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GROUNDWATER QUALITY OF SAIDPUR UPAZILA IN BANGLADESH FOR IRRIGATION, DRINKING AND LIVESTOCK CONSUMPTION

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ABSTRACT

A study was conducted to evaluate the water quality of some groundwater of Saidpur Upazila of Nilphamari district in Bangladesh for irrigation, drinking and livestock consumption. Water samples were slightly acidic to slightly alkaline. Electrical conductivity of most samples was 'low salinity' group (C1). TDS (Total dissolved solids) was graded as 'fresh'. The concentrations of Ca and Mg were suitable for drinking. Fe and Cu were within the safe limit for drinking. The Cl concentrations were suitable for drinking and livestock consumption. Based on SAR (sodium adsorption ratio) and RSC (residual sodium carbonate), all waters were low sodium water (SAR< 10). The SSP (soluble sodium percentage) of 15 samples were 'excellent' and the rest were 'good' classes for irrigation. In case of hardness, out of 25 samples 14 were within 'desirable limit' and 10 samples were 'maximum permissible' limit and one was 'hard' for irrigation and livestock consumption. The permeability index (PI) values ranged between Class II and Class I. All the samples fell in the precipitation dominant area. Based on study parameters, the groundwater quality of the study area was suitable for drinking, irrigation, and livestock consumption.

Keywords: Drinking, Groundwater suitability, Irrigation and Livestock.

INTRODUCTION

Fresh water is already a limiting resource in many parts of the world. In the next century, it will become even more limiting due to increased population, urbanization and climate change (Jackson *et al.* 2001). Unfortunately, in developing countries like Bangladesh, the drinking quality of water is continuously being contaminated and hazardous for human use due to high

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growth of population, expansion in industries, throwing away of waste water and chemical effluents into canals and other water sources. According to recent estimates, the quantity of available water in developing regions of South Asia, Middle East and Africa is decreasing sharply while quality of water is deteriorating rapidly due to fast urbanization, deforestation, land degradation etc and therefore many cities in Asia facing increase in organic and nutrient material in drinking water due to the discharge of untreated domestic and industrial waste water into these resources (Annachhatre 2006).

Groundwater is the main source of irrigation (Shirazi *et al.* 2010), which is around 30-40% of the net cultivable area of Bangladesh (Huq and Naidu 2002). The contribution of groundwater in relation to total irrigated area increased significantly from 41% in 1983 (Ali *et al.* 2003) to 86% in 2002 (BADC, 2002; Hasan *et al.* 2007). About 79% of irrigation in Bangladesh is covered by groundwater sources (DPHE and JICA, 2010) but heavy pumping of groundwater may create another agro-ecological problem (Shirazi *et al.*2010). Human diseases in developing countries are related to contaminated water. Heavy metals such as Cu, Fe, Pb, Mn, Zn, Cd, Co, etc. which are present in water as trace amount, but have significant effect on water environment and thus on human existence (Anonymous, 2004). If low quality water is used for irrigation, drinking, aquaculture, livestock and poultry consumption and other purposes, ionic toxicity may appear (Zaman and Rahman 1996).

Several research papers (Zaman and Mojid 1995; Mridha *et al.* 1996; Talukder *et al.* 1999; Zaman *et al.* 2001, Khan *et al.* 2002; Sarkar and Hassan 2006; Raihan and Alam 2008; Islam and Shamsad 2009; Sultana *et al.* 2009) have documented groundwater quality of various locations in Bangladesh. Considering above mentioned importance, the study was conducted on groundwater sources of different locations of Saidpur upazila in Bangladesh to assess the quality status and its suitability for irrigation, drinking and livestock consumption based on international standard.

MATERIALS AND METHODS

Description of the study area

The study area is located (25° 44′ to 25° 52′N, 88° 52′ to 89.00′ E) in Saidpur Upazilla in the northern part of Bangladesh, and has an area of approximately 121 km^2. The lithology of most northern region of Bangladesh, especially this study area, consists predominantly of medium to coarse grained, poorly sorted sands and gravels with thin surface clays. A previous UNDP study classified the groundwater aquifers of Bangladesh into three zones, namely the upper aquifer, main aquifer and deep aquifer (UNDP 1982). We collected the water samples from the main aquifer. This is the main water bearing zone and occurs at depths ranging from less than 5 m in the northern region of Bangladesh. This aquifer is either semi-confined or leaky, and consists of

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stratified interconnected, unconfined water bearing zones. The aquifer is comprised of medium and coarse grained sediments, in places inter-bedded with gravel (UNDP, 1982).

