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Probable Origin of Salinity in the Shallow Aquifers of Khulna District, Southwestern Bangladesh

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Abstract

This paper describes the origin of salinity and groundwater quality in the shallow aquifers of Khulna district of southwestern Bangladesh. Hydro-stratigraphically two units have been identified from the 100m depth stratigraphic cross sections- one *confined* to *semi-confined aquifer* characterized by very fine to medium sand and another one *aquitard*, underlain by the aquifer characterized by silty and sandy clay. A data collection program has been conducted during the field work from 05 to 08 September, 2013. The hydro-chemical data shows that total dissolved solids (TDS) is in the range 228-5,807 mg/L with a mean value of 2429 mg/L. The Piper diagram of water samples shows that almost all the water samples of shallow aquifer are of Na^+ - Cl- type, showing Cl concentration from 62.13 to 2831.13 mg/L which is directly related to the salinity of the aquifer. By analyzing the chemical constituents and their origin it is evident that the water samples are resulted from the mixing of sea and fresh water. The results also show that about 70% samples of the groundwater of the study area are *hard* to *very hard* and TDS of the samples suggest that about 77.5% of the samples are of brackish water. According to different drinking quality standards, the concentration of sodium, potassium, magnesium, calcium, chloride and nitrate exceeds the maximum attention limits. As far as the irrigation water quality is concerned, most of the water samples are unsuitable (85%) and severely hazardous (75%). The study findings give an indication of groundwater status with respect to salinity for adopting proper measures to address future need of fresh water for about 2.34 million people living in this coastal region.

Keywords: Salinity; Groundwater Quality; Shallow Aquifer

Abbreviation

BDWS: Bangladesh Drinking Water Standard; DoE: Department of Environment; EC: Electric Conductivity; Eh: Oxidation Reduction Potential; pH: Hydrogen Ion Concentration; SAR: Sodium Absorption Ratio; TDS: Total Dissolved Solids; WHO: World Health Organization

Introduction

In the coastal region of Bangladesh generally the fresh water aquifers are overlain or underlain by the saline water aquifer and the availability of water, suitable for different uses, is limited due to the presence of salinity. Therefore, the knowledge of the extent of saline aquifer domains and the evaluation of the degree of salinity are essential to determine the potential for, and sustainability of groundwater resources for irrigated agriculture, domestic water supplies as well as for industrial uses. Khulna, the study area, is one of the 19 coastal districts of Bangladesh, which has been facing the salinity problems. In this area both the surface water and groundwater is highly affected by saline water. However, some aquifers are non-saline or fresh, where the largest number of people has been extracting water for domestic and agricultural purposes. Thus the aim of the paper is to identify the reason of water salinity, its current state and also to identify the potentiality of drinking, domestic and irrigation water supply of the shallow aquifer system.

Description of the study area

Khulna is a district in the south-western Bangladesh and it lies between 21.79N to 22.06N latitude and 89.25E to 89.75E longitude

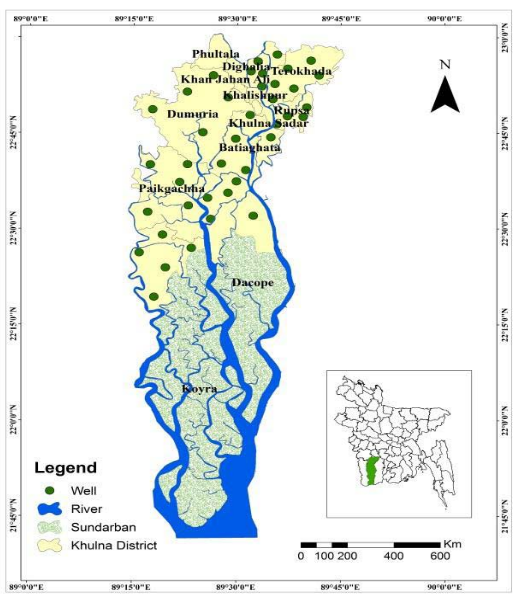

Figure 1: Map showing the study location of Khulna.

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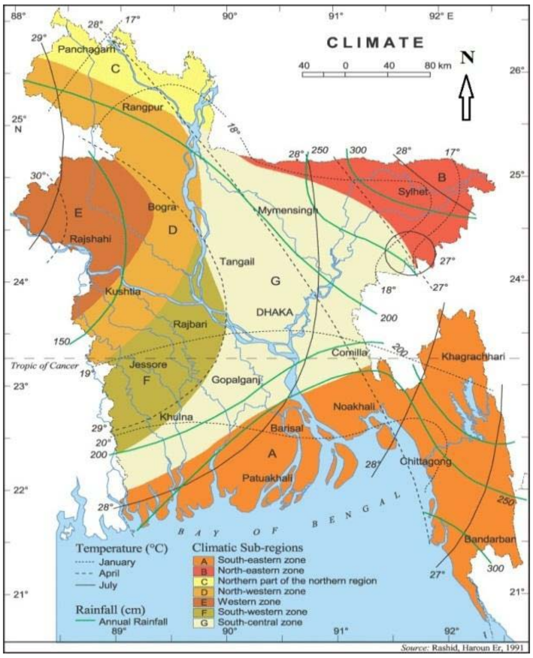

Figure 2: Map showing the climatic zones of Bangladesh [2].

