Original Research

Determination and Distribution of Groundwater Composition in Deep Aquifer of Satkhira Municipality, Bangladesh

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Abstract

Satkhira Municipality is located in the extreme South-Western coastal region of Bangladesh. This area exhibits complex hydro-geochemical characteristics along with the increasing tendency of soil and water salinity which created a need of groundwater quality assurance. The objectives of the study were to identify the composition of groundwater followed by attempts to investigate spatial distribution pattern of groundwater quality. This was done to identify places with the availability of best quality of drinking water. This was achieved by combining the geographical information system, statistical analysis and diagrammatic presentation. A total of 100 deep tube well (450 to 600 feet) water samples were collected during monsoon and dry season in 2018 and were analyzed for hydro-geochemical parameters. The groundwater was neutral to alkaline (pH 7.01 to 8.66) in nature. Total dissolved solids ranged from 132.7 to 1436.0 mg L^{-1} which gradually increased from North to South direction. Sodium was the most dominant cation with mean value of 48.28 ($\pm$27.48) mg L^{-1} in monsoon and 105.35 ($\pm$66.73) mg L^{-1} in dry season. On the contrary, Cl^{-} ion was the dominant anion with mean value of 546.99 ($\pm$34.07) in monsoon and 424.68 ($\pm$398.59) mg L^{-1} in dry season. The high loading (>0.6) in principal component analysis indicated that the major ions originated from mineralization of rocks and soils, which was supported by Gibbs diagram. Silicate weathering supposed to be the responsible factor for releasing Na^{+} ion, while Ca^{2+} and Mg^{2+} ion in groundwater came from both silicate and carbonate weathering. Three distinct types of groundwater facies e.g. the mixed NaCaCl, NaCaHCO$_3$ and NaCl were active along the study area, indicating that the underground cation exchange process. Our study will be helpful for the decision makers for planning a better operation and maintenance of groundwater resources.

Keywords: groundwater modeling, hydro-geochemistry, water- rock interaction, Satkhira municipality

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Introduction

Water is the most important and fundamental essence of life on earth. About 71.0 % of the Earth surface is covered with water, of which only 1.0 % is available as fresh and potable water [1]. Due to global population explosion, the groundwater is becoming increasingly important for the drinking, ecosystem health and economic development. Generally, the groundwater is considered to be safe rather than surface water in terms of microbial contamination. Groundwater is fairly ubiquitous, but its conditions vary enormously and exploitation is often undertaken with a limited understanding of the hydrochemistry and without sufficient evaluation of the resource quality, especially in developing countries [2]. The situation is worse in Bangladesh especially in coastal zone, which covers an area of 47,201 Km^2 and accommodating about 36.8 million of people [3]. Due to climate change, the Southwestern part of Bangladesh is being experienced with various types of disasters. The hydro-geochemical characteristics of the Southwestern coastal belt of Bangladesh is very complex and is frequently subjected to cyclones, storm surges, floods, river bank erosion [4] and salinity intrusion [5-6]. These factors are gradually increasing the surface and groundwater salinity and lead to acute shortage of safe drinking water [7].

The coastal aquifer is flushed and recharged seasonally during the monsoon, bringing an abundance of fresh subsurface water. But the recharge is highly variable due to the presence of intermittent, thick deposits of clays [8] and the groundwater quality determines the environmental characteristics of the area. The main factors that affect the groundwater quality are lithofacies geographical conditions, geochemical process, groundwater recharge and runoff condition which is mainly influenced by land use patterns [9]. Moreover, anthropogenic activities like fertilizer leaching, sewage leaching, spillages and high water supply demand, etc. influence groundwater quality. The contamination in groundwater arises from longer duration due to low flow rate of water through aquifer system. The chemical nature of groundwater is very important for determining the suitability for drinking, domestic, agricultural and industrial uses [10].

In recent times many methodologies are adapted to investigate the quality of groundwater and related hydro-geochemical process. These are multivariate statistical analysis [11], geochemical modeling [12], redox indicator and structural equation modeling [13]. The statistical analysis do not necessarily establish cause and effect relationship, but collects the information in a compact format by removing data redundancy as the first step in the complete analysis and thus assist in generating hypothesis for the interpretation of various hydro-chemical processes [14].

Recently, some works have been done in the Southwestern coastal region of Bangladesh to identify the suitability groundwater for drinking [15] and

irrigation purposes. But the information is very scarce and almost none regarding the water quality of the extreme Southwestern coastal District Sathkhira of Bangladesh. The Southwestern part is very important, because many natural resources are present there and many people are also living there especially in Satkhira Municipal area. Therefore, the water quality information and distribution of suitable water in deep aquifer of the Municipality needs to be investigated. The aims of the study were to investigate the status of groundwater quality and associated geochemical process. The next step was to investigate spatial distribution of groundwater to identify the best places with best quality of drinking water in the study area.

