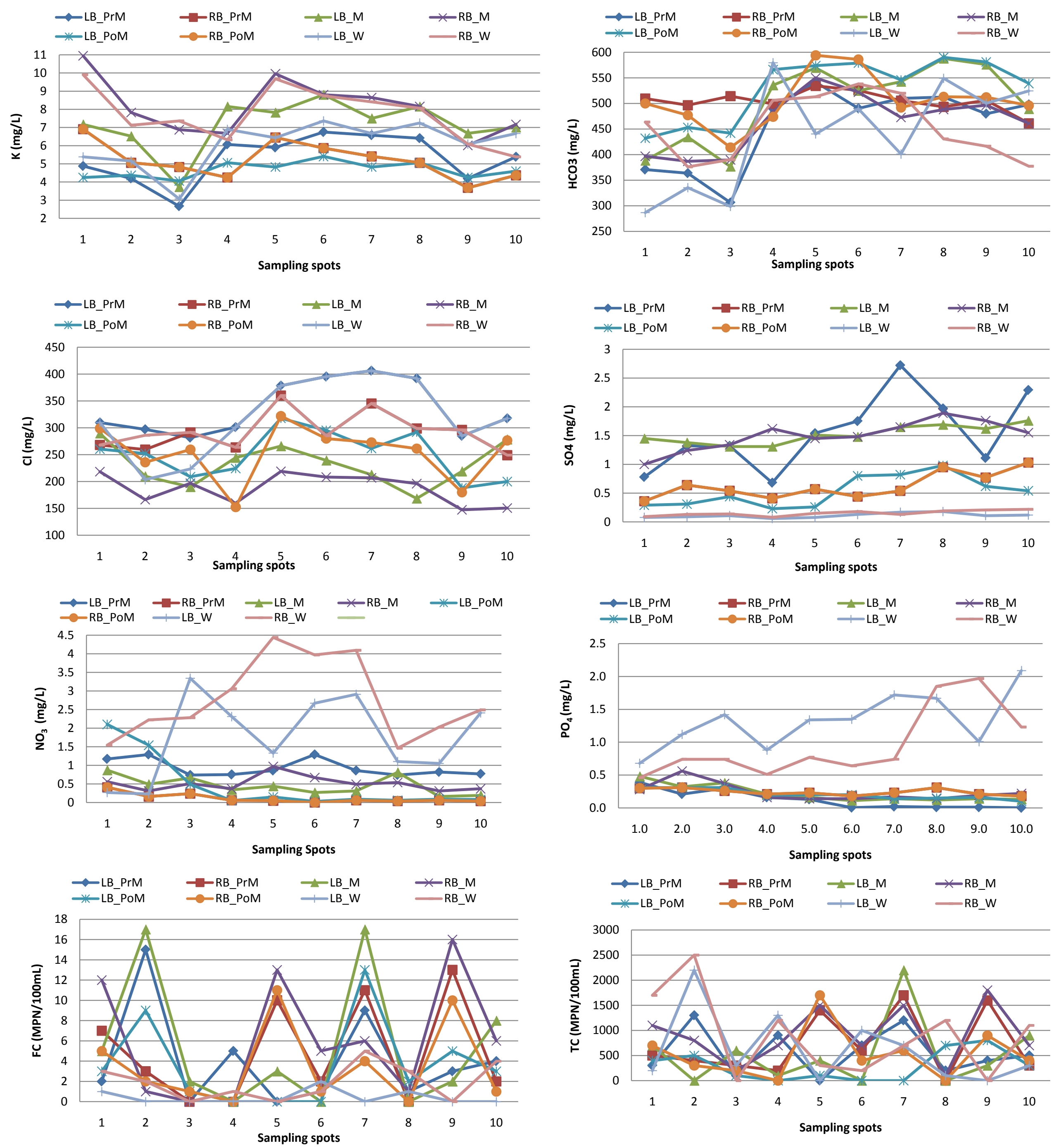


Figure 3. Spatio-temporal variations of water quality parameters in tidal delta of Bangladesh. (Note: LB = Left Bank, RB = Right Bank, PrM = Pre-monsoon, M = Monsoon, PoM = Post-monsoon, W = Winter).

moderately hard (75 to 150 mg/l), 3) hard (150 to 300 mg/l) and 4) very hard (>300 mg/l) (Ahmed & Rahman, 2000). According to aforementioned classification, 70% water samples of left bank and 40% water samples of right bank are fall under very hard category in respective pre-monsoon and winter season. The presence of high content of magnesium, calcium and associated ions accompanied by probable leaching of sewage disposal and rock mineral geochemical interaction, enhance the hardness of ground water (Chidambaram et al., 2009; Mondal et al., 2013). Apart from water chemistry analysis the microbial analysis revealed the highest Faecal Coliform (FC) number is 17 MPN/100 ml and 16 MPN/100 ml in respective left and right bank of the river in the monsoon season. The highest numbers of Total Coliforms (TC) were 2200 MPN/100 ml also in monsoon for left bank and 2500 MPN/100 ml for right bank in post-monsoon season. In monsoon and post-monsoon 2, 5, 7 and 9 no. sampling spot faces significant microbial contamination. This contamination might be caused by peat latrines, sewages connections or entering contaminants into the wells through hydraulic connection which possesses diarrhea, dysentery, stomach problems and even severe health threats to the community people.