(Figure 1). It is located in the Khulna division with an area of 4394.46 km^2, and is bounded by Jessore and Narail districts on the north, the Bay of Bengal on the south, Bagerhat district on the east, Satkhira district on the west. The main rivers are Rupsa-Pasur, Bhairab, Shibsha, Dharla, Bhadra, Ball, and Kobadak. A part of world's largest mangrove forest the Sunderbans occupies here with an area of 166814 hectares [1].

The study area falls in the south-central zone, south-western and

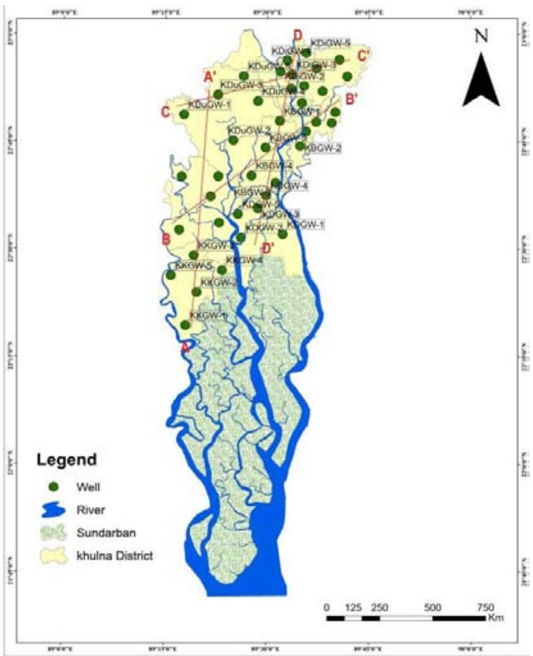

Figure 3: Map showing the Bore Logs and Cross Sections used for the Study Area.

south-eastern zone of the climatic sub-division (Figure 2) and with bulk of rainfall occurring between the months of June to October, high temperature and excessive humidity [2]. The area comprise of three major climatic seasons includes hot summer (March–May), followed by monsoon or rainy season (June–October) and a moderate winter season (November–February). Analyzing the rainfall data from 1993 to 2012 it is observed that maximum rainfall occurs during the rainy season May to October with the peak occurring in July while during the dry period there is almost no rainfall. The mean annual rainfall (from 1993 to 2012) of Khulna district is approximately 1816mm. The mean temperature is 34^{O}C.

Hydrogeological setting

To evaluate the hydrostratigraphy of the area cross-sections in different directions, a 3D model was produced based on the selected 40 bore logs by using RockWorks 15 software. Four lithologic profiles were drawn in the study area along lines AA', BB', CC' and DD' (Figure 3 and 4) considering the spatial distribution of sections, availability of the log in the area, and finally geology of the area. The depth of the bore logs ranges from 190 ft to 330 ft (60-100m). From the cross-sectional profile, it can be assumed that top 25-50 feet of the area is mainly composed of silty clay increasing from southwest toward northeast. Thus it can be said that an aquitard was encountered from the top upto 50 ft depth. Alteration of fine sand and silty clay is observed in the eastern part of the study area. But in the western part of the area outcrops the predominance of fine to very fine sand characterizing the shallow aquifer.

Methodology

A data collection program was undertaken during the field work from 05-08 September, 2013. Groundwater quality parameters like pH, temperature, electrical conductivity (EC), total dissolved solids (TDS) and Eh were measured at each site using the respective field test kits. Forty (40) representative samples were collected from the sites following the standard sampling procedure. A membrane filter of 0.45μS/cm was used to filter groundwater samples in order to remove unwanted particles from the water samples. The water samples were analyzed in the laboratory of Geology Department, University of Dhaka. The chemical parameters analyzed are Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-} and NO_3^-. Titration method was used for Cl^- and HCO_3^- ions, UV visible spectrophotometer was used for SO_4^{2-} and NO_3^- analysis and atomic absorption spectrometer was used for determining the concentration of all cations.

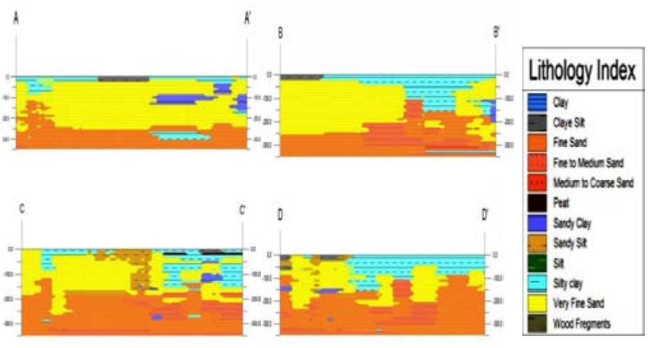

Figure 4: Cross Sectional profiles used for the Study Area.

