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Groundwater Chemistry at Deep Aquifer in Koyra: Khulna, Bangladesh

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Abstract

Koyra (Khulna District) is the coastal Upazila of Bangladesh and is very susceptible to salinity intrusion. The surface and shallow tube well water in the Upazila is naturally saline. The quality of subterranean tube well water in the deliberate area is hardly presented for different Unions of Koyra. Dakshin Bedkashi Union of Koyra is very saline prone. Therefore, the groundwater chemistry of Dakshin Bedkashi Union was determined to legalize if the groundwater is fit for drinking and irrigation or not. Spatially dispersed 30 water samples were collected from the deep aquifer (550 to 700 feet depth) in December, 2016 and analyzed for physico-chemical properties. The outcomes were compared with WHO, USEPA and BBS drinking water quality standard and with FAO standard for irrigation purpose. The pH varied from 6.73 to 8.33, indicating that the water samples were within the WHO drinking water quality standard. The TDS showed a long range variation (230.5 to 2052.0 ppm) with an average of 841.23 ppm, of which 33% of water sources exceeded BBS standard value. The mean value of salinity was 0.65 (±0.43) ppt and EC was 1,400.9 (±904.18) µS cm^{-1}. The loads of key ions were ranked as $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^-$. The Piper diagram demonstrated that the existing hydro-chemical facies of groundwater were Na^+-Cl^--HCO_3^- and Na^+-Ca^{2+}-HCO_3^- type. The Gibbs diagram illustrated that the chemical arrangement of groundwater is mainly misrepresented by rock weathering. Silicate weathering was the profuse process along study area. The Wilcox diagram proved that the greater water sources were allowable to suspicious for irrigation. The core component analysis ensured that rock suspension and sea water intrusion was the primary source of ions in groundwater. The controlling factors of groundwater chemistry were typically related to geologic factors, while the anthropogenic factors have not any momentous effects.

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Abbreviations

APHA = American Public Health Association; BBS= Bangladesh Bureau of Statistics; DTW = Deep Tube Well; EC = Electrical Conductivity; FAO = Food and Agriculture Organization; PC = Principal Component; PCA = Principal Component Analysis; RSC = Residual Sodium Carbonate, SAR = Sodium Absorption Ratio; SP = Sodium Percentage; TDS = Total Dissolved Solids; USEPA = United States Environment Protection Agency; WHO = World Health Organization.

Introduction

Water is the foundation of life on globe. The water quality is the key to all of the roles that water plays in human body or their natural surroundings. Water is vital for human life, ecological functioning, socio-economic evolution, food supply and also poverty lessening.[1] The superiority of accessible water varies spatially. The varying geological and climatic factors determine the provincial differences in water individuality.[2] Depending on weather, the quality of accessible water varies to a great extent whether it may comes from aquifers or exterior water bodies (ponds and rivers).[3] Both the excellence and extent of water in Bangladesh is of great apprehension due to its natural settings and human population. Bangladesh is a low-lying deltaic country with large residents, exposed to a variety of environmental pressures and usual disasters. These pressures are exacerbating the complexity of obtaining drinking water.[4] However; the quality of available water may amplify the degree of water uncertainty.

Twenty out of 64 Districts in Bangladesh are characterized as coastal District (covers approximately 47,201 km^2).[5] The coastal people of Bangladesh essentially employ exterior and groundwater for drinking, irrigation, bathing and household purposes.[6, 7] In coastal area of Bangladesh, usual water sources such as rivers and groundwater are habitually polluted by salts and other metal ions due to salinity intrusion from the Bay of Bengal.[8, 9] Exterior water in the coastal part is subjected to seawater intrusion due to unbroken pressure of high and low tides and the salinity is mounting with time due to effects of climate alteration.[9] Throughout the monsoon, salinity of exterior water decreases but in other times salinity remains high depending on the geology of the area. In the past two decades, shrimp culture has been practiced to the highest degree which tainted the local landscape and pessimistically affecting exterior and groundwater resources.[8]