Bangladesh has a tropical monsoon climate characterized by heavy seasonal rainfall, high temperatures and high humidity. The average rainfall during monsoon ranges from 1194 mm to 3454 mm. Another feature characterizing the precipitation in the study site is its irregular yearly distribution. The area has a sub-tropical climate, with mean maximum summer temperatures (July) about 40°C and minimum winter temperatures (January) of 10°C. The area has complicated land use characteristics, mainly consisting of agricultural and residential areas.

Sampling and analytical methods

A total of 25 groundwater samples (12 shallow tubewells and 13 deep tubewells) were collected from existing wells in the study areas in June to August in the year of 2012 (Fig. 1). Well water samples were collected during the time period when groundwater levels are generally upper relative to other seasons of the year (Shamsudduha et al. 2009). Samples were collected in two liter plastic bottles that had been cleaned with hydrochloric acid (1:1) and then rinsed with tap water followed by rinsing with distilled water. Before collecting each sample, bottles were rinsed 3 to 4 times with sample. Samples were analyzed in Department of Agricultural Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. All reagents are of analytical grade, purchased from Aldrich chemical company, England. For SO_4^{2-} and NO_3^-, samples were refrigerated and analyzed within 24 h. For heavy metals analysis, samples were filtered immediately using 0.45 µm filter paper. The filtrates were acidified to pH = 2 with nitric acid in order to keep the metals in solution.

In order to assess the suitability classes for irrigation, domestic and industrial uses, we measured pH, EC, TDS, SAR, SSP, PI, Ca^{2+}, Mg^{2+}, Na^+, K^+, Zn^{2+}, Cu^{2+}, Mn^{2+}, Fe^{3+}, PO_4^{3-}, CO_3^{2-}, HCO_3^-, SO_4^{2-}, NO_3^- and Cl^-. The pH and conductivity were measured using pH meter (Orion Research, Model SA 520, USA) and conductivity meter (JENWAY, Model 4010, UK), respectively. TDS was measured by drying and weighing method. Zn^{2+}, Cu^{2+}, Mn^{2+} and Fe^{3+} were analyzed by atomic absorption spectrophotometry (APHA 2005) in the Soil Resources Development Institute, Dinajpur, Bangladesh. Ca^{2+} and Mg^{2+} were analyzed by complexometric titration. K+ and Na+ were estimated by flame emission spectrophotometry. SO_4^{2-} was determined turbidimetrically. CO_3^{2-} and HCO_3^- were analyzed titrimetrically. Chloride was estimated by argentometric titration (APHA, 2005) and PO_4^{3-} and NO_3^- were determined colorimetrically (APHA, 2005). The precision of measurements was checked taking three replicates from the sample. The accuracy of the analysis for major ions was cross checked from the electrical balance, since the sum of positive and negative charges should be equal.