3.2. Correlation Matrix

The correlation matrix was conducted by putting the mean value of water samples for the four consecutive seasons incorporated in **Table 4**. The computed analysis shows strong positive correlation of Mg^{2+} with EC, TDS and Ca^{2+} but negatively correlated with pH, EC and HCO_3^- relation indicate this ground water aquifer might be dominated by rock-weathering and geochemical interaction (Chidambaram et al., 2009; Rahman et al., 2011). The strong positive relation between Ca^{2+} and Mg^{2+} may be due to calcite or dolomite weathering in the study area (Bahar & Reza, 2010; Rahman et al., 2011; Islam et al., 2016). There are also more significant correlation pairs was noticed between Ca-Mg, Ca-Na, Ca- HCO_3^- and Mg- HCO_3^- where their association with TDS insight these ions probably derived from the same source of saline water as found in surrounding river water (Bahar & Reza, 2010; Islam et al., 2016). As both NO_3^- and PO_4^{3-}

Table 4. Correlation coefficient of water quality parameters (n = 80 for four consecutive seasons).

Variables	pH	EC	TDS	Salinity	Ca^{2+}	Mg^2	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}
pH	1												
EC	−0.679**	1											
TDS	−0.302**	**0.829****	1										
Salinity	−0.632**	**0.711****	**0.544****	1									
Ca^{2+}	−0.048	0.363**	0.538**	0.079	1								
Mg^{2+}	0.008	0.196	0.294**	−0.180	**0.751****	1							
Na^+	−0.508**	**0.764****	**0.675****	**0.749****	−0.011	−0.242*	1						
K^+	−0.284*	0.166	0.080	−0.016	0.198	0.389**	−0.039	1					
HCO_3^-	0.127	0.292**	**0.499****	0.007	**0.795****	**0.600****	0.046	0.195	1				
Cl^-	−0.534**	**0.823****	**0.747****	0.687**	0.252*	0.091	**0.869****	0.051	0.087	1			
SO_4^{2-}	0.446**	−0.283*	0.015	−0.550**	0.221*	0.347**	−0.388**	0.145	0.132	−0.194	1		
NO_3^-	−0.714**	0.415**	0.067	0.521**	−0.103	−0.064	0.332**	0.297**	−0.219	0.345**	−0.398**	1	
PO_4^{3-}	−0.711**	0.245*	−0.091	0.449**	−0.151	−0.098	0.306**	0.115	−0.334**	0.298**	−0.581**	0.585**	1

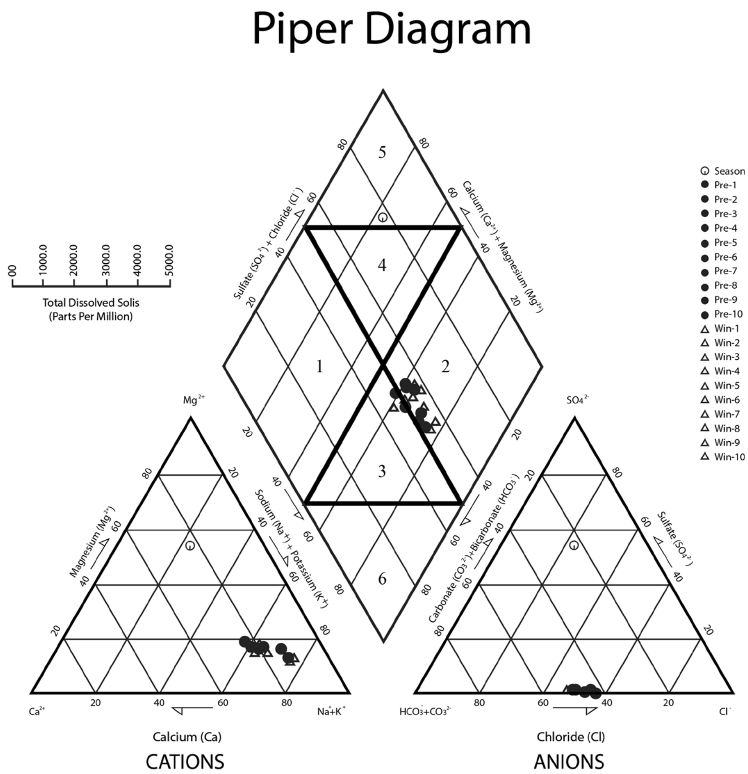
Note: ** Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level.

are derived from anthropogenic sources the strong association between this two indicate the anthropogenic influence on groundwater via leaching or hand pumps tubewells in this locality (Chidambaram et al., 2009).