Groundwater is the central resource and must meet growing household, agricultural and industrial requirements. The weakening of water quality is directly interrelated to human health has exacerbated the global groundwater crises.[9] Groundwater quality is unevenly distributed and it is extensively depended on position, lithology, renew water quality and environmental factors. The factors determine the quality of groundwater are the geological setting, characteristics of source rock, composition of invigorated water, soil formation and extent of water been trapped in underground.[7] Throughout Bangladesh, groundwater is far and wide used as drinking water. In coastal areas, the largest part of the groundwater used for water supply is pumped from a depth of 150 m, but nearly all of it is brine.[9, 10] In coastal Bangladesh, lots of shallow aquifers have high salinity due to seawater intrution.[9] The profound aquifer of coastal area of Bangladesh has been tainted by salinization due to entrapped seawater. The half of the profound aquifer of the Northern side of Bangladesh is also secure for irrigation as well as for drinking purpose in respect of SAR, SP, EC, RSC, arsenic and physico-chemical characteristics of water.[11]

Due to diversified geographic locations of Bangladesh, the groundwater quality of all aquifers is not appropriate for drinking and irrigation purpose. Since each and every location of groundwater are not tainted with saline water, it is therefore necessary to make out likely aquifers which can supply water as much as needed to meet up the demand of local community. Some parts of Bangladesh are contaminated with arsenic and some parts with salinity. The Southern parts of Bangladesh (Khulna and Satkhira Districts) are contaminated with saline water which ultimately responsible for the scarcity of drinking water.[4] The pond water of Gabura and DTW water of Gabura and Burigualini Unions was saline and was not appropriate for drinking. However, pond water of Buri Goalinin Union was not saline.[9] Salinity causes due to intrusion of saline water both in surface and groundwater. The groundwater of the South Central costal region (Barguna and Patuakhali Districts) of Bangladesh was affected by seawater intrusion. The higher EC (>5,000 μS cm^{-1}) and TDS

(>4,500 ppm) clearly showed that the groundwater was not suitable for drinking, irrigation and domestic purposes.[7] The literature showed that the salinity of groundwater in the Southern part of Bangladesh was determined, but there was hardly or almost none about the water quality of Koyra (Khulna). Therefore, the present research was conducted. The aims of the investigation were to uncover the physico-chemical properties of deep aquifer water and to identify the convenient water sources for drinking and irrigational use. Additionally, the governing species of the water quality and the sources of the mineral elements were also calculated.

Materials and Methods

Study Area

The study was regulated at Dakshin Bedkashi Union of Koyra Upazila, Khulna, Bangladesh. Total population in Dakshin Bedkashi was 16,755 with 3,881 households.[12] The Union is encircled by Shamnagar Upazila on the West, Sundarban Mangrove forest on the North, East and South. The natives are predominantly involved with agriculture and aquaculture and rice is cultivated in a single season.[13] There are mammoth numbers of planted trees in this village.[13] This region receives a total of 2,500 mm rainfall in monsoon (June to October). The winter season (October to March) was very cold and dry, followed by a hot summer from March to June. At the end of summer (April and May), the tidal river showed high salinity.[14] People in this area drink DTW water.[12]

Water Sample Collection

About 30 water samples were collected randomly in 1.0 L potable cleaned plastic bottles from DTW in December 2016. The bottles were prewashed with acidic water, rinsed with distilled water and were oven dried for 24 h. The bottles were again rinsed properly with sample water to avoid probable contamination. The depth of all tube well varied from 550 to 700 feet and the tube wells were pumped exact times with respect to the depth of the tube well in feet (i.e. a 500 feet tube well was primarily pumped for 500 times) and thereafter water samples were collected. The physiographic positions of the sampling points were marked in Fig.1.

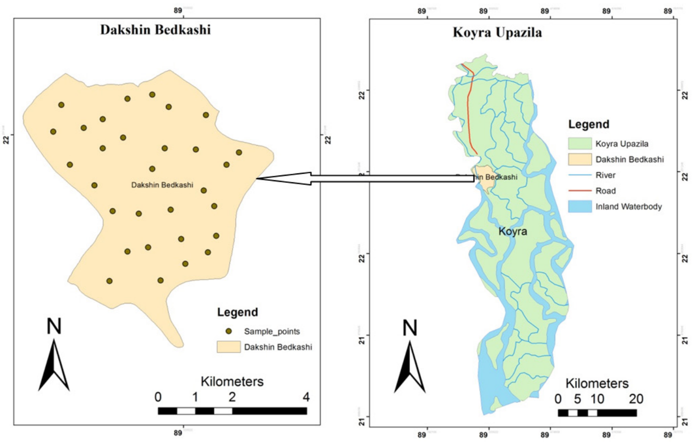

Fig. 1: Sample location of sampling point along the study area. Samples were collected from Dakshin Bedkashi Union at Koyra Upazila, Khulna District, Bangladesh. The study areas were in Southern Parts of Bangladesh and are very near to the Bay of Bengle