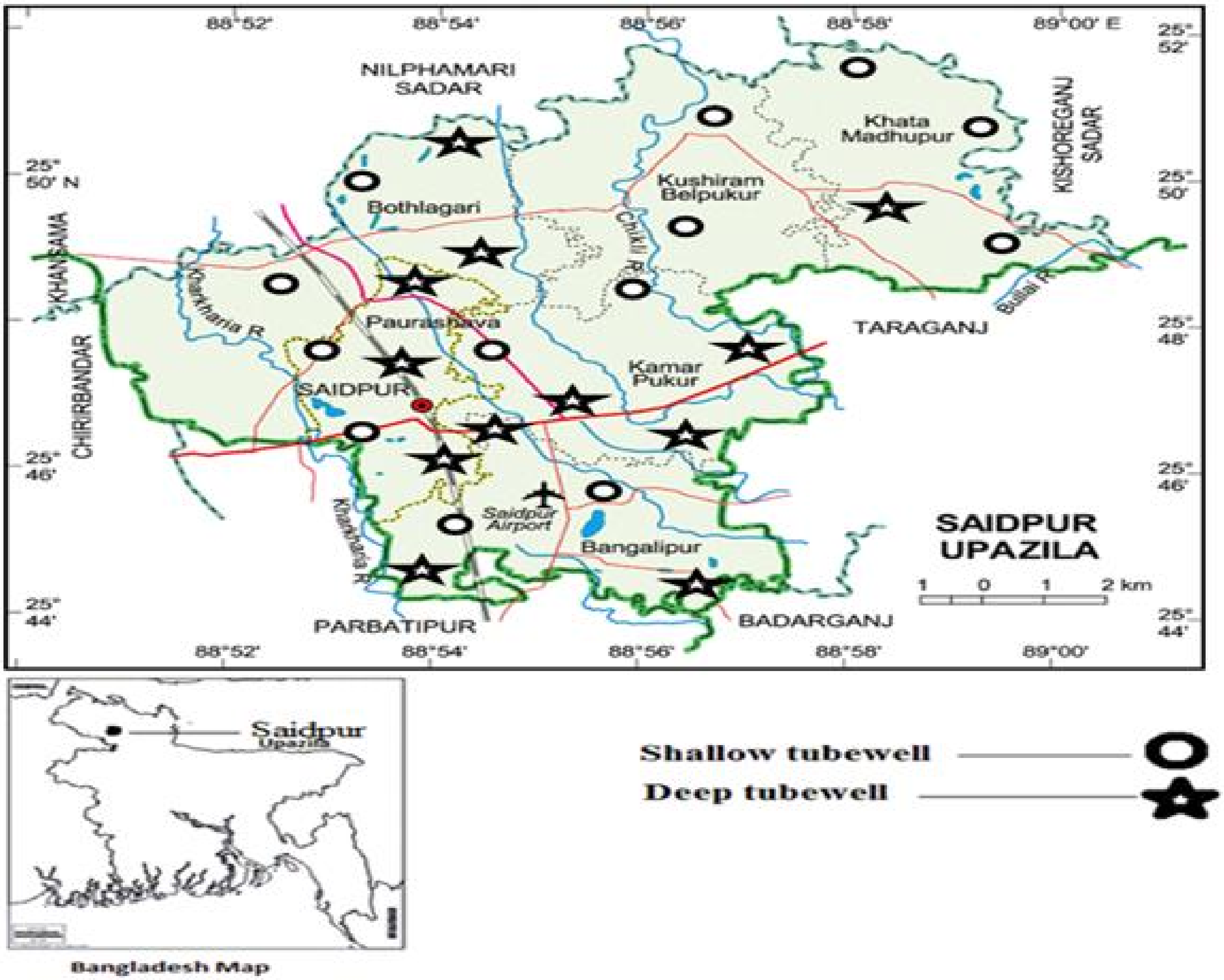

Figure 1: Map of sampling sites of the Saidpur Upazila (12 shallow tubewells and 13 deep tubewells) under the district of Nilphamari along with the map of Bangladesh

The techniques/apparatus and formulae used in water quality determination

For irrigation water quality assessment, the following techniques/apparatus, book references and formulae used to measure the parameters.

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Table 1: The techniques/apparatus, book references used to measure the parameters

Parameters	Unit	Techniques/apparatus	References
Temperature	^{o}C	Centigrade Mercury Thermometer	Ramesh and Anbu, 1996 and APHA, 2005
pH	-	Microprocessor pH meter (HANNA instruments, pH 211)	
EC	µs/cm	TDS meter (H1-9635, portable water proof Multirange Conductivity/TDS meter, HANNA)	
TDS	mg/L	TDS meter (H1-9635, portable water proof Multirange Conductivity/TDS meter, HANNA)	
Ca^{2+}	mg/L	Titrimetric method	Ramesh and Anbu, 1996 and APHA, 2005
Mg^{2+}	mg/L	Titrimetric method	
Cl^{-}	mg/L	Titrimetric method	
Na^{+}	mg/L	Flame photometric method	
K^{+}	mg/L	Flame photometric method	
HCO_3^{-}	mg/L	Titrimetric method	
$PO4^{3-}$	mg/L	Ascorbic acid method (Thermospectronic, UV-visible Spectrophotometers, Helios 9499230 45811)	
NO^{3-}	mg/L	Ultraviolet spectrophotometric screening method (Thermospectronic, UV-visible Spectrophotometers, Helios 9499230 45811)	
SO_4^{2-}	mg/L	Turbidimetric method	
Zn, Mn, Fe	mg/L	Atomic Absorption Spectrophotometer (Model: Perkin–Elmer Analyst 100)	APHA, 2005

Using identical methods the measured parameters were: pH, EC, TDS, $Ca^{2+,}$ Mg^{2+}, Na^{+}, K^{+}, Zn^{2+}, Cu^{2+}, Mn^{2+}, Fe^{3+}, PO_4^{3-}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-} and Cl^{-} (Table 1). To classify water samples for irrigation, following formulae were used.