Material and Methods

Study Area

Satkhira Municipality is situated between 21º36'-22º54'N Latitudes and 88º54'-89º20'E Longitudes (Fig. 1) and it covers an area of 31.1 Km^2. This municipality is an important sub-urban area in Southwestern Bangladesh. The world's largest tidal mangrove forests the Sundarbans is located in the Southern part of Satkhira District. Majority of the area of this District is predominantly rural and the main income comes from aquaculture and agriculture [16]. In 1977, the Satkhira Municipality was declared as "A" class Municipality and it is very sincere in providing good municipal facilities to its dwellers [17]. Geo-morphologically the Southwestern coastal zone of Bangladesh was under the process of active
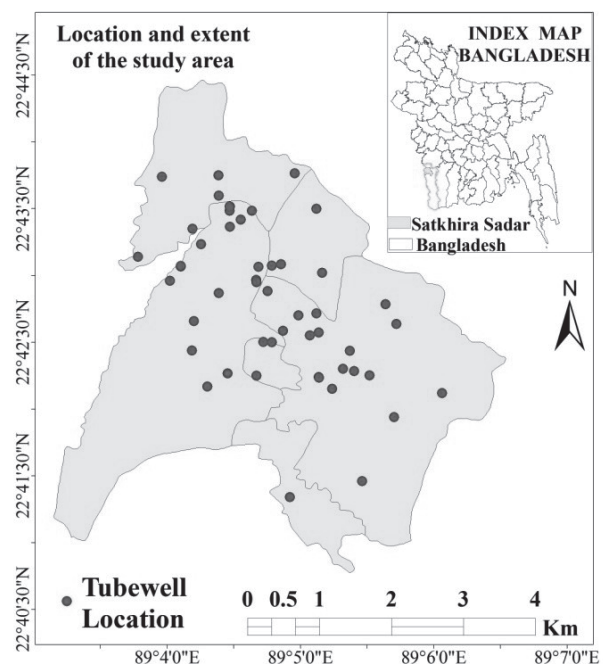

Fig. 1. Study area along with sampling locations. The samples were collected from July - December, 2018.

delta formation by Ganges-Brahmaputra-Meghna river system. The major areas of this Ganges delta are frequently flooded with quaternary sediments eroded from high lands and deposited to those river tributaries [18]. The climate is of humid in nature and the average rainfall ranges from 1474 to 2265 mm, while in dry months it varies from 20 to 65 mm. The average temperature in the study area ranges from 296.15 K to 313.15 K. The Ganges delta is extremely complex and dynamic because three distinct delta types exist are: tidal dominated, tide-river dominated and tide wave dominated [19]. The study area is characterized by three distinct aquifers. The first one is shallow aquifer overlain by a clay aquitard, while the second one is the first deep aquifer and the third aquifer is the deepest aquifer separated by deep aquitard from the upper deep aquifer [20].

Sample Collection and Analysis

A total of 100 deep tube-wells (DTW) (depth 450 to 600 ft) water samples were randomly collected from densely populated area of Satkhira Municipality during July to December, 2018. Two water samples were collected from same tube well in two different seasons (1) monsoon, when maximum rainfall occurs and (2) dry season, when minimum rainfall occurs. The samples were collected in 500 mL potable water bottles. At first, the bottles were washed with detergent and tap water and were socked in 0.1 N HNO_3 for 24 hours. Then the bottles were washed with tap water, rinsed with distilled water and finally were oven dried at 55ºC for overnight. During sample collection, the bottle was prewashed and rinsed properly with sample water to avoid probable contamination. Firstly, tube wells were pumped exactly the number of times corresponding to the depth of the aquifer in feet (i.e. a 500 feet tube well was initially pumped for 500 times) and there after the water samples were collected. After collection, it was immediately brought to the Environmental Chemistry Laboratory of Jashore University of Science and Technology and analyzed. Sample temperature, pH, electrical conductivity (EC) and total dissolve solids (TDS) were measured at the sampling points using Microprocessor pH meter (model- HANNA instrument pH 211) and conductivity meter (model- HI 8033). The measurement of Na^+ and K^+ were done by Flame Photometric Method (flame photometer- PEP7). The TH, Ca^{2+}, Mg^{2+} and HCO_3^- were analyzed by titration colorimetric method and Cl^- by titration ergonometric method. The NO_3^-, PO_4^-, and SO_4^{2-} were analyzed by Turbidimetric method with Spectrophotometer (model- UV-visible spectrophotometer, helios 949923045811) [21].

Used Geochemical Modeling

The Gibbs Diagram is widely used to establish the relationship between water composition and aquifer lithological characteristics [22]. Gibbs ratio I (for anion) = $Cl^-/(Cl^- + HCO^-)$; Gibbs ratio II (for cation) = $Na^+/(Na^+ + Ca^{2+})$, where all the ionic concentration were expressed in meq L^{-1}. The Wilcox Diagram represents the suitability of water for irrigation and domestic purposes [23]. The spatial analysis tools of ArcGIS 10.5 were used to analyze the spatial variation of groundwater quality parameter in the study area. For interpolating point data in surface map inverse distance weighted algorithm was used [24].

Statistical Analysis

All statistical analysis was performed by using SPSS 20.0 and MS-Excel 2010. The factor analysis was applied to identify the chemical characteristics of water that were responsible for generating most of the variability within data set. The Principal Component Analysis (PCA) is ordinational statistical methods that essentially transform original data into a form that can be evaluated in multidimensional space [25]. Each factors in independent and varimax rotation was used to identify factors containing the greatest variability, the variability is represented as an eigenvalue [12]. The factors representing relatively large eigenvalue are highly important in describing the variability exhibited within the systems. The PCA is also a useful tool for providing idea about sub-surface geochemical process [26].

Results and Discussion

Distribution of pH, EC, TDS and Salinity

During monsoon, the pH values ranged from 7.01 to 8.66, but in dry season the values were from 7.51 to 8.26 (Table 1). The pH values in all the samples were above >7.0, indicated that the water samples were slightly alkaline in nature. It seemed that the pH values of water samples were within the permissible value of Department of Environment (DoE) and World Health Organization (WHO) (Table 1). A study in Southwestern coastal Bangladesh also represented a similar range of pH, which varies from 6.0 to 8.20. It was mentioned that, this was due to abrasion of abundant rock forming minerals like calcic plagioclase, micas, carbonates, clay and quartz [27].