Table 1: Physical Parameters of representative samples.

Well ID	Upazila	Temperature (°C)	pH	Eh	EC (µS/cm)	TDS (mg/l)
KHBGLW-1	Batiaghata	27.6	7.08	-6.5	9777	5123
KHBGLW-2	Batiaghata	28.4	7.44	-23.9	6447	3447
KHBGLW-3	Batiaghata	27.1	7.32	-21.2	7030	4274
KHBGLW-4	Batiaghata	28.6	7.69	-35	7112	3852
KHBGLW-5	Batiaghata	27.1	7.39	-24.5	4464	2332
KHDKLW-1	Dacope	30.6	6.55	26.8	6763	4163
KHDKLW-2	Dacope	28.7	6.45	33.1	7368	3825
KHDKLW-3	Dacope	28.4	6.43	34.3	7850	4152
KHDKLW-4	Dacope	28.9	6.41	34.9	9284	5807
KHDKLW-5	Dacope	27.8	6.41	35.3	6902	3569
KHDLLW-1	Dighalia	28.1	7.35	-12	1546	843
KHDLLW-2	Dighalia	30.3	7.37	-13.1	5458	3981
KHDLLW-3	Dighalia	26.9	7.43	-23.7	4760	2694
KHDLLW-4	Dighalia	26.4	7.4	-18	432	233
KHDLLW-5	Dighalia	26.5	7.57	-436	394	228
KHDRLW-1	Dumuria	27.1	6.32	40.4	5503	2949
KHDRLW-2	Dumuria	27.9	6.39	36.7	1619	1143
KHDRLW-3	Dumuria	27.4	6.37	37.4	6468	4294
KHDRLW-4	Dumuria	27.8	6.39	36.5	5027	3183
KHDRLW-5	Dumuria	28.1	6.43	34	716	417
KHKRLW-1	Koyra	27.6	8.52	-55.4	1781	926
KHKRLW-2	Koyra	28.1	7.45	-2.7	2700	1406
KHKRLW-3	Koyra	28	7.44	-21.8	5400	2800
KHKRLW-4	Koyra	27.9	7.52	-32.3	3350	1982
KHKRLW-5	Koyra	28	7.8	-40.6	2230	1159
KHPGLW-1	Paikgacha	29.9	6.51	29.1	1288	984
KHPGLW-2	Paikgacha	26.9	6.4	36.4	7062	4530
KHPGLW-3	Paikgacha	27.3	6.37	37.4	604	321
KHPGLW-4	Paikgacha	27.5	6.4	36.1	1231	871
KHPGLW-5	Paikgacha	27.6	6.45	32.6	6555	4030
KHRSLW-1	Rupsa	27.3	7.41	-22.8	5727	3913
KHRSLW-2	Rupsa	28.3	7.55	-26.7	4793	2509
KHRSLW-3	Rupsa	27.7	7.4	-28.2	3739	2474
KHRSLW-4	Rupsa	27.3	7.27	-18	2146	1361
KHRSLW-5	Rupsa	27.9	7.51	-29.3	4341	2468
KHTKLW-1	Terokhada	28.2	7.61	-29.7	5835	2540
KHTKLW-2	Terokhada	27.1	7.5	-32.4	5761	2492
KHTKLW-3	Terokhada	28.8	8.23	-69.4	1325	952
KHTKLW-4	Terokhada	28.5	7.85	-54.6	2680	1441
KHTKWL-5	Terokhada	27.7	8.02	-55	2619	1399

Results and Discussion

Hydrochemistry

The hydrochemical results of collected water samples are shown in Table 1 and 2. Table 1 shows that, groundwater temperatures are in the range of 26.4-30.4°C while the pH varies from 6.32 to 8.52 with a mean value of 7.37. The electrical conductivity value varies from 394 to 9777 µS/cm. The relatively low conductivity groundwater occurs mainly in the north – northeast toward the inland areas. Among the chemical parameters high Cl concentration was observed, which ranged from 62.13 to 2831.13 mg/l; this could be directly related to the salinity of the aquifer. The salinity of the aquifer increases toward south.