Water Sample Analysis

The temperature, EC, pH, TDS and salinity of the samples were measured at the source point. The temperature and pH were determined by using a Microprocessor pH meter (model- HANNA instrument pH 211). The EC and TDS were deliberated by using an EC/TDS/Temperature Tester (HANNA; HI 98312 model; IP57 waterproof; Mauritius). The salinity was measured by using multimeter analyzer (Sense Ion 156, HACH, USA). The Na^+ and K^+ were measured by using flame photometer (flame photometer-PEP7; London, UK). The Ca^{2+}, Mg^{2+} and HCO_3^- were analyzed by using titration colorimetric method. The NO_3^-, PO_4^-, and SO_4^{2-} were analyzed by using Turbidimetric method with Spectrophotometer (model- UV-visible spectrophotometer, helios 949923045811)[15] and Cl^- by using Argenometric method.

Data Analysis

The data were evaluated by MS Excel 2017, SPSS version 20 and Aqua Cham Version 4. Hydro-chemical arrangement and groundwater appraisal were discussed by using carbonate Vs silicate weathering, PCA, Gibbs diagram, Piper diagram and Wilcox diagram. The obtained results were compared with WHO, USEPA and BBS drinking water quality standards to evaluate drinking water quality. Gibbs diagrams are widely used to establish the rapport between water content and lithological uniqueness of aquifers.[16] Gibbs ratio I (for anions) = $Cl^-/(Cl^- + HCO_3)$; Gibbs ratio II (for cations) = $Na^+ / (Na^+ + Ca^{+2})$, where all ion concentrations were expressed in meq L^{-1}. The Wilcox chart represents the suitability of water for irrigation and domestic use.[17] Samples were collected with 3 replications.

Results and Discussion

General Hydro-Geochemistry

The temperature variation of groundwater samples ranged from 29ºC to 31ºC (results were not shown). Most of the samples were monochrome, but few samples exhibited brownish color.[18, 19] The brownish color was possibly due to dissolve silicate contents.[19, 20] The collected samples were turbid in nature. The turbidity of groundwater (results were not shown) was possibly due to dissolve solids and silicates.[20]

Table 1: Comparison of Drinking Water Quality with the Recommended Values of WHO (1984)[45], USEPA (1992)[46] and BSS (2009)[47]. The table contained minimum, maximum and mean value of determined parameters

Parameters	Range	Mean (± SD)	Standards		
			WHO	USEPA	BBS
General hydro-geochemistry					
EC (µS/cm)	383.3 – 3,317.0	1,400.91 (±904.18)	750	*	300-1,500
pH	6.73 - 8.03	7.33 (± 0.35)	6.5-8.5	6.5-8.5	6.5-8.5
TDS (ppm)	230.5 – 2,052.0	841.23 (±546.51)	1,000	1,000	1,000
Salinity (ppt)	0.20 - 1.60	0.65 (± 0.43)	*	*	*
Major cation chemistry					
Na^+ (ppm)	130.29 - 930.78	308.37 (±192.42)	200	*	200
K^+ (ppm)	6.15 - 27.59	10.41 (± 4.92)	30	*	*
Ca^{2+}(ppm)	8.0 – 146.0	60 (± 45.03)	100	*	75
Mg^{2+}(ppm)	1.20 - 69.60	22.24 (± 20.68)	150	*	30-35
Major anion chemistry					
HCO_3^- (ppm)	280.6 - 841.8	429.64 (±115.24)	*	*	*
NO_3^- (ppm)	0.32- 4.64	1.43 (± 1.12)	50	*	10
PO_4^{3-} (ppm)	0.006 - 3.69	0.61 (± 1.01)	*	10	6
SO_4^{2-} (ppm)	2.24 - 85.16	9.62 (± 14.40)	400	250	400
Cl^- (ppm)	20.21 - 939.43	331.06 (±282.03)	250	250	600

BBS = Bangladesh Bureau of Statistics; EC = Electrical Conductivity; SD = Standard Deviation; TDS = Total Dissolved Solids; USEPA = United States Environment Protection Agency; WHO = World Health Organization. *The values were not available.