The EC values varied a wide range, but the average was almost similar in both the seasons. In dry season, EC ranged from 304.10 to 2,347.0 μS cm⁻¹, while in monsoon the values ranged from 216.0 to 2,072.0 μS cm⁻¹ (Table 1). With few exceptions, most of the cases the EC values in Satkhira Municipality were within the permissible limit (Table 1). The kriging interpolation conducted by Naus et al. (2019) in Southwestern Bangladesh represent large scale regional trend in groundwater EC. It was found that EC value increased gradually from North to South in coastal

Table 1. Descriptive statistics and the values compared with World Health Organization [48] and Department of Environment (DoE) [49] guideline for drinking water quality parameter.

Variable	Season	Min.	Max.	Mean (±SD)	Standards limits		% above WHO limits
					WHO	DoE	
pH	M	7.01	8.66	7.79 (±0.41)	6.5-8.5	6.5-8.5	2
	D	7.51	8.26	7.82 (±0.17)			0
EC (μS cm^{-1})	M	216.00	2072.00	829 (±485.84)	-	300-1500	2
	D	304.10	2347.00	731.7 (±434.4)			1
TDS (mg L^{-1})	M	132.70	1253.00	490.71 (±300.64)	500	1000	4
	D	187.50	1436.00	456.65 (±281.32)			3
Salinity (ppt)	M	0.10	1.00	0.37 (±0.23)	-	-	0
	D	0.10	1.10	0.34 (±0.21)			0
Na$^+$ (mg L^{-1})	M	8.27	130.69	48.28 (±27.48)	200	200	0
	D	15.22	283.71	105.35 (±66.73)			5
K$^+$ (mg L^{-1})	M	0.01	4.93	0.46 (±0.92)	30	12	0
	D	2.12	26.77	7.06 (± 5.25)			0
Ca^{2+} (mg L^{-1})	M	12.00	104.00	55.64 (±19.88)	100	75	8
	D	34.00	130.00	72.64 (± 20.85)			23
Mg^{2+} (mg L^{-1})	M	6.00	42.00	24.31 (±8.93)	150	30-35	6
	D	9.60	78.00	25.12 (± 10.91)			6
PO$_4^{3-}$ (mg L^{-1})	M	0.73	11.92	2.33 (±2.92)	-	6	6
	D	0.01	5.38	1.04 (± 1.25)			0
SO$_4^{2-}$ (mg L^{-1})	M	1.63	105.09	14.74 (±30.61)	250	400	0
	D	0.01	3.53	0.64 (± 0.81)			0
NO$_3^-$ (mg L^{-1})	M	0.42	3.99	0.86(±0.49)	50	10	0
	D	0.42	3.92	0.83 (± 0.48)			0
Cl$^-$ (mg L^{-1})	M	70.90	1932.03	546.99 (±534.07)	250	150-600	18
	D	70.09	1834.53	424.68 (±398.59)			15
HCO$_3$ (mg L^{-1})	M	170.80	518.50	344.65 (±67.87)	100	-	0
	D	186.70	420.90	291.77 (±54.88)			0

N.B. DoE = Department of Environment, D = Dry Season, EC = Electrical Conductivity, M. = Monsoon, Max. = Maximum, Min. = Minimum, SD = Standard Deviation, TDS = Total Dissolve Solid, WHO = World Health Organization

Bangladesh. Most of the groundwater in predominantly flashed Northern part is fresh and the Southern part is saline, as close to the Bay of Bengal [28]. The causes of increased salinity might also be rock mineralization and high evaporation (not possible in deep aquifer) due to increasing temperature in Satkhira region [4]. A report from China showed that about 42% samples were suitable (EC<500 μS cm^{-1}) for drinking while 50% were marginal (EC 500 to 1500 μS cm^{-1}) and the rest 8% (EC>1500 μS cm^{-1}) were unfit for drinking purpose [29]. Generally, the deep tube wells of Jashore Municipality (depth 300 to 500 ft) contained low EC values [15]. The distance of Jashore Municipality is far from the

Bay of Bangle. But the present study area Satkhira is nearer to the Bay of Bengal and therefore, there was high possibility to have much higher concentration of soluble salts in Satkhira Municipality which was ultimately responsible for higher EC values for some samples.

In monsoon, the mean concentration of TDS was 490.71 (±300.64) mg L^{-1}, but in dry season the value was 456.65 (±281.32) mg L^{-1} (Table 1). In the case of higher values, high TDS levels might be responsible for hardness of water which could affect the taste. In the present study, almost 55% of water samples exceeded the WHO and 8% exceeded the DoE drinking water

quality standard (Table 1). The concentration of TDS gradually increased from West to Eastern part (Fig. 2). Another study of Southern Bangladesh reported that the TDS value ranged from 266.0 to 1770.0 mg L^{-1}. The TDS level in the aquifer shows statistically significant variation at 1% significance level. This represents a spatial heterogeneous aquifer in the study area [27, 30].