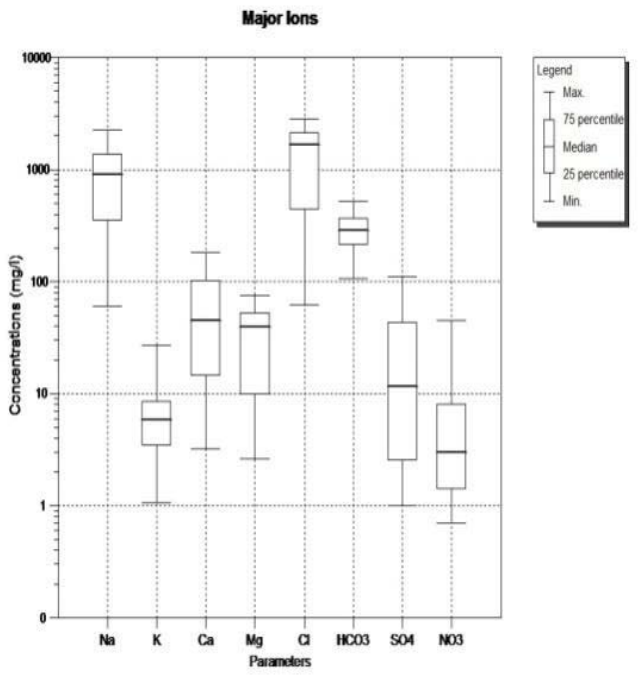

Figure 5: Box and whisker diagram (concentrations expressed in log scale).

The comparison between the range of concentration of cations and anions in mg/l has been shown in the Box and whisker diagram (Figure 5). It is clear from the diagram that sodium (Na) is the dominant cation and chloride is the dominant anion in the study area.

The Piper-trilinear plots, representative of groundwater samples major cations and anions composition (Figure 6) suggest that among the cationic species, Na is predominant and tends to shift towards Ca-Mg. On the other hand, chloride is the major anion showing dominance and tends to shift towards bicarbonate [3]. Thus, majority of groundwater samples from shallow aquifer belongs to Na-Cl type. Almost all of the water samples fall near the right corner of the diamond which is the region of saline water (i.e. rich in Na^+ + K^+ and Cl^-). However, a few samples shift towards Ca-Mg-HCO_3 from Na-Cl type, which is due to mixing of fresh groundwater with saline water. The plot of various cations and anions against TDS has been presented in Figures7a and 7b, which indicates that Na^+ and Cl^- behave as conservative chemical parameters in the groundwater system.

Origin of salinity

There are several causes of the salinity in groundwater. These include leaching of salt during or after infiltration; seawater intrusion; mixing with brines and surface evaporation before recharge. From

Table 2: Chemical data of representative samples.

Well ID	Location	Ca2+ (mg/l)	Mg2+ (mg/l)	Na+ (mg/l)	K+ (mg/l)	Cl- (mg/l)	HCO3-(mg/l)	NO_3- (mg/l)	$SO_4$2-(mg/l)
KHBGLW-1	Batiaghata	100.58	38.76	2118	4.86	2831.13	366	1.7	13
KHBGLW-2	Batiaghata	44.72	52.96	1590	10.86	2121.13	289.75	7.3	20
KHBGLW-3	Batiaghata	86	45.27	1463.2	22.56	2209.88	366	7.3	16
KHBGLW-4	Batiaghata	107.28	52.6	1471.4	12.8	2209.88	366	2.9	107
KHBGLW-5	Batiaghata	142.46	61.36	805.7	14.4	1322.38	366	6.9	87
KHDKLW-1	Dacope	100.62	49.32	1387	1.065	2209.88	366	19.7	1
KHDKLW-2	Dacope	79.36	56.24	2006.8	26.81	2387.38	366	44.8	7
KHDKLW-3	Dacope	40	31.52	1870	26.67	2476.13	289.75	9.1	70
KHDKLW-4	Dacope	58.34	47.16	2249	26.93	2831.13	289.75	8.4	111
KHDKLW-5	Dacope	101.72	41.44	1628	20.35	2121.13	289.75	8	101
KHDLLW-1	Dighulia	9.5	5.25	268.7	2.34	434.88	213.5	1.5	7
KHDLLW-2	Dighulia	50.08	36.92	1355.3	3.32	1766.13	213.5	1.3	8
KHDLLW-3	Dighulia	5.1	6.89	1271.3	6.43	1499.88	289.75	3.3	10
KHDLLW-4	Dighulia	3.26	2.6	78.2	5.74	62.13	106.75	2.8	1
KHDLLW-5	Dighulia	9.68	4.49	69.8	1.46	62.13	190.625	1.5	1
KHDRLW-1	Dighulia	50.24	39.1	1133.4	6.99	1677.38	289.75	8.1	0
KHDRLW-2	Dumuria	121.54	59.76	223.8	3.16	346.13	289.75	0.8	56
KHDRLW-3	Dumuria	149.98	76.04	894.7	6.02	1943.63	366	1.4	79
KHDRLW-4	Dumuria	14.24	4.86	1095.7	3.43	1677.38	213.5	2.7	0
KHDRLW-5	Dumuria	7.02	7.24	142.6	2.68	177.5	190.625	1.2	3
KHKRLW-1	Koyra	44.62	33	348.7	6.925	434.88	289.75	0.7	0
KHKRLW-2	Koyra	102.54	55.92	411.8	4.673	701.13	213.5	1.1	1
KHKRLW-3	Koyra	44.42	5.48	1239.5	5.101	2121.13	213.5	1.6	7
KHKRLW-4	Koyra	10.66	5.26	861.3	5.862	1056.13	213.5	1.7	21
KHKRLW-5	Koyra	26.8	7.4	458.6	2.09	612.38	213.5	1.3	29
KHPGLW-1	Paikgacha	9.7	43.68	214.9	3.54	301.75	366	4.8	1
KHPGLW-2	Paikgacha	21.08	62.52	1567.9	8.58	2209.88	442.25	3	0
KHPGLW-3	Paikgacha	26.28	32.96	60.2	3.39	66.56	366	4.7	0
KHPGLW-4	Paikgacha	7.5	33.72	223.4	4.55	346.13	289.75	9.9	0
KHPGLW-5	Paikgacha	13.14	45.92	1464.5	8.05	1766.13	518.5	2.4	0
KHRSLW-1	Rupsa	109.3	40.72	1172.5	8.08	1854.88	366	7.3	0
KHRSLW-2	Rupsa	157.96	69.12	878.2	7.59	1677.38	442.25	1.1	0
KHRSLW-3	Rupsa	180.26	63.56	694.9	12.85	1499.88	366	4.3	0
KHRSLW-4	Rupsa	52.94	35.4	404.6	2.3225	523.63	289.75	23.9	0
KHRSLW-5	Rupsa	105.76	57.32	899.7	11.19	1677.38	289.75	20.3	0
KHTKLW-1	Terokhada	104.14	51.36	1137.5	4.99	1854.88	213.5	1.1	29
KHTKLW-2	Terokhada	100.42	46.28	1141.6	7.25	1766.13	289.75	1.2	39
KHTKLW-3	Terokhada	22.08	36.08	231.8	4.42	301.75	213.5	10.4	8
KHTKLW-4	Terokhada	15.26	11.03	762.6	8.51	878.63	213.5	5.1	1
KHTKWL-5	Terokhada	21.4	9.76	595.6	5.313	612.38	366	10.9	0