The EC value varied from 383.3 to 3,317 µS cm^{-1} with the middling value of 1,400.91 µS cm^{-1} (Table 1). The WHO suggested value of drinking water is 750.0 µS cm^{-1} and BBS suggested value is 300 to 1,500 µS cm^{-1} (Table 1). Considering the middling standard value the DTW water could be consumed. But the true fact was that the EC values of some samples were to a large extent which needs to be clogged without delay for drinking. Again, the BBS suggested value of EC for irrigation is 2,250.0 μS cm^{-1} and the FAO suggested value is 700.0 to 3,000.0 μS cm^{-1}.[9] Bearing in mind the above facts, the DTW water could be applied for irrigation purpose. But care must be taken as continuous application of this type of water may develop soil EC which is damaging for crop production. The EC value in DTW water was reported to be 1,330.0 to 7,790.0 μS cm^{-1} in coastal Unions of Buri Goalini and Gabura, Shyamnagar, Satkhira, Bangladesh.[9]

The pH of the water samples were in the tolerable boundary of WHO and USEPA drinking water quality standards, which ranged from 6.73 to 8.03 where the typical value was 7.33 (± 0.35; Table 1). Thus, the water could be used for drinking purpose and without doubt for irrigation. The conclusion of this study is comparable with the study of Buri Goalini and Gabura Unions of Shyamnagar Upazila, Bangladesh, where the groundwater is acidic to minor alkaline in nature.[9] The pH ranged from 7.07 to 8.01 in the DTW water of those samples.[9] A comparable discovery was also reported for Shyamnagar Upazila. The pH ranged from 7.23 to 8.01 in the DTW water samples with the represent value of 7.69.[21] The other reports demonstrated that the pH of tube well water was from 6.53 to 6.66 in the salinity affected South-west coastal region of Bangladesh.[22] The pH in soil samples in coastal Gabura Union wide-ranging from 6.5 to 7.20, but in Buri Goalini Union the values varied from 6.70 to 7.50.[23] The pH of groundwater in South-central part ranged from 6.38 to 7.35, which was comparable to current study.[24]

Salinity of the samples varied from 0.20 to 1.60 ppt with the middling value of 0.60 ppt (Table 1). The salinity level ~ 0.50 ppt is considered as fresh water. The BBS and FAO suggested value for irrigation water is ~ 2.00 ppt.[9] For that reason, the sampled water could be applied for irrigation. Again, long term impacts of using brackish water needs to be considered gravely.

The TDS in groundwater samples ranged from 230.5 to 2,052.0 ppm with a representative value of 841.23 (±546.51; Table 1). Most of the groundwater samples were suitable for drinking, because TDS concentration of nearly every one of the samples did not exceed the WHO, USEPA and BBS drinking water excellence standards. The TDS < 1,000.0 ppm is believed to be as fresh and the TDS 1,000.0 to 3,000.0 ppm is fresh to brackish, 3,000.0 to 5,000.0 ppm is brackish, 5,000.0 to 35,000 ppm is saline water and > 35,000 ppm is hyper saline in nature.[25, 26] About 21 samples out of 30 samples were in the class of fresh water and 9 samples were in the class of fresh to brackish water. But the brackish water could be used for irrigation purpose. The farmers need to be alert, because salt ions could be accumulated in soil after long period use of fresh to brackish water. The TDS must be considered in the result of water excellence, because many toxic solid substances may be embedded in the water, which may cause harm. The TDS in DTW water in coastal Union Gabura and Buri Goalini Unions in the coastal Shyamnagar Upazila wide-ranging from 665.0 to 3,900.0 ppm.[9] A lately published paper demonstrated that the TDS of DTW water samples of 6 Unions of Shymnagar Upazil (Satkhira, Khulna Division, Bangladesh) varied from 161.0 to 2,929.0 ppm with the middling value of 905.88 ppm.[21] On the contrary, the TDS of beel water connected with tidal river in Keshabpur Upazil (Jashore) is moderately higher and the values ranged from 1,780.0 to 9,390.0 ppm.[26] The TDS of water samples of Nolamara Beel (Narail, Bangladesh) was reported to be 2,105.6 to 2,924.9.[27]