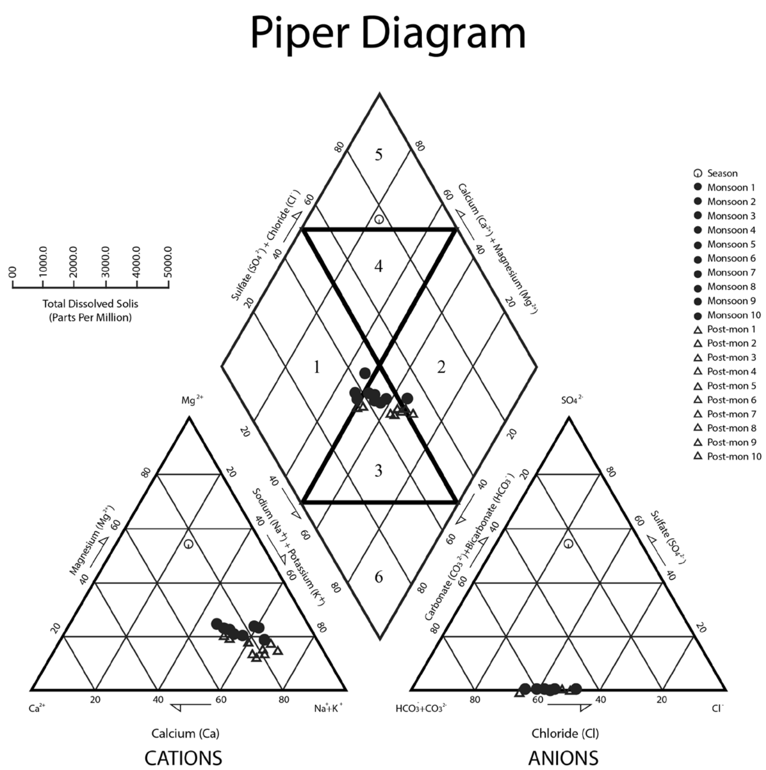
The correlation matrices of groundwater samples for pre-monsoon and winter also shows that pH have strong negative correlation with EC but strong positive correlation TDS whereas Ca^{2+} have strong positive correlation with EC and TDS. There is a perfect positive correlation of HCO_3^- also found with EC, TDS, Ca^{2+}, Mg^{2+}, Na and Cl^- where Na and Cl^- are moderately related with salinity in pre-monsoon but highly correlated in winter season indicating such ions are mostly derived from sea water. On the contrary, PO_4^{3-} showed strong negative correlation with EC, Ca^{2+}, Mg^{2+}, HCO_3^- and SO_4^{2-} whereas Cl^- shows positive correlation with EC, TDS, Ca^{2+}, Mg^{2+}, Na^+ and K^+ for both pre-monsoon and winter season. Ca^{2+} and Mg^{2+} are moderately correlated with HCO_3^- in pre-monsoon and winter season. On the contrary, PO_4^{3-} showed no correlation as we found in the left bank in both season but Cl^- shows almost similar positive correlation with EC, TDS, Ca^{2+}, Mg^{2+}, Na^+ and Mg^{2+} except K^+ and pH for the right bank water samples. For monsoon and post-monsoon it is found that EC and TDS show a strong negative correlation with pH at the 1% level of significance, whereas EC and TDS shows a highly positive significant correlation in case of both left bank and right bank respectively. There is a strong positive correlation between Ca^{2+} and Mg^{2+} in case of left bank but no observed correlation in case of right bank for the monsoon season. In both season Na^+ and Cl^- shows moderate positive correlation in left bank but perfectly positive correlation was found in case of right bank at the 1% level, indicating such ions are mostly derived from sea water. The computed analysis also indicated that EC and TDS shows strong positive correlation with Ca^{2+}, NO_3^-, PO_4^{3-} and HCO_3^- in case of left bank whereas in case of right bank it shows moderate positive correlation with Ca^{2+}, HCO_3^-, Mg^{2+} and K^+ but no relation with NO_3^- and PO_4^{3-}. The strong correlation among EC, TDS, Na^+ and Cl^- in pre-monsoon and winter is regarded as the salinization index which may indicate the sea water intrusion in this region while moderate correlation in monsoon season reflects the freshening of the water samples compared with pre-monsoon and winter season (Bahar & Reza, 2010).