Table 3 it can be observed that about 70% of the groundwater samples have Cl^-/Σ anions ratio greater than 0.8, HCO_3^-/Σ anions ratio less than 0.8 as well as having low SO_4^{2-} values. These indicate that the water is either derived from sea water or brine or evaporates [4]. The table also shows that about 45% of the sample have both Cl^-/Σ anions ratio greater than 0.8 as well as $Na^+/(Na^+ + Cl^-)$ ratio 0.5 or above which suggest that at least 45% of the groundwater samples within the study area may derive their salinity from the dissolution of halite from the

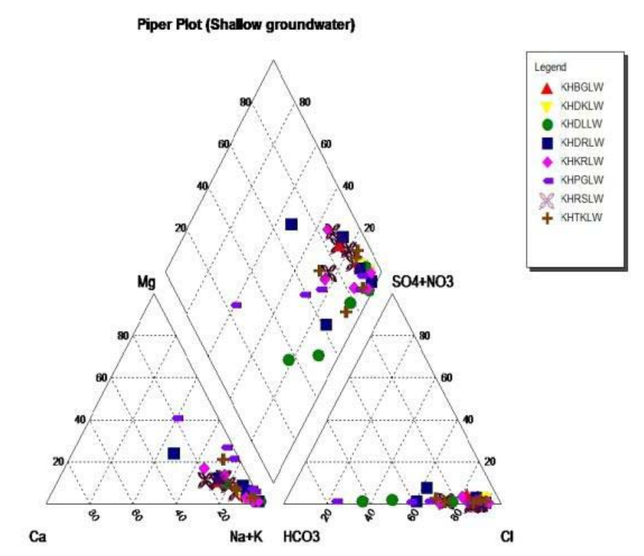

Figure 6: Piper diagram of groundwater samples of shallow aquifer.

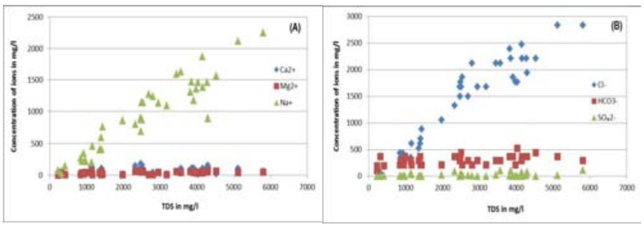

Figure 7: (A) Relationship between major cations and TDS; (B) Relationship between major anions and TDS.