Major Cation Chemistry

The combination of Na^+, K^+, Ca^{2+} and Mg^{2+} ranged from 130.29 to 930.78 ppm, 6.15 to 27.59 ppm, 8.0 to 146.0 ppm and 1.2 to 69.6 ppm, respectively with mean values of 308.37 (±192.42) ppm, 10.41 (± 4.92) ppm, 60.0 (± 45.03) ppm and 22.24 (± 20.68) ppm, respectively. The results were just about comparable to a different study conducted at adjacent coastal Upazila, Shyamnagar (Satkhira, Bangladesh).[9, 21] The elevated concentration of Na^+, Ca^{2+} and Mg^{2+} in groundwater was mainly caused by clay minerals such as montmorillonite, illite and chlorite.[28] In most cases, the core cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) go beyond the WHO drinking water quality standard. Among the 30 samples, 21 exceeded the standards limit of Na^+, 5 K^+, 7 Ca^{2+} and 9 Mg^{2+}. Sodium is one of the indispensable ions for human strength but elevated intake may cause congenial heart disease e.g. - hypertension, kidney diseases and nervous disorder. High salt content in drinking water can make the water turbid and taste less.[7, 9] It was established that nearly all of the water samples contained elevated concentration of Na^+ ions. For that reason the water should not be used for drinking purpose considering Na^+. However, the DTW water could be used for irrigation but care should be taken as extended time application of groundwater may increase Na^+ concentration in the farming soils.

The Ca^{2+} and Mg^{2+} ions present in groundwater might enter from the leaching of limestone, dolomite, gypsum and anhydrous gypsum. Furthermore, Ca^{2+} ion might come from cation substitute process.[28] Compared with Ca^{2+}, the concentration of Mg^{2+} in groundwater samples is somewhat far above the ground, and both minerals are caused by weathering and leaching of dolomite (Ca, Mg) $CO_3 + CO_2 + H_2O = 2HCO_3^- + Ca^{+2} + Mg^+$.

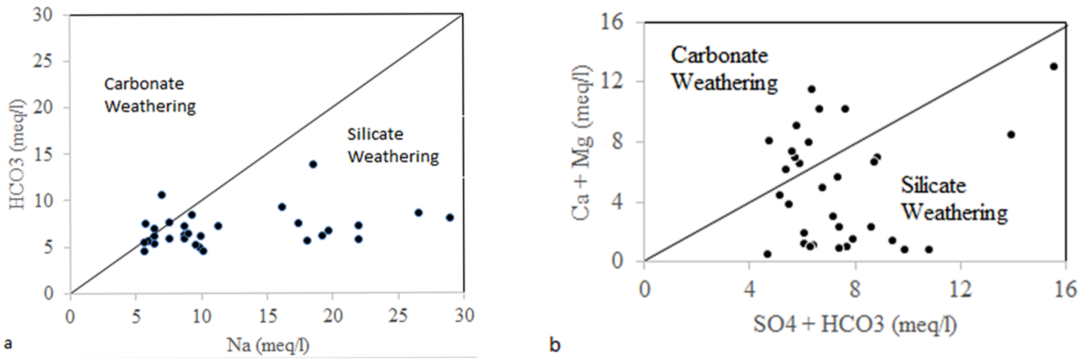

Fig. 2: (a)(b) Scatter diagram for carbonate weathering Vs silicate weathering process of groundwater samples

Again, in HCO_3^- Vs Na^+ disperse diagram,[29] the largest part of the samples were below the contour, which indicated that silicate weathering was the foremost process of releasing Na + ions in groundwater (Fig. 2a). In addition to silicate weathering, carbonate weathering might be a supplier to those ions in groundwater. The probable origin of Na+ in groundwater was a good number probably caused by dissolution of rock salt and weathering of Na+ bearing minerals. The ($Ca^{+2} + Mg^{+2}$) Vs ($SO_4^- + HCO_3^-$) dispersed diagram[30] represented that nearly all of the samples were below contour, which proved that most of the Ca^{2+} and Mg^{2+} in groundwater originated from silicate weathering (Fig. 2b). Compared with the Na^+ ion in groundwater, the increase in HCO_3^- concentration indicated that the silicate weathering progression was governing. The lofty concentration of HCO_3^- can maintain it well.