3.3. Hydro-Geochemical Facies (Piper)

To reveal the cation and anion concentration within defines composition categories, the samples were plotted on trilinear diagram for indicating their types (**Figure 4**). It is a combination of distinct zones of hydrochemical facies that lie on common baseline (Hounslow, 1995). The trilinear diagram of this study is classified into six hydrochemical facies: 1) Ca-Mg-HCO_3 type; 2) Na-Cl type; 3) Mixed Na-HCO_3-Cl type; 4) Mixed Ca-Mg-Cl type; 5) Ca-Mg-SO_4 type and 6) Na-HCO_3 type (Pipper, 1944). **Figure 4(a)** shows the majority of the water samples were in type 2 (Na-Cl type), followed by the rest of the samples were in type 3 (Mixed Na-HCO_3-Cl type) in pre-monsoon and winter season. Based on the dominance of different cations and anions the order were $Na^+ > Cl^- > HCO_3^- >$



(a)



(b)

Figure 4. (a) Piper-tri-linear diagram showing the water quality of pre-monsoon and winter season (after Pipper, 1944); (b) Piper-tri-linear diagram showing the water quality of monsoon and post-monsoon season (after Pipper, 1944).

$Ca^{2+} > Mg^{2+} > K^{+} > SO_4^{2-} > NO_3^{-}$ in pre-monsoon and winter season. This type of chemical composition of ground water samples were mostly controlled by sea water and tidal channels or structural interferences to the natural water flow via ground water layer which consist of recent alluvium deposit. This specifies that ground water becomes more Na-Cl types in these two seasons denoting the influence of sea-water mixing (Bahar & Reza, 2010). In monsoon and post monsoon the trilinear diagram depicted that the majority of the water samples were intype 3 (Mixed Na-HCO_3-Cl type), while rest of the samples were in type 1 (Ca-Mg-HCO_3 type) and type 2 (Na-Cl type) depicted in **Figure 4(b)**. The piper diagram advocates that majority of the water samples are dominated by alkali carbonate which has altered the concentration of sodium and chloride into fresh water by ion exchange method with exchange to Ca-Mg-HCO_3 (Pipper, 1944). The overall result revealed the intrusion of saline water into coastal aquifers with significant percentages of sodium and chloride.

3.4. Ground Water Vulnerability Analysis

The analytical results of pH, EC, TDS, Salinity, DO, Total Hardness and major ions of ground water were put in CCME water quality index to understand the overall scenario and ongoing condition of the water (CCME, 2001; Rocchini & Swain, 1995). Sixteen water quality parameters for four consecutive seasons were used to find out the CCME WQI value considering:

F_1) scope—the number of variables not meeting water quality objectives;

F_2) frequency—the number of times these objectives are not met and

F_3) amplitude—the amount by which the objectives are not met

The graph (**Figure 5**) and table (**Table 5**) in combination depicts that nearly three quarter of total water samples are felled under marginal category which means water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels. Tiny fraction of water samples of left bank and almost a quarter portion of water samples of right bank were under fair category demonstrating that water quality is usually protected but occasionally threatened or impaired. From the calculated value it is evident that the water

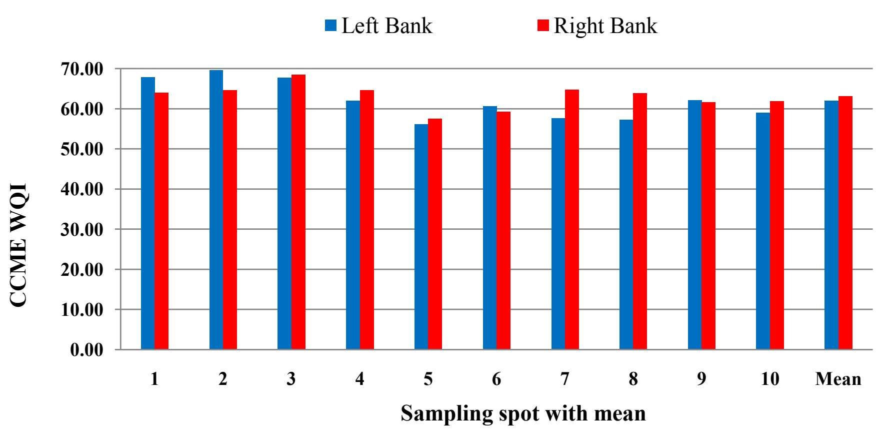


Figure 5. Estimated groundwater quality index (CCME WQI).

Table 5. CCME WQI index for the water samples.