The salinity of collected water samples showed a similar pattern of pH, EC and TDS in both seasons and the values ranged from 0.10 to 1.10 ppt (Table 1). A study from Assasuni Upazila of Satkhira District reported that about 25% groundwater comes from sea water sources. The groundwater salinity in first aquifer is mostly related with surface elevation. The water of
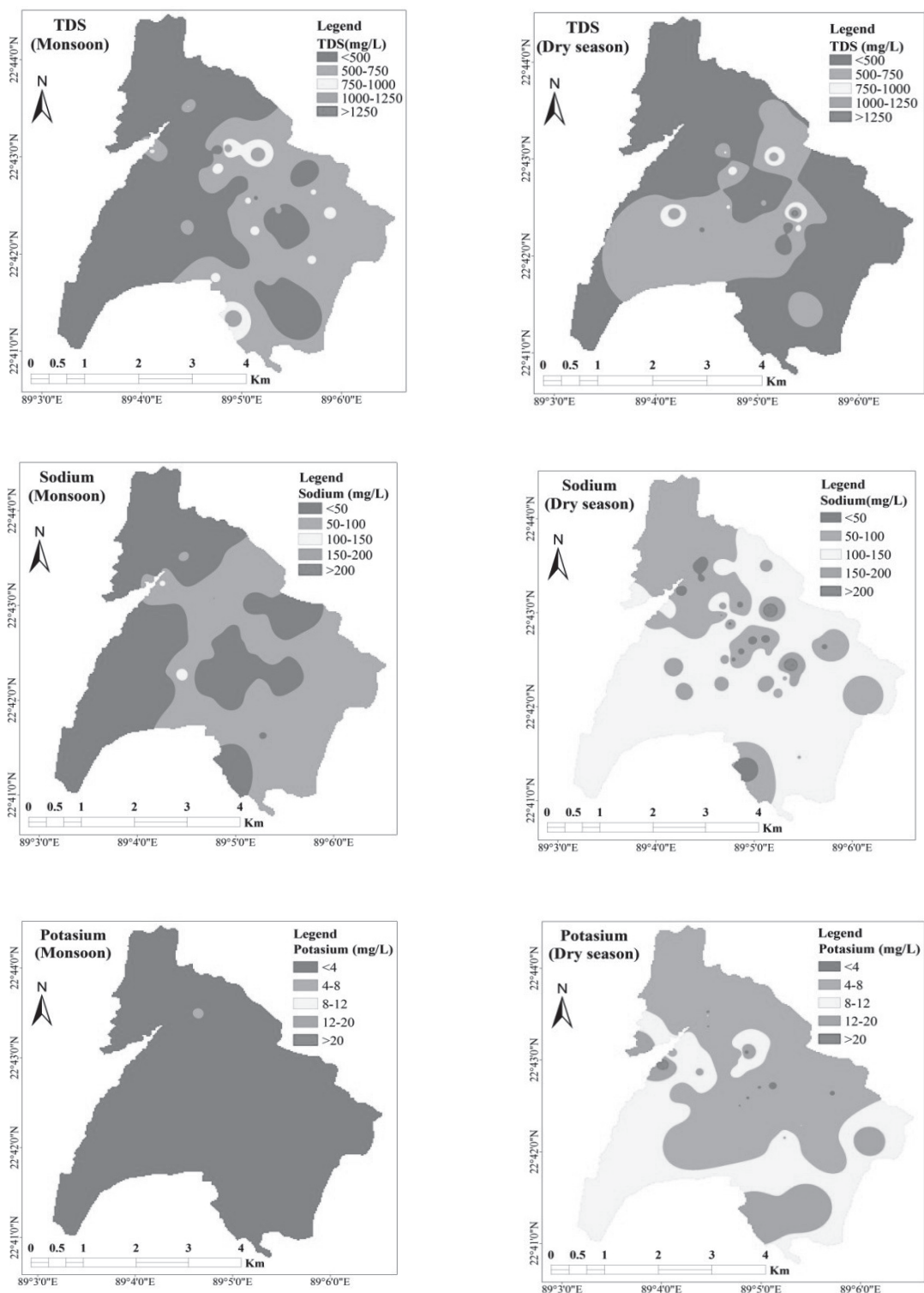

Fig. 2. Spatial distribution patterns of TDS, sodium and potassium in the study area. The samples were collected from July - December, 2018.

higher elevated areas is relatively fresher than the lower elevated areas [26].

Distribution of Major Cations

Based on the concentrations of major cations, Na^+ was the most dominating cation species. The values ranged from 8.27 to 130.69 mg L^{-1} in monsoon and 15.22 to 283.71 mg L^{-1} in dry season, followed by Ca^{2+}, Mg^{2+} and K^+ (Table 1). Similar trend of anion, cation were also found in another study in Satkhira District [31] . The Na^+ is conservative in nature and it binds with clay minerals due to ion exchange [32]. The relatively high concentration of Na^+ was found in East-central part of Satkhira Municipality (Fig. 2). The weathering of rock forming minerals like sodium plagioclase, halite and the influence of domestic and animal wastes were mainly responsible for high concentration of Na^+ in groundwater. The ingestion of higher concentration of Na^+ may cause cardiac, renal and circulatory diseases to human beings [33]. In monsoon, the distribution of K^+ was almost homogeneous in all parts of the study area, but in dry season high concentrations were found in central part (Fig. 2). The K^+ concentrations ranged from 2.12 to 26.77 mg L^{-1} (Table 1).

During monsoon the mean concentration of Ca^{2+} was 55.64 ($\pm$19.88) mg L^{-1} but in dry season it was relatively higher 72.64 ($\pm$20.85) mg L^{-1} (Table 1). A total of 8 samples in monsoon and 23 samples in dry season exceeded the WHO and DoE drinking water quality standard (Table 1). The Ca^{2+} concentration was relatively higher in Northern part as compared to other parts of the Municipality (Fig. 3). The Ca^{2+} concentration in the present underground water samples was relatively lower than the other reported data of coastal region of Bangladesh. This lover concentration of Ca^{2+} and sulfates may be due to the reaction of calcium and sulfates and subsequent precipitation [33].

The Mg^{2+} concentration in monsoon ranged from 6.00 to 42.00 mg L^{-1} and in dry season the values ranged from 9.60 to 78.0 mg L^{-1} (Table 1). The WHO recommended permissible limit value of Mg^{2+} concentration in drinking water is 150 mg L^{-1}. About 12% of collected water samples crossed the permissible limit in both seasons. The higher concentration of Mg^{2+} was most probably due to the dissolution of Mg^{2+}-bearing minerals in rocks. The other sources might be animal, domestic and or industrial wastes [34].

The concentrations of total Ca^{2+} and Mg^{2+} along with HCO_3^- might be responsible for determination of total hardness in water. The high concentrations of Ca^{2+} and Mg^{2+} in groundwater were mostly responsible for increasing temporary hardness. The other cause was most probably due to leaching of those elements from soil, caused by flash irrigation or rainwater. The high standard deviation of some water quality parameters indicated the heterogeneous geochemistry in the study area.