Major Anion Chemistry

The concentration of HCO_3^- in groundwater sample varied from 280.6 to 841.8 ppm (Table 1). The HCO_3^- was one of the dominating anions in the study area. The concentration of CO_3^{2-} and HCO_3^- in groundwater might come from carbonate weathering and the dissolution of carbonic acid in aquifers.[31] The dissolution process could be offered by the equation of $CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2HCO_3^-$ and $CO_2 + H_2O = H^+ + HCO_3^-$.[31] The accessibility of CO_3^{2-} minerals in the aquifer and silicate weathering might be liable for mounting HCO_3^- in the groundwater.

The Cl^- concentration in groundwater ranged from 20.20 to 939.42 ppm (Table 1). About 17 samples out of 30 exceeded the principles limit for Cl^- (WHO and USEPA). Natural processes such as weathering, salt dissolution and irrigation drainage backflow may be the cause of the Cl^- content in groundwater, which is supported by Cl^-/HCO_3^- ratio of 0.4 to 3.0.32 The continuation of Cl^- in drinking water is advised as one of the central causes of salinity. The lofty concentration of Cl^- in drinking water can make it inapt for drinking.

The concentration of SO_4^{2-} ranged from 2.24 to 85.16 ppm (Table 1). The SO_4^{2-} in groundwater might come from weathering of sulfate minerals and sedimentary rocks containing gypsum.[31] The SO_4^{2-} concentration in all water samples were within WHO, USEPA and BBS drinking water excellence values. The PO_4^{3-} concentration along study area ranged from 0.0059 to 3.69 ppm with the common concentration of 0.61 ppm (± 1.01). The domino effect indicated that the stage did not go beyond the permissible limit prescribed by WHO, USEPA and BSS. The pretty low concentration of PO_4^{3-} was reported in the different sources e.g. profound tube well water, pond water and pond sand filter water.[9]

The NO_3^- consolidation in groundwater samples varied from 0.32 to 4.64 ppm (Table 1). The WHO approved concentration of NO_3^- in drinking water is 50.0 ppm and the BBS permissible concentration of NO_3^- is 10.0 ppm.[9, 19] Considering the both values mentioned, the investigational samples were incredibly fine for drinking purpose. The NO_3^- concentration in DTW water varied from 2.50 to 4.60 ppm in Gabura and Buri Goalini Unions of Shyamnagar Upazila of the coastal District Satkhira.[9] It is also reported that the NO_3^- concentration in the water of Beel Khuksia varied from 9.50 to 10.21 ppm.[26] It is believed that the existence of lower combination of NO_3^- in the drinking water is good. Conversely, consumption of lofty NO_3^- in water can cause blue babies or methemoglobinemia, stomach cancer, abnormal pain, central nervous system, birth defects and diabetes.[34] The juvenile coal deposit is universally found in all the coastal zone of Bangladesh, which might be the apparent source of NO_3^- in groundwater samples. The lower concentration of NO_3^- in groundwater samples used for drinking purpose were recently reported for Jashore University of Science and Technology Campus, Bangladesh.[35]

Table 2: Correlation matrix of major cations and anions of the water samples along the study area

	pH	Salinity	TDS	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	PO_4^{3-}	NO_3^-	Cl^-	HCO_3^-	SiO_2
Salinity	-.541**	1												
TDS	-.549**	.998**	1											
EC	-.550**	.998**	1.000**	1										
Na^+	-.180	.542**	.546**	.538**	1									
K^+	-.427*	.700**	.687**	.685**	.561**	1								
Ca^{2+}	-.805**	.472**	.483**	.485**	.090	.283	1							
Mg^{2+}	-.455*	.607**	.607**	.613**	.055	.557**	.453*	1						
SO_4^{2-}	.396*	-.162	-.142	-.143	.321	-.159	-.246	-.205	1					
PO_4^{3-}	.508**	-.142	-.150	-.149	.157	.217	-.418*	-.111	.459*	1				
NO_3^-	.376*	.211	.203	.205	.282	.436*	-.382*	.022	.348	.801**	1			
Cl^-	-.649**	.967**	.970**	.970**	.526**	.700**	.594**	.662**	-.170	-.209	.113	1		
HCO_3^-	.356	.213	.195	.193	.322	.548**	-.289	.144	.109	.762**	.748**	.109	1	
SiO_2	-.421*	-.078	-.061	-.060	-.200	-.406*	.454*	.081	-.140	-.837**	-.835**	.037	-.877**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