Samp-ling Spot	Factors			CCME WQI	Range	Water quality condition
	F1 (Scope)	F2 (Frequency)	F3 (Amplitude)			
LB_1	37.50	35.94	20.26	67.81	(CCME WQI Value 65 - 79)	**Fair**-Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
LB_2	37.50	31.25	19.68	69.61		
RB_2	43.75	35.94	23.31	64.65		
LB_3	43.75	28.12	20.45	67.73		
RB_3	43.75	26.56	18.96	68.49		
RB_4	50.00	29.69	19.03	64.67		
RB_7	43.75	35.94	22.30	64.72		
RB_1	43.75	37.50	23.61	64.06	(CCME WQI Value 45 - 64)	**Marginal**-water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
LB_4	50.00	37.50	20.50	62.02		
LB_5	56.25	42.19	28.83	56.12		
RB_5	50.00	45.31	29.23	57.54		
LB_6	50.00	39.06	25.15	60.59		
RB_6	50.00	42.19	26.63	59.22		
LB_7	50.00	45.31	28.62	57.68		
LB_8	50.00	45.31	30.26	57.30		
RB_8	50.00	31.25	20.70	63.92		
LB_9	43.75	40.63	27.22	62.11		
RB_9	50.00	35.94	24.60	61.72		
LB_{10}	50.00	42.19	27.27	59.08		
RB_{10}	50.00	35.94	23.78	61.89		

Note: LB and RB represent the left bank and right of the river respectively.

quality of major tubewells often exceeds usual or allowable limits which elicit the ground water vulnerability and public health concern (CCME, 2001). Salinity intrusion into the shallow aquifers, upstream reduction of tidal channel's flow, excessive withdrawal of ground water for irrigation, sewage connection or leaching might be the prime cause of ground water vulnerability (CCME, 2001; Chidambaram et al., 2009).

3.5. Drinking Water Suitability

The water quality parameters were compared with the standard guideline values recommended by the both Bangladesh and WHO standards for drinking purposes (Rocchini & Swain, 1995; CCME, 2001). Table 6 shows the comparison of analytical results with the prescribed guidelines and their percentages exceeding the recommended limits. The computed result indicates that 100% samples of EC surpassed the allowable limit recommended by WHO standard. Probably ground water inflows will contribute to the high electrical conductivity depending

Table 6. Percentage (%) of groundwater samples exceeding the allowable limits for drinking purposes and the resulting undesirable effects.

Parameters	B.D. Standard[a]	WHO Standard[b]	River Bank	Pre-monsoon		Monsoon		Post-monsoon		Winter		Undesirable effects
				BD	WHO	BD	WHO	BD	WHO	BD	WHO	
pH	6.5 - 8.5	6.5 - 8.5	LB	0	0	0	0	0	0	0	0	Metabolic alkalosis or acidosis including vomiting, dehydration, anorexia and chronic obstructive pulmonary disease (EPA, 2001) Taste, Gastrointestinal irritation (Plunkett, 1976)
			RB	0	0	0	0	0	0	0	0	
EC	*	1400	LB	-	100	-	100	-	100	-	100	
			RB	-	100	-	100	-	100	-	100	
TDS	1000	1000	LB	100	100	70	70	90	90	80	80	
			RB	100	100	20	20	70	70	90	90	
DO	6.0	*	LB	100	100	100	100	100	100	100	100	
			RB	100	100	100	100	100	100	100	100	
Ca^{2+}	75	200	LB	70	0	70	0	70	0	70	0	Scale formation (Bahar & Reza, 2010)
			RB	20	0	70	0	30	0	10	0	
Mg^{2+}	30 - 35	150	LB	70	0	60	0	40	0	50	0	Indirect effects on health which cause eczema (EPA, 2001)
			RB	30	0	100	0	10	0	30	0	
Na^{+}	200	200	LB	90	90	20	20	60	60	90	90	Joint effect, congestive heart failure and hypertension (EPA, 2001)
			RB	100	100	0	0	80	80	100	100	
K^{+}	12	12	LB	0	0	0	0	0	0	0	0	Bitter taste (Bahar & Reza, 2010)
			RB	0	0	0	0	0	0	0	0	
HCO_3^-	*	240	LB	-	100	-	100	-	100	-	100	Destroy acid balance and causes diarrhea, kidney diseases etc.
			RB	-	100	-	100	-	100	-	100	
Cl^-	150 - 600	250	LB	0	100	0	20	0	60	0	80	Acid-base imbalance, Salty taste etc. (EPA, 2001; Bahar & Reza, 2010)
			RB	0	90	0	0	0	80	0	90	
SO_4^{2-}	400	250	LB	0	0	0	0	0	0	0	0	Laxative effect in combination with magnesium or sodium (EPA, 2001)
			RB	0	0	0	0	0	0	0	0	
NO_3^-	10	10	LB	0	0	0	0	0	0	0	0	Blue baby (Bahar & Reza, 2010)
			RB	0	0	0	0	0	0	0	0	
PO_4^{3-}	6	*	LB	0	0	0	0	0	0	0	0	Heart attacks risk, kidney, bone &muscle problems (EPA, 2001)
			RB	0	0	0	0	0	0	0	0	
FC	0	0	LB	80	80	70	70	70	70	30	30	Waterborne gastroenteritis including dysentery, typhoid fever, hepatitis A and ear infections (Ashbolt, 2015)
			RB	70	70	80	80	80	80	70	70	
TC	0	0	LB	90	90	70	70	70	70	80	80	
			RB	90	90	100	100	80	80	80	80	