Distribution of Major Anions

Among the anions, Cl^- was the most dominating anion followed by HCO_3^-, SO_4^{2-}, PO_4^{3-} and NO_3^- (Table 1). The Cl^- concentrations ranged from 70.90 to 1932.03 mg L^{-1} in monsoon and 70.09 to 1834.53 mg L^{-1} in dry season (Table 1). About 40% of water samples exceeded the WHO drinking water quality standard. The relatively high concentration of Cl^- was found in Southern part of the study area (Fig. 3), which is closed to the Bay of Bengal. The natural process like dissolution of salt deposits, weathering and sea water intrusion might be responsible for higher Cl^- contents [35]. The higher concentrations of Cl^- in the study area were also most probably due to influence of sea water intrusion or high evaporation rate [36].

During monsoon the mean concentration of HCO_3^- was 344.65 ($\pm$67.87) mg L^{-1} but in dry season the value was 291.77 ($\pm$54.88) mg L^{-1} (Table 1). The high concentrations of HCO_3^- ions in groundwater indicated the presence of carbonate minerals in aquifer. Weathering of carbonate and silicate minerals along with organic matter deposition from mangrove forest might contribute high concentrations of HCO_3^- in groundwater [37]. The Cl^- and HCO_3^- showed a similar pattern of distribution along the study area (Fig. 3). It meant, the concentrations of HCO_3^- increased gradually from Northern part to the Southern part (Fig. 3).

The concentration of SO_4^{2-} in monsoon ranged from 1.63 to 105.09 mg L^{-1}, but in dry season the value was 0.01 to 3.55 mg L^{-1} (Table 1). The concentrations of SO_4^{2-} in groundwater might arise from dissolution of gypsum and anhydrite minerals. It might also be arisen from leaching, as the coastal soil of Bangladesh is SO_4^{2-} and Cl^- dominated [38].

The monsoon and dry season showed different patterns of PO_4^{3-} distribution along the study area (data were not shown). In monsoon, the values ranged from 0.73 to 11.92 mg L^{-1} and the values were from 0.10 to 5.38 mg L^{-1} for dry season (Table 1). The high concentrations of PO_4^{3-} were found in the Northeastern part of the study area in both seasons (data were not shown).

The concentrations of NO_3^- in the study area were very negligible and it showed similar patterns of distribution (Table 1), which gradually increased from Northern part to Southern part (data were not shown). During monsoon, the mean concentration of NO_3^- was 0.86 ($\pm$0.49) mg L^{-1}, but in dry season it was 0.83 ($\pm$0.48) mg L^{-1} (Table 1). The low concentration of NO_3^- in our samples indicated that the NO_3^- came from mineralization. Generally, the high NO_3^- concentration in groundwater reflects that NO_3^- comes from municipal waste, agricultural runoff and fertilizer leaching.

Principal Component Analysis

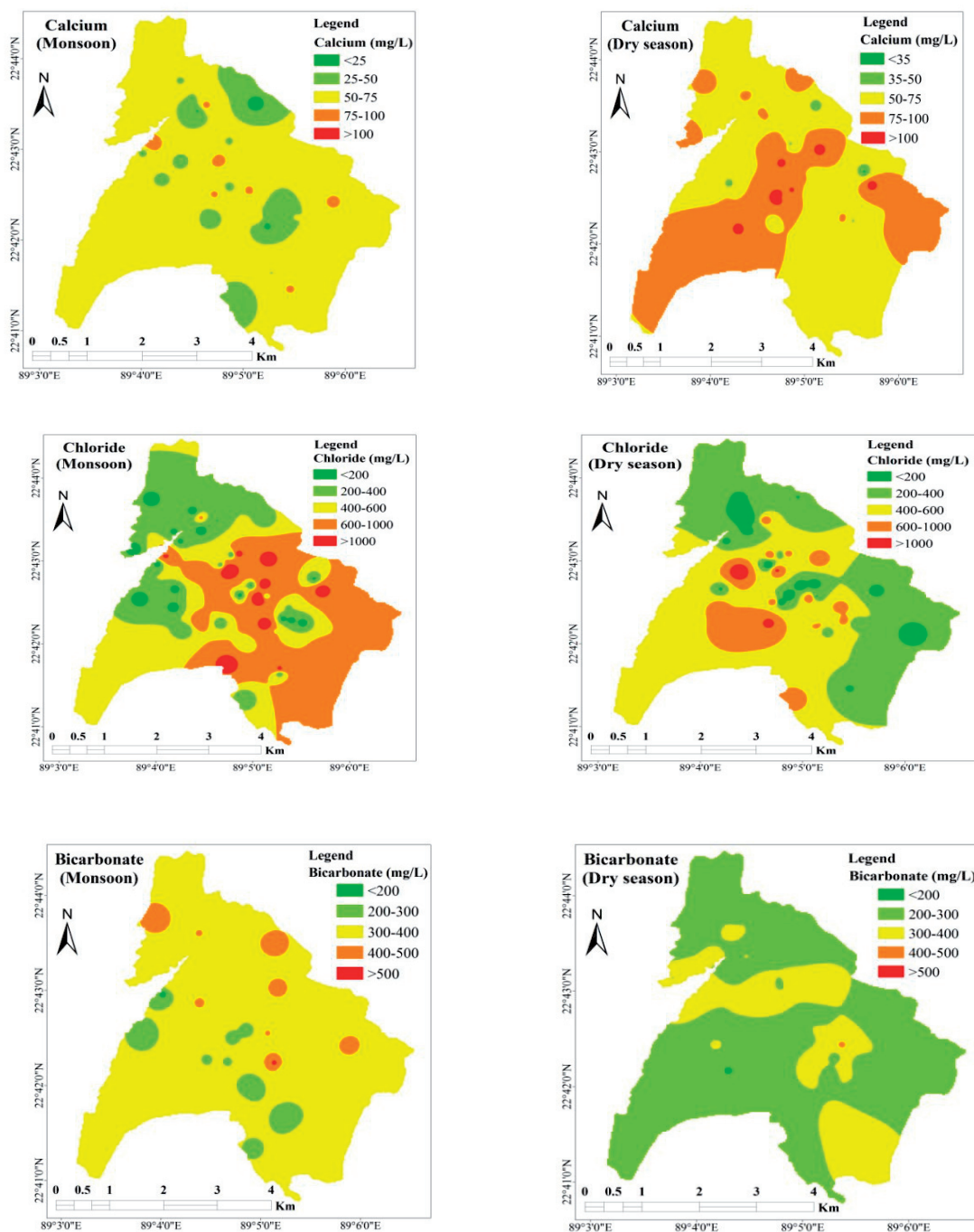The PCA results of 13 water quality parameters of 100 deep tube well water samples were shown in Table 2.