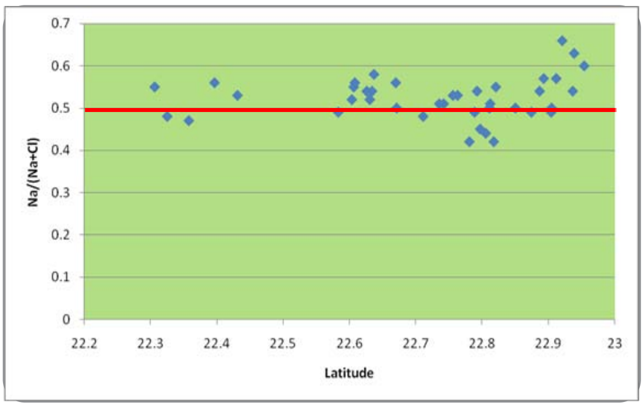

Figure 8: Variation in molar concentration of $Na^+/(Na^+ + Cl^-)$ in the study area.

deposition of various sources of halite. However, according to Hasan et al. 2009 it is possible that the ratio of Na^+/Cl^- approximating to 1(that is $Na^+/(Na^+ + Cl^-)$ approximating 0.5) may be due to mixing of sea water (Na^+/Cl^- slightly less than 1) and fresh water ($Na^+/Cl^- > 1$). On the other side about 25% of the groundwater samples with Cl^-/Σ anions ratio greater than 0.8 and having $Na^+/(Na^+ + Cl^-)$ ratio of less than 0.5 (Figure 8) suggesting that they possibly derived from seawater intrusion or brine [4]. Further evidence of seawater intrusion is provided with the existence of cation exchange. Usually,

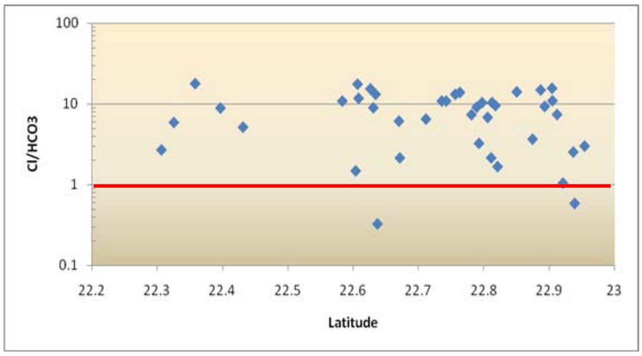

Figure 9: Molar ratio of Cl^-/HCO_3^- with space (red line showing the fresh and mixed water contact).

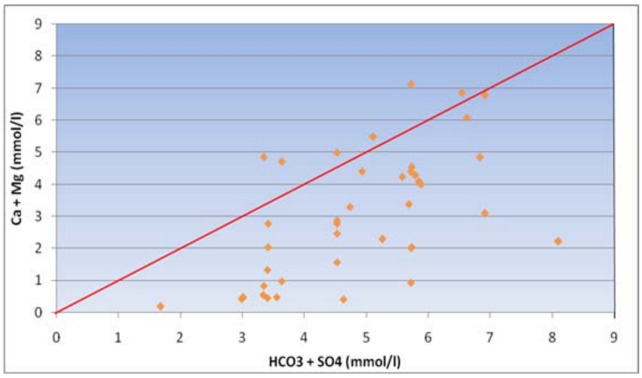

Figure 10: Scatter plot of (Ca + Mg) Vs (HCO_3 + SO_4) showing carbonate-silicate weathering.

the composition of fresh groundwater in the coastal aquifer was often dominated by Ca^{2+} and HCO_3^- ions, which resulted from the carbonate aquifer dissolution. In seawater, the most dominant ions are Na^+ and Cl^-; and aquifer systems in direct contact with seawater due to seawater intrusion will mostly have Na^+ in the aquifer's matrix. When seawater intrudes into coastal aquifers, an exchange of cations occurs [5]. It is indicated by very low value of Ca^{2+}/Na^+ ratio of approximately 67.5% of the sample which is less than or equal to 0.1. Low values of Ca^{2+}/Na^+ ratio suggest that the water has the tendency of replacing Na^+ with Ca^{2+} to produce $CaCl_2$ or $MgCl_2$.

Another way to get idea about the origin of the groundwater is using molar ratio of Cl^-/HCO_3^-. The ratio $Cl^-/HCO_3^- > 200$ indicate sea water, whereas the ration less than 1 normally indicate fresh water and the ratio in between 200 and 1 indicate mixing of fresh and sea water [6]. The scatter plot of molar ratio of Cl^-/HCO_3^- greater than 1 indicate that the water is mixing of sea and fresh water (Figure 9). From the graph it can be observed that about 95% of the sample has the molar ratio of Cl^-/HCO_3^- in between 1 and 200 indicating mixing of fresh and sea water.

To understand the origin of groundwater it is also important to understand the reaction between groundwater and aquifer materials. It also has significant role on the quality of water [7]. In a (Ca+Mg) versus (HCO_3+SO_4) scatter plot the ionic concentration falling above the equiline (1:1 concentration line) results from carbonate weathering, whereas the samples falling along the line results from

Table 3: Milli-equivalent Ratios of the various chemical parameters of representative samples.