Note: LB = Left Bank, RB = Right Bank, EC = Electrical conductivity, TDS = Total dissolved solids, DO = Dissolved oxygen, TH = Total hardness, FC = Faecal coliform, TC = Total coliform. [a](Ahmed & Rahman, 2000); [b](WHO, 2011).

on the geology, rock erosion and leakage to sewage disposal or heavily ionized dissolved minerals that have been evaporated to dryness (Rahman et al., 2011). Sodium and chloride are found in ground water naturally. However, increasing the concentration in pre-monsoon and winter season might be caused by underground salt deposition, pollution from septic and salt water intrusion due to proximity of tidal channels in coastal belt (EPA, 2001; Hasan et al., 2013). TDS exceeds the permissible limit of both Bangladesh and WHO standard followed by the 100% for pre-monsoon. In respective monsoon, post-monsoon and winter season 70%, 90% and 80% water samples for left bank as well as 20%, 70% and 90% water samples for right bank surpassing the desirable limit. High values of TDS may be caused by stagnation of water in most of this tubewells due to the weight of residue left when a water sample has been evaporated to dryness and hydraulic connection with the river (Bahar & Reza, 2010). This result indicates the degree of unsuitability for different consumption scheme (Chitradevi & Sridhar, 2011). In view of HCO_3^- it was found that 100% water samples of all seasons are beyond the limit of WHO standard for the probability of carbonate weathering coupled with hydraulic connection into the aquifer. High concentration of bicarbonate also might be caused by dissolution of organic matter leading to an increase residual sodium carbonate with Na^+ content in the soil (Zahid et al., 2008; Bahar & Reza, 2010).

Faecal contamination in drinking water is a serious health threat due to the potential for contracting diseases from pathogenic organisms. From the microbial analysis of Faecal Coliform and Total Colifom it was found that 80% (pre-monsoon), 70% (monsoon), 70% (post-monsoon) and 30% (winter)water samples for left bank exceeded the limit of both Bangladesh and WHO standard. The right bank of the riverine union also showed almost similar pattern in all the successive seasons. Agricultural runoff, effluent from septic systems of sewage discharges, infiltration of domestic or wild animal fecal matter, poor well operation and construction (particularly shallow dug wells) are might be the prime source of microbial contamination in ground water (Ashbolt, 2015). From overall comparison scheme of this study it has been demonstrated that majority of the water samples do not satisfy the limit of both Bangladesh and WHO standards signifying their degree of unsuitability for drinking purposes.

4. Concluding Remarks

The result of the study from hydro-chemical characterization elicits that the ground water in the adjacent river basins is hard, fresh to brackish and alkaline to saline in respective different seasons. Majority of the water quality parameters vary considerably within the seasons whereas TDS, EC, sodium and chloride concentration in pre-monsoon and winter were found as a persistently growing threat particularly in the study region. Correlation matrix recognized strong and moderate correlation among the most water quality parameters. Good association among EC, Cl^-, Na^+ and salinity of water samples in pre-monsoon and winter thereby indicated sea water intrusion. Na^+ and Cl^- governed the major cationic and anionic chemistry in pre-monsoon and winter season, showing an order of $Na^+ > Cl^- > HCO_3^- > Ca^{2+} > Mg^{2+} > K^+ > SO_4^{2-} > NO_3^{2-}$ accordingly. In monsoon and post-monsoon season, the order of cations and anions was found as $Na^+ > HCO_3^- > Cl^- > Ca^{2+} > Mg^{2+} > K^+ > SO_4^{2-} > NO_3^{2-}$ for the successive period. For pre-monsoon and winter, the piper diagram indicates Na-Cl type water whereas other seasons indicate mixed Ca-Na-HCO_3 type water. CCME water quality index demonstrated that the ground water quality is recurrently vulnerable and the conditions often departed from natural desirable limits. Surpassing the water samples from the allowable limits of recommended standards by a significantly greater margin recapitulates the degree of threat to drinking quality. The microbial analysis designated the unhygienic consumption pattern and sewage disposal connection into the aquifer system. Therefore, from the study, it could be concluded that the ground water is frequently threatened and is not fully suited for drinking purposes.

Acknowledgements

The authors gratefully acknowledge the University Grants Commission (UGC) of Bangladesh under the project entitled "Assessment and Evaluation of the Natural Waters Suitability for Irrigation in and around Sailmari River, Khulna" for the valuable support for this study. The authors are also thankful to the Environmental Science Discipline and Chemistry Discipline of Khulna University, Bangladesh for providing all sorts of support during laboratory analysis.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

ADB (2011). *Bangladesh: Khulna Water Supply Project.* Dhaka: Asian Development Bank.