Fig. 3. Spatial distribution of calcium, chloride and bi-carbonate in deep tube well water samples collected from Satkhira Municipality. The samples were collected from July - December, 2018.

Four principal components (e.g. PC1, PC2, PC3 and PC4) have Eigenvalue >1 affecting the deep aquifer groundwater quality, which represented about 69.8% of variance in the data set. The PC1 represent 32.1% of variance, while the value was 49.1% for PC2, 61.1% for PC3 and 69.8% for PC4 (Table 2). For data interpretation the component loading factor >0.6 was considered [26].

The PC1 represented 32.1% of total variance. High positive loading value of EC, TDS, salinity, Na^+ and Cl^- were 0.956, 0.964, 0.948, 0.709 and 0.751, respectively

(Table 2). A strong linear correlation between factor and parameter was found. The high concentration of EC and TDS were most probably due to higher dissolved minerals in water. The high loading of Na^+ and Cl^- indicated that the dissolution of evaporitic minerals. The significant loading of those ions in PC1 indicated a similar source of those ions. The soil water interaction and dissolution of Na^+ bearing minerals might be responsible for high Na^+ loading [26, 39]. The PC2 accounted for 17% of total variance, which was positively correlated with SO_4^{2-} and HCO_3^-

Table 2. Factors loading plot of different principal component with eigenvalue, % of variance and cumulative %.

Factor Loading	F1	F2	F3	F4
pH	.123	-.627	-.501	.066
EC	.956	.152	-.137	.051
TDS	.964	.136	-.089	.029
Salinity	.948	.162	-.118	.039
Na	.709	-.383	.170	-.236
K	.070	-.348	.601	-.313
Ca	.328	-.187	.666	.264
Mg	.015	.459	.637	.143
PO_4	-.378	.582	-.076	.040
SO_4	-.097	.658	-.100	-.089
NO_3	-.082	-.068	-.005	.906
Cl	.751	.101	-.025	.145
HCO_3	.299	.671	-.066	-.163
Eigenvalue	4.183	2.211	1.551	1.130
% of Variance	32.181	17.008	11.932	8.696
Cumulative %	32.181	49.189	61.120	69.816

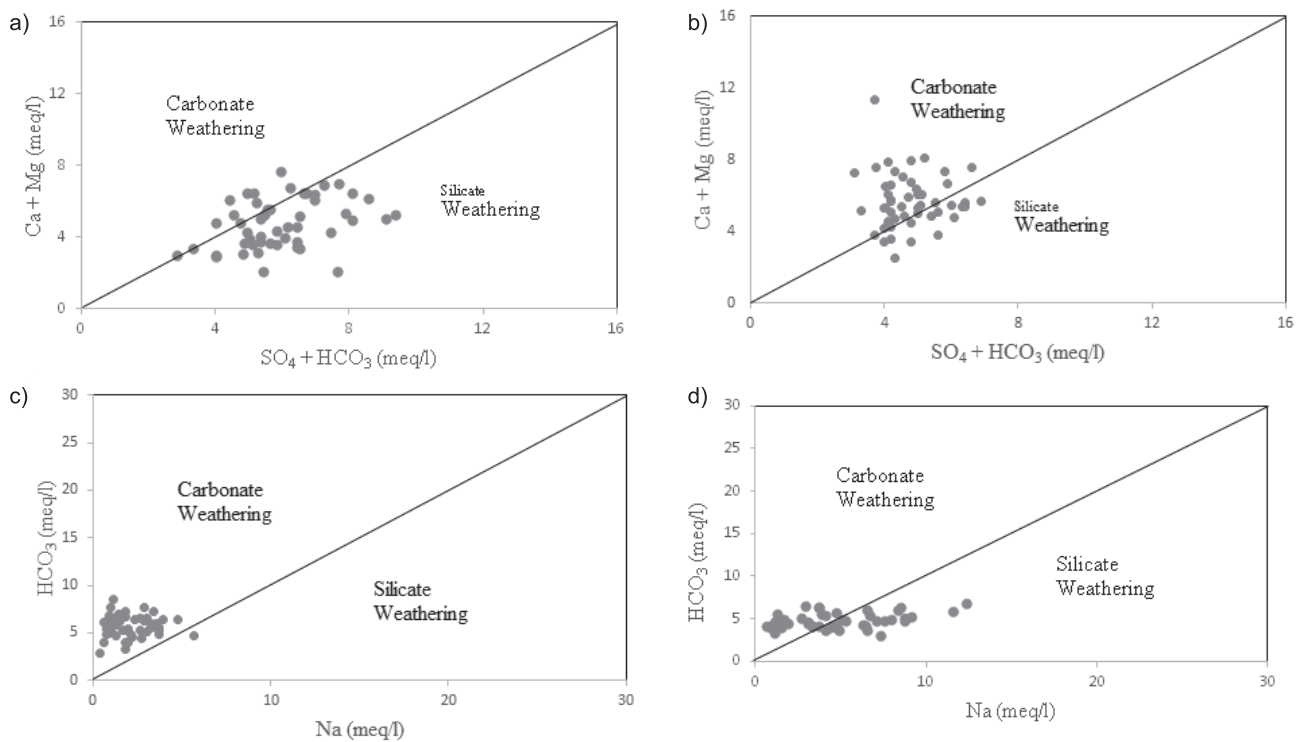Extraction Method: Principal Component Analysis