Sample ID	Mg/Ca	Ca/Na	Na/(Na+Cl)	Cl/SO4	Cl/Σanions	HCO3/Σanions
KBGW-1	0.64	0.05	0.53	294.46	0.93	0.07
KBGW-2	1.95	0.03	0.53	143.4	0.92	0.07
KBGW-3	0.87	0.07	0.51	186.75	0.91	0.08
KBGW-4	0.81	0.08	0.51	27.93	0.89	0.08
KBGW-5	0.71	0.2	0.48	20.55	0.83	0.13
KDGW-1	0.81	0.08	0.49	2988.01	0.91	0.08
KDGW-2	1.17	0.05	0.56	461.14	0.91	0.08
KDGW-3	1.3	0.02	0.54	47.83	0.92	0.06
KDGW-4	1.33	0.03	0.55	34.49	0.92	0.05
KDGW-5	0.67	0.07	0.54	28.4	0.9	0.07
KDiGW-1	0.91	0.04	0.49	84	0.78	0.21
KDiGW-2	1.22	0.04	0.54	298.5	0.93	0.06
KDiGW-3	2.23	0.01	0.57	202.8	0.9	0.1
KDiGW-4	1.31	0.05	0.66	84.01	0.5	0.48
KDiGW-5	0.76	0.16	0.63	84.01	0.37	0.62
KDuGW-1	1.28	0.05	0.51	0	0.91	0.09
KDuGW-2	0.81	0.62	0.5	8.36	0.63	0.29
KDuGW-3	0.84	0.19	0.42	33.27	0.88	0.09
KDuGW-4	0.56	0.01	0.5	0	0.93	0.07
KDuGW-5	1.7	0.05	0.55	80	0.62	0.37
KKGW-1	1.22	0.15	0.55	0	0.73	0.27
KKGW-2	0.9	0.29	0.48	948.01	0.85	0.14
KKGW-3	0.2	0.04	0.47	409.72	0.94	0.05
KKGW-4	0.81	0.01	0.56	68	0.89	0.1
KKGW-5	0.46	0.07	0.53	28.55	0.81	0.16
KPGW-1	7.42	0.05	0.52	408	0.59	0.4
KPGW-2	4.89	0.02	0.52	0	0.9	0.1
KPGW-3	2.07	0.5	0.58	0	0.24	0.75
KPGW-4	7.41	0.04	0.5	0	0.68	0.31
KPGW-5	5.76	0.01	0.56	0	0.86	0.14
KRGW-1	0.61	0.11	0.49	0	0.9	0.1
KRGW-2	0.72	0.21	0.44	0	0.87	0.13
KRGW-3	0.58	0.3	0.42	0	0.88	0.12
KRGW-4	1.1	0.15	0.54	0	0.75	0.23
KRGW-5	0.89	0.13	0.45	0	0.91	0.09
KTGW-1	0.81	0.1	0.49	86.48	0.93	0.06
KTGW-2	0.76	0.1	0.5	61.23	0.9	0.08
KTGW-3	2.69	0.11	0.54	51	0.7	0.27
KTGW-4	1.19	0.02	0.57	1188.01	0.88	0.12
KTGW-5	0.75	0.04	0.6	0	0.75	0.25

both carbonate and silicate weathering and points those are below the equiline are caused by silicates weathering [8]. The scatter plot of (Ca+Mg) against (HCO_3+SO_4) (Figure 10) shows that about 85% of the samples fall below the equiline indicating silicate weathering. The samples which are above the equiline are enriched with Mg^{2+} indicating sea water influence [9].

Groundwater Quality

Drinking water quality

Groundwater quality should be given special emphasis and the

Table 4: Comparison of groundwater quality results with WHO and BDWS for drinking purpose.

Parameters	WHO (2004)	BDWS (DoE,1997)	% of sample exceeds WHO limit (count)	% of sample exceeds BDWS limit (count)
Calcium (mg/l)	75-200	75	0 (0)	40 (16)
Magnesium (mg/l)	50-150	30-35	0 (0)	62.5 (25)
Sodium (mg/l)	200	200	90 (36)	90 (36)
Potassium (mg/l)	-	12	-	20 (8)
Bicarbonate (mg/l)	-	-	-	-
Chloride (mg/l)	200-600	150-600	82.5 (33)	82.5 (33)
Sulfate (mg/l)	250	400	0	0
Nitrate (mg/l)	50	10	0	15 (6)
Total Hardness (mg/l)	100-500	200-500	15 (6)	15 (6)
Ph	6.5-8.5	6.5-8.5	2.5 (1)	2.5 (1)
TDS (mg/l)	1500	1000	62.5 (25)	87.5 (35)

Table 5: Water Salinity Classification based on TDS and comparison of representative samples with the classification [12].