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a) Sodium adsorption ratio (SAR): $SAR = \frac{Na+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$

b) Soluble sodium percentage (SSP):

$$SSP = \frac{\text{Soluble Na concentration } (meqL^{-1})}{\text{Total cation concentration } (meqL^{-1})} \times 100$$

c) Residual sodium carbonate (RSC):
$RSC = (CO_3^{2-} + HCO_3^-) – (Ca^{2+} + Mg^{2+})$

d) Hardness or total hardness (H_T):
$H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$ (Freeze and Cherry, 1979)

e) Potential salinity (PS) = $Cl^- + (SO_4^{2-}/2)$

f) Permeability index (PI)= $\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+}$

g) Kelly's ratio = $Na^+/(Ca^{2+} + Mg^{2+})$

h) Gibbs ratio 1 for anion = $Cl^- / (Cl^- + HCO_3^-)$ and Gibbs ratio 2 for cation = $(Na^+ + K^+) / (Na^+ + K^+ + Ca^{2+})$, Here concentrations for all ionic constituents for calculating all parameters are in $meqL^{-1}$ except hardness (mgL^{-1}).

RESULTS AND DISCUSSION

The pH of the samples ranged from 6.1 to 7.5 (Table 3). All of the waters were slightly acidic to alkaline in nature. Water having pH value less than 6.5 and more than 9.5 is unsuitable for drinking (WHO 2004). According to this limit 22 groundwater samples had limitation for drinking (Table 4). The pH ranging from 6-9 is suitable for the existence of most biological life (Metcalf and Eddy 2003).

The electrical conductivity of the waters varied from 60.00 to 900.00 μScm^{-1} with a mean value of 165.68 μScm^{-1}. The standard deviation was 181.084 (Table 3). Based on of EC, Wilcox (1955) classifies irrigation water into 4 classes. They are: excellent water (EC=<250μScm^{-1}); good water (EC=250-750 μScm^{-1}); permissible water (EC=750-2000 μScm^{-1}) and doubtful water (EC > 2000 μScm^{-1}). According to his classification 21 the samples were rated as 'excellent' (C2) class for irrigation (Table 4). Zakir et al. (2012) found the EC of Karatoa river water in Bangladesh ranging from 450 to 1653 μScm^{-1}.

High TDS indicates the presence of sufficient amounts of bicarbonates, sulphates and chlorides of Ca, Mg, Na and Si (Karanth 1994).TDS of the samples ranged from 38.40 to 495.00 mgL^{-1}, with the respective mean and SD of 101.90 and 105.6 (Table 3). All the samples were in 'desirable' limit for drinking and irrigation according to WHO (2004) and Freeze and Cherry (1979) (Table 3, 4).

Calcium concentration fluctuated from 17.03 to 40.08 mgL^{-1} (Table 3). WHO (2004) reported that the highest desirable and maximum permissible limit of Ca for drinking is 0.75 and 200.00 mgL^{-1}, respectively. Accordingly all the water samples were in 'desirable' limit for drinking. Irrigation water having less than 100 mg L^{-1} Ca is suitable for raising crop plants (Todd, 1980). The concentration of Mg varied from 15.15 to 21.87 mgL^{-1} with the mean value of 15.98 mgL^{-1}. According to WHO (2004), all samples were within 'desirable' class for drinking. Nizam *et al.* (2011) reported that the 32 groundwater of Dumki upazila in Bangladesh contained 3.06 to 24.04 mgL^{-1} Mg. The concentration of sodium ranged from 0.43 to 0.87 $meqL^{-1}$ with a mean value of 0.55 meq L^{-1} (Table 2). All the samples of were 'suitable'. However, the concentration of potassium was lower the sodium varying from 0.08 to 0.34 $meqL^{-1}$(Table 2). The contents of K in water samples collected from Sherpur, Gaibanda and Naogaon varied from 0.01 to 0.74 $meqL^{-1}$(Rahman *et al.* 2005).