Fig. 4. Scattered diagram of different elements. a) $Ca^{2+}+Mg^{2+}$ vs $SO_4^{2-}+HCO_3^-$ scatter plot in monsoon, b) $Ca^{2+}+Mg^{2+}$ vs $SO_4^{2-}+HCO_3^-$ scatter plot in dry season, c) HCO_3^- vs Na^+ plot in monsoon and d) HCO_3^- vs Na^+ plot in dry season. The samples were collected from July - December, 2018.

and strong negative correlated with pH. The high loading factor of SO_4^{2-} and HCO_3^- was most probably due to dissolution of SO_4^{2-} and HCO_3^- bearing minerals and their mineralization decreased with increasing pH [40]. In PC3, high loading factors of K^+, Ca^{2+} and Mg^{2+} were observed, which represented about 11.93% of total variance. Interestingly, high positive loading factor of NO_3^- was observed in PC4 (Table 2). The anthropogenic activities like fertilizer application, organic matter deposition and seepage from septic tanks might be associated with high NO_3^- concentration in the groundwater [41].

Weathering and Dissolution

The scatter plots between $Ca^{2+} + Mg^{2+}$ vs $SO_4^{2-} + HCO_3^-$ and HCO_3^- vs Na^+ were used to determine the impacts of weathering of carbonate or silicate minerals or evaporation dissolution on groundwater. Figs 4(a, b) showed that the weathering of carbonate and silicate minerals was equally responsible for determining groundwater quality. The Ca^{2+} and Mg^{2+} ions in groundwater were most probably originated from weathering of both carbonate and silicate minerals (Figs 4a, b). The scatter plot between HCO_3^- vs Na^+ was used to explain ion exchange process. The sample

with 1:1 ratio indicated the dissolution of dolomite, gypsum or calcite. Our result showed that the Na^+ ion in groundwater originated from dissolution of carbonate minerals (Fig. 4). Dissolution of calcite, dolomite and gypsum in underground water was the dominated phenomenon. In our study, the relationships between $(Ca^{2+} + Mg^{2+})$ and $(SO_4^{2-} + HCO_3^-)$ were very close to 1:1 [42, 43]. The ion exchange known as direct tends to shift the points because of the excess $(SO_4^{2-} + HCO_3^-)$ over $(Ca^{2+} + Mg^{2+})$. The reverse ion exchange shifted the points to the left. This was most probably due to increasing Ca^{2+} and/or Mg^{2+} released from rocks [43].

Hydro-Chemical Facies

Our results demonstrated that cations and anions in groundwater were mainly derived from rock weathering rather than evaporation, crystallization and precipitation (Fig. 5). More specifically, the majority of those ions were derived from weathering of Ca and Mg carbonate and crystalline dolomitic limestone. Both Ca^{2+} and Mg^{2+} may react with HCO_3^- precipitating as calcite or dolomite. As Ca^{2+} and Mg^{2+} react with HCO_3^-, there would be straight positive correlation between Ca^{2+}/HCO_3^- and Mg^{2+}/HCO_3^- ratios [44]. The calcite and dolomite minerals precipitate when TDS value is more than 600.00 mg L^{-1}. The TDS value in monsoon
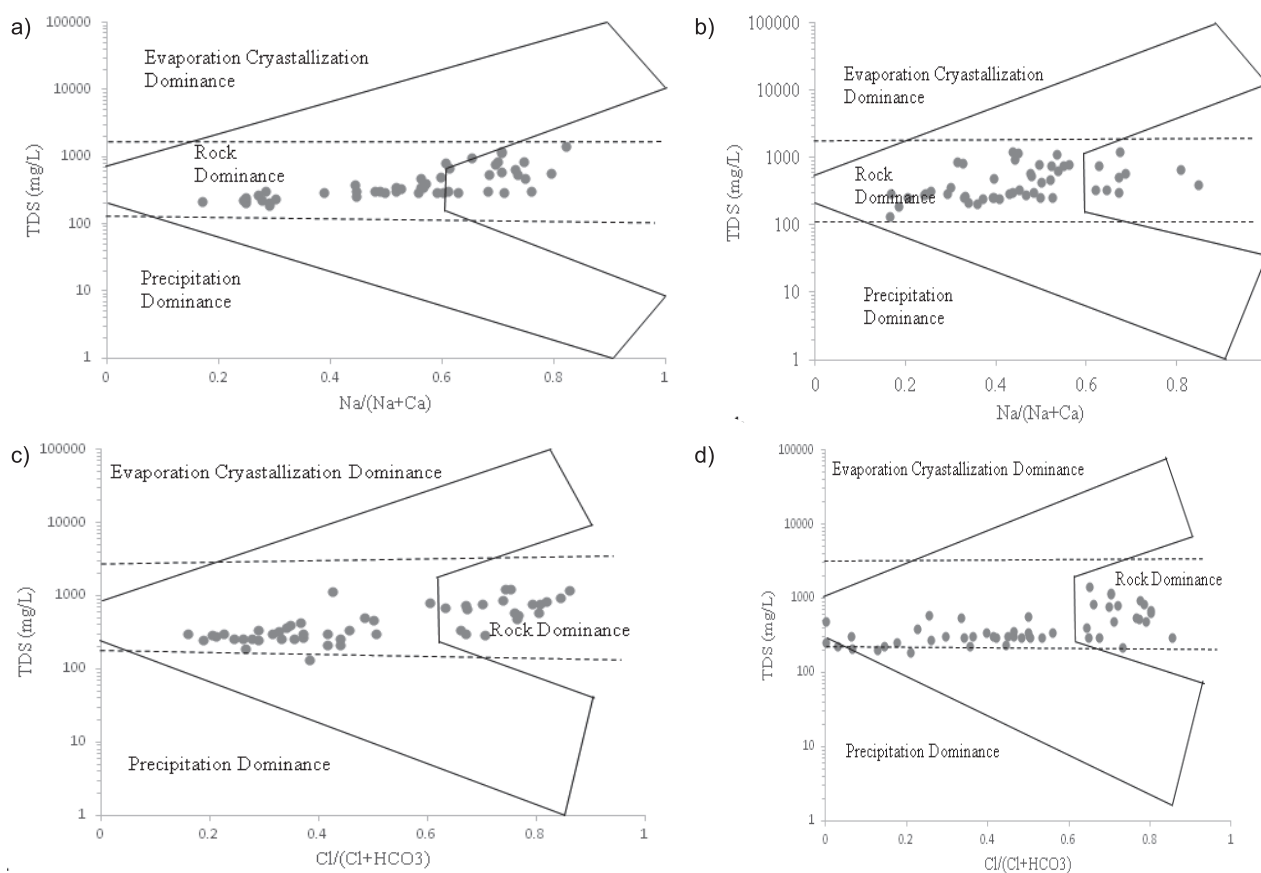