TDS mg/l	Water type	Frequency Percentage (Counts)
<1000	Fresh	22.5 (9)
1000 – 10000	Brackish	77.5 (31)
10000 – 100000	Saline	0.00
>100000	Brine	0.00

classification of water according to possible uses and assessment of groundwater resources must be done. Water quality standard ensures physical, chemical and microbiological purity. Potable water should be free from undesirable physical properties, cloudiness and objectionable odor and taste. An attempt has been made in Table 4 to compare the results of groundwater quality analyses of the study area with the standards of WHO and BDWS [10,11]. Comparison of the data suggests that most of the samples are of poor quality due to the presence of salinity. Among the chemical constituents sodium concentration (90%) and chloride concentration (82.5%) in water sample exceeds both WHO and BWDS limit. However, calcium, magnesium, sulfate and nitrate do not exceed the WHO limit but they exceed in significant percentage with respect to BDWS limits.

TDS value of the sample was also found very high exceeding the drinking standard. For the classification of TDS, Freeze and Cherry (1979) identified four groups (Table 5) [12]; according to that only 22.5% of the samples are fresh water and rest 77.5% of the shallow aquifer shows high TDS value signifying brackish water type.

Irrigation water quality

Concentration of sodium is important to classify irrigation water because sodium reacts with soil to reduce its permeability. When high sodium water is applied to soil the number of sodium ions combined with the soils increases while an equivalent quantity of calcium or other ions is displaced. These reactions cause deflocculation and reduction of permeability. In the opposite case where calcium is the dominant cation, the exchange occurs in the reverse direction, creating a flocculated and more permeable soil so the soil texture and the drainability can be improved. Sodium concentration is usually expressed in terms of percent sodium, defined by

$$Na (\%) = (Na + K)*100/ (Ca + Mg + Na + K)$$

Table 6: Groundwater quality classification for irrigation [13].

Percent Sodium	Water Class	Frequency Percentage (Counts)
<20	Excellent	-
20-40	Good	-
40-60	Permissible	5 (2)
60-80	Doubtful	10 (4)
>80	Unsuitable	85 (34)

According to Todd's (1980) classification of the irrigation water (Table 6), there is no shallow tube well sample showing values less than 40%, only 2 samples show value within the range 40-60% that is permissible for irrigation [13]. Four tubes well samples fall in the range of 60-80%, doubtful irrigation water. And majority of the samples (about 85%) in the study area show over 80% sodium, suggesting unsuitable for irrigation use.

For classifying irrigation water, Sodium adsorption ratio (SAR) was estimated by the following equation using the values obtained for, Na^+, Ca^{2+}, and Mg^{2+} in meq/l [14].

$$SAR = Na^+ / \{(Ca^{2+} + Mg^{2+}) / 2\}^{1/2}$$

The high SAR in any irrigation water implies hazard of sodium (Alkali) replacing Ca^{2+} and Mg^{2+} of the soil through cation exchange process, a situation eventually damaging soil structure, namely permeability which ultimately affects the fertility status of the soil and reduce crop yield. The Sodium Adsorption Ratio (SAR) influences infiltration rate of water. That is why low SAR is always desirable. Water classification based on EC, TDS and SAR has been given in Table 7 [15]. High SAR value was found where the EC value was also high. Table 7shows that among the samples only about 25 – 40% samples are found with up to moderately hazardous EC, TDS and SAR value; the rest 75 – 60% are severely hazardous for soil. Therefore, the SAR results support that most of the shallow groundwater have sodium hazard and highly unsuitable for irrigation.

Conclusion

Chemical analyses show that high electrical conductivity values in the shallow aquifer are associated with high concentrations of chloride and other major and minor elements typically contained in seawater. Silicate weathering (hydrochemical process), high TDS

Table 7: Irrigation water quality classification based on EC, TDS and SAR [15].

Parameters	Hazard	Frequency Percentage (Counts)
EC(μS/cm)	None (<700)	7.5 (3)
	Slightly to Moderate (700-3000)	30 (12)
	Sever (>3000)	62.5 (25)
TDS (mg/l)	None (<450)	10 (4)
	Slightly to Moderate (450-2000)	30(12)
	Sever (>2000)	60 (24)
SAR	None (<3)	2.5 (1)
	Slightly to Moderate (3-9)	22.5 (9)
	Sever (>9)	75 (30)

and EC value with the mili-equivalent ratio of Ca^{2+}/Na^{+}, $Na^{+}/(Na^{+} + Cl^{-})$, Cl^{-}/Σ anions, HCO_3^{-}/Σ anions as well as the molar ratio of Cl^{-}/HCO_3^{-} suggest that saline and fresh water mixing is the dominant mode of salinization of the shallow aquifer of the study area. Most of the groundwater samples have poor water quality exceeding the recommended level of both WHO (2004) and DoE (1997) guideline values of TDS, Total Hardness, Sodium, Chloride etc. Only a few samples of pocket fresh water show good quality shallow groundwater. In terms of irrigation water quality most of the samples are unsuitable for irrigation (about 85%) exceeding 80 percent sodium value. According to the SAR value 70% water samples are severe hazardous. It can be concluded that, the shallow aquifer of Khulna District is unsuitable for both drinking and irrigation except a few pocket fresh water demine.

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