The content of Cu in groundwater varied from 0.01 to 0.06 meq L^{-1}. WHO (2004) and USEPA (1975) recommended that the Cu concentration in drinking water should be within 0.05 to 1.5 and 1.0 mg L^{-1} respectively. Therefore, the waters of the study area were within safe limits and suitable for drinking. The samples were also suitable for irrigation and livestock consumption in respect of Cu.

Chloride contents of the samples ranged from 15.98 to 117.51 mg L^{-1}, having mean and SD of 28.73 and 22.96, respectively. The recommended concentration of Cl for livestock consumption is 30 mg L^{-1} (Ayers and Westcott, 1985). HCO_3^- values fluctuated from 45.75 to 98.82 mg L^{-1}, having the mean value of 78.13 mgL^{-1} (Table 3). HCO_3^- concentrations were found almost at normal level (WHO, 2004).

Sulphur concentration fluctuated from 0.14 to 12.00 meq L^{-1} (Table 4). The present investigation showed that the S concentrations in groundwater sources were suitable for multipurpose use. This finding was similar to Zaman *et al.* (2001) in Mymensingh district of Bangladesh. The mean and SD of P concentration were 0.03 meq L^{-1} and 0.016, respectively (Table 2).

Sodium adsorption ratio (SAR), soluble sodium percentage (SSP) and residual sodium carbonate (RSC)

The SAR values ranged from 0.33 to 0.81 (Table 3). Based on Todd (1980) SAR categorized all the samples as 'excellent' class for irrigation. SAR and EC together classified the 21 samples as 'low salinity' and 'low alkalinity' (C1S1) group and 4 were C2S1 group for irrigation (Richards,

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1968). The SAR of 32 groundwater samples in Dumki upazila in Bangladesh were ranged from 0.82 to 2.34 (Nizam *et al.* 2011).

SSP values ranged from 11 to 26 (Table 3). According to the classification of Wilcox (1955), SSP rated 15 samples as 'excellent' and 10 as 'good' for irrigation. Reseaechrs found the value of soluble sodium percentage (SSP) of the 20 groundwater samples of Rajshahi district in Bangladesh were ranged from 19.41 to 39.39%. RSC of the waters fluctuated from -1.88 to -0.25 meqL^{-1}(Table 3). On the basis of RSC, Eaton (1950) classified irrigation water into suitable (RSC <1.25 meqL^{-1}), marginal (RSC 1.25-2.50 meqL^{-1}) and unsuitable (RSC >2.50 meqL^{-1}). Based on his classification all samples were 'suitable' for irrigation (Table 3).

Hardness of samples fluctuated from 39.00 to 168.70 mgL^{-1}(Table 3). With respect to H_T, out of 25 samples 14 were within 'desirable limit' and 10 samples were 'maximum permissible' limit and 01 were hard' for irrigation and livestock consumption as per reports of Ayers and Westcot (1985).

Table 2: Chemical analysis summary of groundwater samples in the study area

Chemical parameters	Unit	Max.	Min.	Mean	SD
Na	meq L^{-1}	0.87	0.43	0.55	0.127
K	meq L^{-1}	0.34	0.08	0.11	0.058
Cu	meq L^{-1}	0.06	0/ND	0.02	0.015
Zn	meq L^{-1}	0.04	0.01	0.03	0.012
Mn	meq L^{-1}	0.50	0.32	0.41	0.057
Fe	meq L^{-1}	0.38	0.02	0.12	0.109
SO_4	meq L^{-1}	0.25	0/ND	0.07	0.058
NO_3	meq L^{-1}	0.111	0.059	0.09	0.015
PO_4	meq L^{-1}	0.087	0.012	0.03	0.016

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Table 3: Chemical and irrigation water quality parameters of the analyzed groundwater samples

Parameters	Unit	Max.	Min.	Mean	SD
pH		7.5	6.1	6.7	0.28
Ca	mg L^{-1}	40.08	17.03	26.1	5.38
Mg	mg L^{-1}	21.87	12.1525	15.98	2.745
Cl	mg L^{-1}	117.51	15.98	28.73	22.96
SO_4	mg L^{-1}	12	0.14	3.69	2.73
EC	mg L^{-1}	900	60	165.68	181.08
TDS	mg L^{-1}	495	38.4	101.9	105.6
SAR	mg L^{-1}	0.81	0.33	0.49	0.127
SSP	mg L^{-1}	26	11	17	4.28
RSC	mg L^{-1}	-0.25	-1.88	-0.89	0.356
H_T	mg L^{-1}	168.7	39	79.07	24.229
HCO_3	mg L^{-1}	98.82	45.75	78.13	14.37