Ahmed, M. F., & Rahman, M. M. (2000). *Water Supply and Sanitation, Rural and Low Income Urban Communities*. Dhaka: ITN-Bangladesh.

Alam, M. (1990). *Bangladesh in World Regional Geology*. New York: Columbia University Press.

Apello, J., & Postma, D. (2005). *Geochemistry, Groundwater and Pollution* (2nd Ed.). Leiden: Balkema. https://doi.org/10.1201/9781439833544

APHA (1999). *Standard Methods for the Examination of Water and Wastewater* (p. 541). Standard Methods.

Ashbolt, N. J. (2015). Microbial Contamination of Drinking Water and Human Health from Community Water Systems. *Current Environmental Health Reports, 2,* 95-106. https://doi.org/10.1007/s40572-014-0037-5

Bahar, M. M., & Reza, M. S. (2010). Hydrochemical Characteristics and Quality Assessment of Shallow Groundwater in a Coastal Area of Southwest Bangladesh. *Environmental Earth Sciences, 61,* 1065-1073. https://doi.org/10.1007/s12665-009-0427-4

Banks, D., Midtgard, A. K., Morland, G., Reimann, C., Strand, T., Bjorvatn, K. et al. (1998). Is Pure Groundwater Safe to Drink? Natural Contamination of Groundwater in

Norway. *Geology Today, 14,* 104-133.
https://doi.org/10.1046/j.1365-2451.1998.014003104.x

CCME (2001). Canadian Water Quality Guidelines for the Protection of Aquatic Life: CCME Water Quality Index 1.0, Technical Report. In *Canadian Environmental Quality Guidelines 1999*. Winnipeg: Canadian Council of Ministers of the Environment.

Chidambaram, S., Kumar, G. S., Prasanna, M. V., Peter, A. J., Ramanthan, A. L., & Srinivasamoorthy, K. (2009). A Study on the Hydrogeology and Hydrogeochemistry of Groundwater from Different Depths in a Coastal Aquifer: Annamalai Nagar, Tamilnadu, India. *Environmental Geology, 57,* 59-73.
https://doi.org/10.1007/s00254-008-1282-4

Chitradevi, S., & Sridhar, S. G. D. (2011). Water Quality Studies of Groundwater in the Proximity of River Noyyal, Tiruppur, South India. *International Journal of Environmental Sciences, 2,* 281.

DPHE-JICA (2015). *Final Report on Development of Deep Aquifer Database and Preliminary Deep Aquifer Map* (p. 2100). Dhaka: Department of Public Health Engineering, Government of People's Republic of Bangladesh.

Drever, J. I. (1988). *The Geochemistry of Natural Waters*. Englewood Cliffs, NJ: Prentice Hall.

EPA (2001). *Parameters of Water Quality-Interpretation and Standards* (pp. 26-116). Wexford: Environmental Protection Agency.

FAO (2011). *Irrigation in Southern and Eastern Asia in Figures*. Rome.

Hasan, K. F., Khaleque, M., Shahjahan, M., & Haque, M. A. (2007). *Water Quality for Irrigation, Emphasis on Arsenic Contamination in Agriculture, 2004-2007*.

Hasan, M. R., Shamsuddin, M., & Hossain, A. F. M. A. (2013). Salinity Status in Groundwater: A Study of Selected Upazilas of Southwestern Coastal Region in Bangladesh. *Global Science and Technology Journal, 1,* 112-122.

Hounslow, A. (1995). *Water Quality Data: Analysis and Interpretation*. Boca Raton: CRC Press.

Huang, J., Huang, Y., & Zhang, Z. (2014). Coupled Effects of Natural and Anthropogenic Controls on Seasonal and Spatial Variations of River Water Quality during Base Flow in a Coastal Watershed of Southeast China. *PLoS ONE, 9,* e91528.
https://doi.org/10.1371/journal.pone.0091528

Islam, M., Azad, A. K., Ara, M. H., Rahman, M., Hassan, N., Swarnokar, S. C., & Rabeya, I. (2016). Environmental Study on a Coastal River of Bangladesh with Reference to Irrigation Water Quality Assessment: A Case Study on Shailmari River, Khulna. *Journal of Geoscience and Environment Protection, 4,* 41.
https://doi.org/10.4236/gep.2016.410003

Karim, Z., Hussain, S. G., & Ahmed, M. (1990). *Salinity Problems and Crop Intensification in the Coastal Regions of Bangladesh* (Soils Publication No. 33, pp. 1-20). Dhaka: Bangladesh Agricultural Research Council (BARC).