EC = Electrical Conductivity; TDS = Total Dissolved Solids

Correlation Matrix and Factor Analysis

The correlation matrix of physico-chemical parameters of groundwater samples was shown in Table 2. The PCA results showed that three foremost element have eigen value >1 and it explained about 82.718% of total variance of the data. The PC1 explain about 46.99% of entire variance, while PC2 and PC3 explained about 26.88% and 8.84%, respectively. The component loading >.6 is considered as momentous and used for progress interpolation.[36] The PC1 explained about 46.99% of total variance and have a encouraging loading of salinity, EC, TDS, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-. The lofty loading factors of TDS and EC were due to occurrence of dissolve ions in groundwater. The foremost ions like K^+, Ca^{2+}, Mg^{2+} and Cl^- might be linked with hydro-chemical variables from mineral dissolution and water-rock interface in the aquifer, which indicates PC1 habitually reflects geological effects.[37] The PC2 explained about 26.88 % of total variance and high positive loading of PO_4^{3-}, NO_3^- and HCO_3^-. The loading of NO_3^- and HCO_3^- represents the presence of organic matter in the aquifer.[38] The PC3 explained about 8.84% of total variance and positive loading of SO_4^{2-}. Weathering process and human input are the two main factors that change the geochemical composition of groundwater.[36]

Table 3: Factor analysis of major cations and anions of the groundwater samples

Water quality variables	PC1	PC2	PC3
pH	-0.691	0.548	-.010
Salinity	.963	.093	.059
TDS	.963	.083	.083
EC	.963	.082	.077
Na^+	.534	.412	.575
K^+	.780	.386	-.212
Ca^{2+}	.616	-.519	.042
Mg^{2+}	.697	-.062	-.372
SO_4^{2-}	-.223	.485	.685
PO_4^{3-}	-.183	.889	-.123
NO_3^-	.122	.906	-.112
Cl^-	.981	-.017	.078
HCO_3^-	.174	.857	-.338
Eigenvalue	6.109	3.495	1.150
% of Variance explained	46.992	26.882	8.844
Cumulative %	46.992	73.875	82.718

Extraction Method: Principal Component Analysis.

EC = Electrical Conductivity; PC = Principal Component; TDS = Total Dissolved Solids.

Piper and Gibbs diagram

The hydro-chemical facies is fundamental to identifying the chemical background of water, and these phases can be explained by portrayal Piper diagrams.[39] It is commonly used to make out the foremost ionic composition of the groundwater sample.[40] This diagram also represents the corollary of chemical reaction occurred between the minerals and groundwater.[41] The concentration of main cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}), anions (CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^-) and TDS in meq L^{-1} were plotted in Piper trilinear diagram to evaluate the hydro-chemistry of the groundwater of the study area (Fig. 4). The figure indicated that the mixing composition of Na-Ca-HCO_3, Na-Ca-Cl were NaCl type domination in hydro-geochemical facies in groundwater. The lofty concentrations of Na and Cl were the sign of their derivation from identical sources.

The Gibbs diagram was universally used to evaluate hydro-chemistry of water in the study area. This diagram assess the functional sources of dissolve chemicals in water, such as precipitation dominance, rock dominance and evaporation dominance.[16, 42] The ratios of $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ is the representation of a function of TDS. The distribution of sampling points in Gibbs diagram was shown in Fig. 3. The diagram showed that most of the water samples were in rock domain area towards the zone of evaporation. This suggested that the evolution of chemical composition along the study area was habitually related with chemical weathering of rock forming minerals. A small number of samples were in evaporation dominance zone which suggested the salt precipitation and anthropogenic influence.[43]