Table 4: Classification of groundwater quality based on suitability of water for irrigation or drinking purposes

Parameters	Reference	Range	Classification	Number of sample within standard range
Electrical conductivity	Wilcox (1955)	<250 µScm^{-1}	Low salinity	21
		250-750 µScm^{-1}	Medium salinity	3
		>750 µScm^{-1}	High salinity	1
Sodium adsorption ratio	Richards (1968)	<10 mg/l	Excellent	25
Total dissolved solids	Freeze and Cherry (1979)	0-1000 mg/l	Freshwater	25
Hardness	Sawyer and McCarty (1967)	0-75 mg/l	Soft	14
		75-150 mg/l	Moderately hard	10
		150-300 mg/l	Hard	1
Residual sodium carbonate	Eaton (1950)	<1.25meq/l	Suitable	25

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Parameters	Reference	Range	Classification	Number of sample within standard range
Kelly's ratio	Kelly (1940)	<1	Suitable	25
Percentage of Na	Wilcox (1955)	<20	Excellent	25
pH	WHO(2004)	<6.5 and > 9.5	suitable	22
			unsuitable	3

Table 5: Pearson's correlation Matrix of different chemical constituents of groundwater samples (n = 25)

	pH	**EC**	**TDS**	**HT**	**SAR**	**SSP**	**RSC**	**Ca^{2+}**	**Mg^{2+}**	**Cl^-**	**HCO_3^-**	**PO_4^{3-}**
pH	1.00											
EC	-0.16	1.00										
TDS	-0.17	0.99	1.00									
HT	0.05	0.17	0.17	1.00								
SAR	-0.13	-0.25	-0.21	-0.33	1.00							
SSP	-0.16	-0.29	-0.24	-0.32	0.99	1.00						
RSC	-0.08	-0.52	-0.47	-0.24	0.70	0.75	1.00					
Ca^{2+}	0.28	0.22	0.22	0.01	-0.32	-0.40	-0.59	1.00				
Mg^{2+}	-0.11	0.43	0.39	0.35	-0.62	-0.65	-0.66	0.14	1.00			
Cl^-	-0.16	0.21	0.22	0.82	-0.39	-0.40	-0.23	0.03	0.48	1.00		
HCO_3^-	0.19	-0.11	-0.12	0.52	-0.22	-0.16	0.04	-0.23	0.17	0.30	1.00	
PO_4^{3-}	0.44	-0.25	-0.27	-0.26	-0.15	-0.19	-0.29	0.44	0.04	-0.26	-0.30	1.00

To find out the interrelations among various water quality parameters, Pearson's correlation matrix was done (Table 5). According to Table 5, statistically positive significant correlations were found between EC and TDS (r = 0.99). In additions, HT was significantly correlated with EC, TDS, Mg^{2+}, Ca^{2+}, Na^+, K^+, Fe^{2+}, and Cl^- positively and with pH and HCO_3^- anion it had shown a significant negative correlation.