Kumar, S. K., Rammohan, V., Sahayam, J. D., & Jeevanandam, M. (2009). Assessment of Groundwater Quality and Hydrogeochemistry of Manimuktha River Basin, Tamil Nadu, India. *Environmental Monitoring and Assessment, 159,* 341-351.
https://doi.org/10.1007/s10661-008-0633-7

Mondal, M. S., Jalal, M. R., Khan, M., Kumar, U., Rahman, R., & Huq, H. (2013). Hydro-Meteorological Trends in Southwest Coastal Bangladesh: Perspectives of Climate Change and Human Interventions. *American Journal of Climate Change, 2,* Article ID: 29106. https://doi.org/10.4236/ajcc.2013.21007

Mondal, M. K., Tuong, T. P., Ritu, S. P., Choudhury, M. H. K., Chasi, A. M., Majumder, P. K., Islam, M. M., & Adhikary, S. K. (2006). Coastal Water Resource Use for Higher Productivity: Participatory Research for Increasing Cropping Intensity in Bangladesh. In C. T. Hoanh, T. P. Tuong, J. W. Gowing, & B. Hardy (Eds.), *Environment and Livelihoods in Tropical Coastal Zones: Managing Agriculture-Fishery-Aquaculture Conflicts* (pp. 72-85). London: CABI Publishing. https://doi.org/10.1079/9781845931070.0072

Pethick, J., & Orford, J. D. (2013). Rapid Rise in Effective Sea-Level in Southwest Bangladesh: Its Causes and Contemporary Rates. *Global and Planetary Change, 111,* 237-245. https://doi.org/10.1016/j.gloplacha.2013.09.019

Pipper, A. M. (1944). A Graphical Procedure in the Geochemical Interpretation of Water Analysis. *Transactions of the American Geophysical Union, 25,* 914-923. https://doi.org/10.1029/TR025i006p00914

Plunkett, E. R. (1976). *Handbook of Industrial Toxicology* (pp. 99-101). New York: Chemical Public Company Limited.

Rahman, M. A. T., Majumder, R. K., Rahman, S. H., & Halim, M. A. (2011). Sources of Deep Groundwater Salinity in the Southwestern Zone of Bangladesh. *Environmental Earth Sciences, 63,* 363-373. https://doi.org/10.1007/s12665-010-0707-z

Rahman, M. M., Hassan, M. Q., Islam, M. S., & Shamsad, S. Z. K. M. (2000). Environmental Impact Assessment on Water Quality Deterioration Caused by the Decreased Ganges Outflow and Saline Water Intrusion in South-Western Bangladesh. *Environmental Geology, 40,* 31-40. https://doi.org/10.1007/s002540000152

Ramesh, R., & Anbu, M. (1996). *Chemical Methods for Environmental Analysis: Water and Sediment*. London: Macmillan Publishers.

Rocchini, R., & Swain, L. G. (1995). The British Columbia Water Quality Index (p. 13). Victoria: Water Quality Branch, EP Department, BC, Ministry of Environment, Land and Park.

Roy, M. K., Datta, D. K., Adhikari, D. K., Chowdhury, B. K., & Roy, P. J. (2005). Geology of the Khulna City Corporation. *Journal of Life and Earth Science, 1,* 57-63.

Sappa, G., Ergul, S., Ferranti, F., Ngalya, L., & Luciani, G. (2015). Effects of Seasonal Change and Seawater Intrusion on Water Quality for Drinking and Irrigation Purposes, in Coastal Aquifers of Dar es Salaam, Tanzania. *Journal of African Earth Sciences, 105,* 64-84. https://doi.org/10.1016/j.jafrearsci.2015.02.007

Sawyer, C. N. (2003).*Chemistry for Environmental Engineering and Science*. New York: McGraw-Hill.

Shahid, S., Chen, X., & Hazarika, M. K. (2006). Evaluation of Groundwater Quality for Irrigation in Bangladesh Using Geographic Information System. *Journal of Hydrology and Hydromechanics, 54,* 3-14.

Shamsudduha, M., Marzen, L. J., Uddin, A., Lee, M. K., & Saunders, J. A. (2009).Spatial Relationship of Groundwater Arsenic Distribution with Regional Topography and Water-Table Fluctuations in the Shallow Aquifers in Bangladesh. *Environmental Geology, 57,* 1521. https://doi.org/10.1007/s00254-008-1429-3

UNESCO (2007). UNESCO Water Portal Newsletter No. 161: Water-Related Diseases.

Vyas, A., & Jethoo, A. S. (2015). Diversification in Measurement Methods for Determination of Irrigation Water Quality Parameters. *Aquatic Procedia, 4,* 1220-1226. https://doi.org/10.1016/j.aqpro.2015.02.155

WHO (2011). *Guidelines for Drinking-Water Quality* (4th Ed.). Geneva: World Health Organization.

Zahid, A., Hassan, M. Q., Balke, K. D., Flegr, M., & Clark, D. W. (2008). Groundwater Chemistry and Occurrence of Arsenic in the Meghna Floodplain Aquifer, Southeastern Bangladesh. *Environmental Geology, 54,* 1247-1260. https://doi.org/10.1007/s00254-007-0907-3