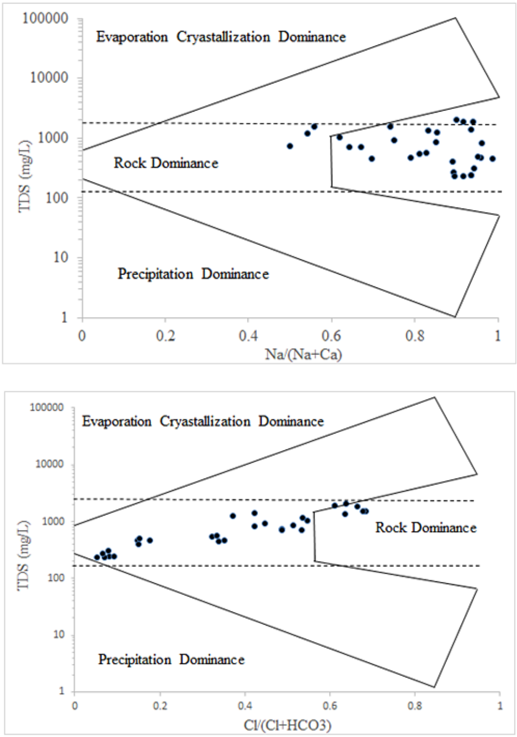

Fig. 3: Gibbs diagram representing major processes controlling groundwater chemistry of the study area (Gibbs, 1970)

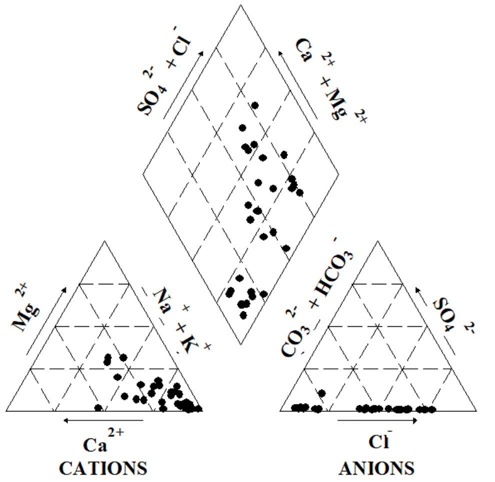

Fig. 4: Piper trilinear diagrams for hydro-geochemical facies of groundwater samples

Wilcox Classification of Water Samples

Sodium percent is plotted alongside EC and the illustration was termed as Wilcox diagram.[17] The chemical breakdown of 30 water samples were plotted in Wilcox diagram (Fig. 5). About 12 samples were in tolerable to distrustful, 8 samples were distrustful to inappropriate, 3 samples were inappropriate, 5 samples were good to tolerable and 2 samples were admirable to fine. Based on Wilcox diagram larger part of water samples were apposite for irrigation in every type of soil. The EC and Na^+ played a central role in aptness of irrigation water.[44] The TDS and EC are the indicators of salinity even in absence of non-ionic dissolved constituents. The TDS values <450 mg L^{-1} represents as "none saline". Similarly, 450 to 2,000 mg L^{-1} represents "slight to moderate salinity" and the value >2,000 mg L^{-1} represents 'severe' salinity for irrigation water.[45]

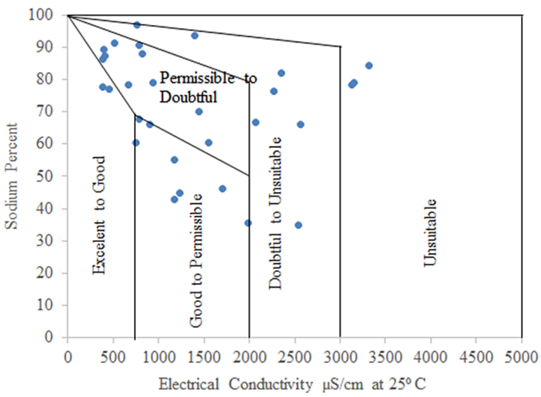

Fig. 5: Wilcox diagram of the water samples for suitability analysis for irrigation purpose

Conclusions

The collected samples were slightly alkaline in nature and high TDS value was mainly due to excessive dissolved salts. A total of three foremost components were found to explain 82.718% of data set when subjected to PCA. The PCA outcome showed that mineral dissolution, rock weathering, ion exchange and sea water intrusion were the overriding factors of overall geochemistry of the study area. The groundwater was habitually Na-Ca-HCO_3^- type, which indicated that the organic deposits in aquifer. Rock weathering was the principal process along the study area. Silicate weathering was essentially at fault for dissolved ions in groundwater. Irrigation with these types of saline water can boost up the salinity of soil and exterior water. The development of management strategies and using of different water sources will be the most excellent solution to meet the increasing demand of drinking and irrigation water. The hydro-geochemical composition of groundwater in the study area was largely prejudiced by geologic factors, while anthropogenic factors have very insignificant effects.

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Conflict of Interest

We are fully agreed with the sequence of authorship.

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