Fig. 5. Gibbs diagram for groundwater sample. a). TDS vs Na/(Na+Ca) in monsoon, b) TDS vs Na/(Na+Ca) in dry season, c). TDS vs Cl/(Cl+HCO$_3$) in monsoon, and d). TDS vs Cl/(Cl+HCO$_3$) in dry season. The samples were collected from July - December, 2018.
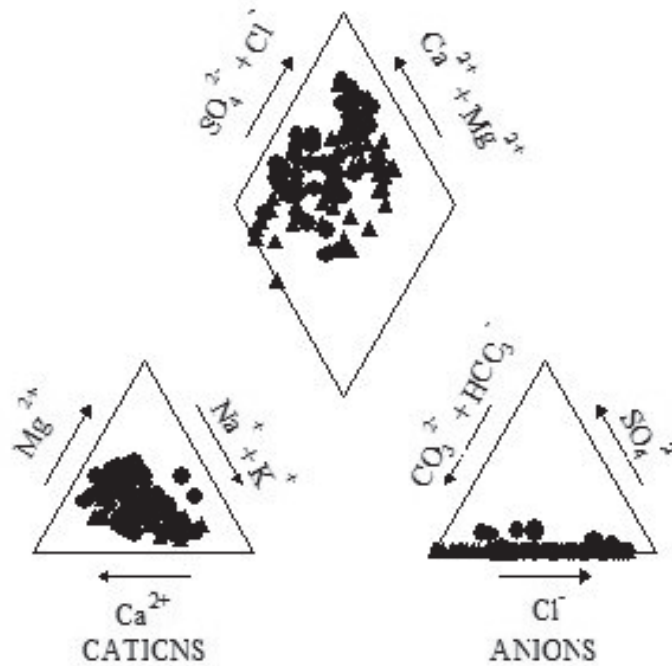
Fig. 6. Piper diagram. (● = monsoon, ▲ = dry season). The samples were collected from July - December, 2018.

was 490.71 mg L^{-1} and in dry season the value was 456.65 mg L^{-1}, which was lower than required value. Therefore, calcite and dolomite dissolution might not be occurred in the study area. If Ca^{2+} and Mg^{2+} ion originated from carbonate minerals then $(Ca^{2+} + Mg^{2+})/SO_4^{2-} + HCO_3^-$ ration would be 0.5 [45] which was observed in Fig. 4. These ions in groundwater might be originated from weathering of carbonate minerals like pyroxene and amphibole (Fig. 4).

The chemical characteristics of aquifer system were mostly reflected in hydro-chemical facies, which was conceived by Hill and improved by Piper [46] and widely used for groundwater and surface water classification [47]. It is mainly represented bodies of groundwater in an aquifer that differ in their chemical composition. The facies are a function of the lithology, solution kinetics and flow patterns of the aquifer. Piper trilinear diagram indicated that cationic species Na^+ and Ca^{2+} and anionic species Cl^- and HCO_3^- were very much dominated in groundwater of Satkhira Municipality. Thus most of the water type in the study area consisted of Na^+ or Ca^{2+}- Cl^-/HCO_3^- type (Fig. 6).

Conclusions

The mean trend of cations in the deep tube well water of Satkhira Municipality were $Na^+>Ca^{2+}>Mg^{2+}>K^+$ and majority of the water samples were dominated with Na^+ and Ca^{2+}. While the trends of anions were $Cl^->HCO_3^->SO_4^{2-}>PO_4^{3-}>NO_3^-$ and most of the water samples were in Cl^- and HCO_3^- geochemical facies. The weathering of carbonate minerals mostly influenced

the groundwater quality in the study area. The higher values of TDS and EC were found in Northern part while and Cl^- and HCO_3^- were found in Southern part of the study area. Most of the water in the study area was Ca^{2+} or Mg^{2+}- Cl^-/HCO_3^- dominated. Considering the all determined parameters the sampled water was recommended as suitable for drinking and certainly for irrigational use.

Conflicts of Interest

The authors declare no conflict of interest.

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