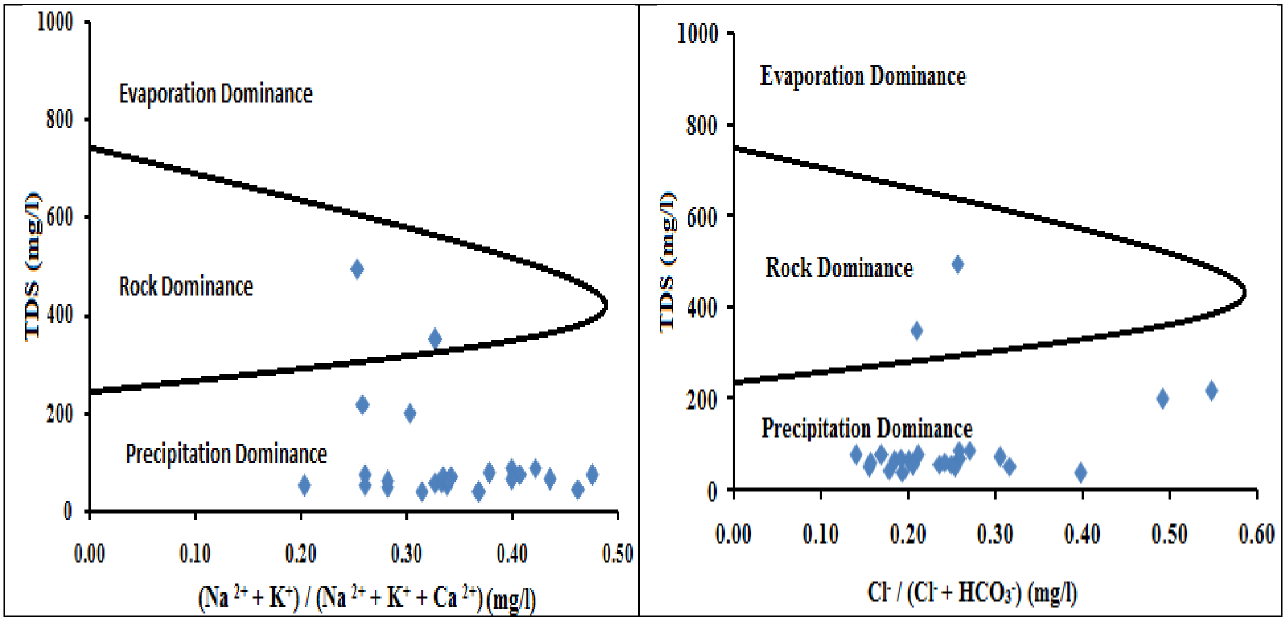

Figure 2: The Gibb's Ratios (weight ratio) of a. TDS versus (Na^{+}+ K^{+}) / (Na^{+}+ K^{+} + Ca^{2+}) and b. TDS and Cl^{-} / (Cl^{-} + HCO_3^{-})

Gibb's diagram explains the mechanism of chemical reactions which lead to changes in the composition of groundwater and sources (Gibb's 1970). Two plots (Fig. 2a) represent TDS versus (Na^{+}+ K^{+}) / (Na^{+}+ K^{+} + Ca^{2+}) and TDS versus Cl^{-} / (Cl^{-} + HCO_3^{-}). Figure shows that about 80 % of the water samples of both 2a and 2b fell in the precipitation dominance region. It is interesting to note that both the cation and anion plots clearly describe the occurrence of weathering reaction in the study area.

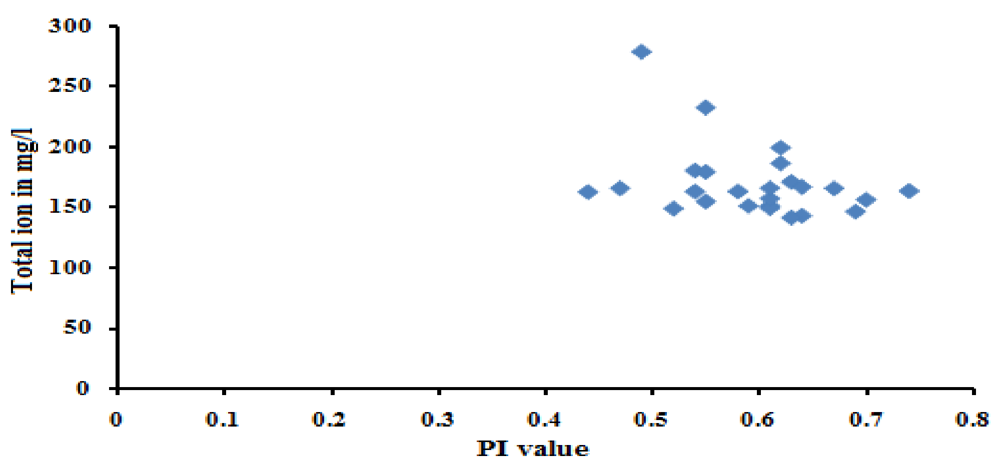

Figure 3: Permeability index (PI) scale showed maximum PI value ranges in the study area

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Permeability Index (PI)

Sodium, magnesium, calcium, and bicarbonate content influence the permeability of soil which in turn influences the quality of irrigation water on uses for a long time. Doneen (1964) evolved a criterion for assessing the suitability of water for irrigation based on permeability index (PI) and calculated by the following Equation, where all the ions were expressed in $meqL^{-1}$. According to the PI, water can be classified as class I, Class II, and Class III levels. Class I and Class II water are categorized as good for irrigation and Class III water is unsuitable. It was confirmed that the maximum PI values ranged between Class II and Class I, so in terms of PI groundwater were more suitable for irrigation.

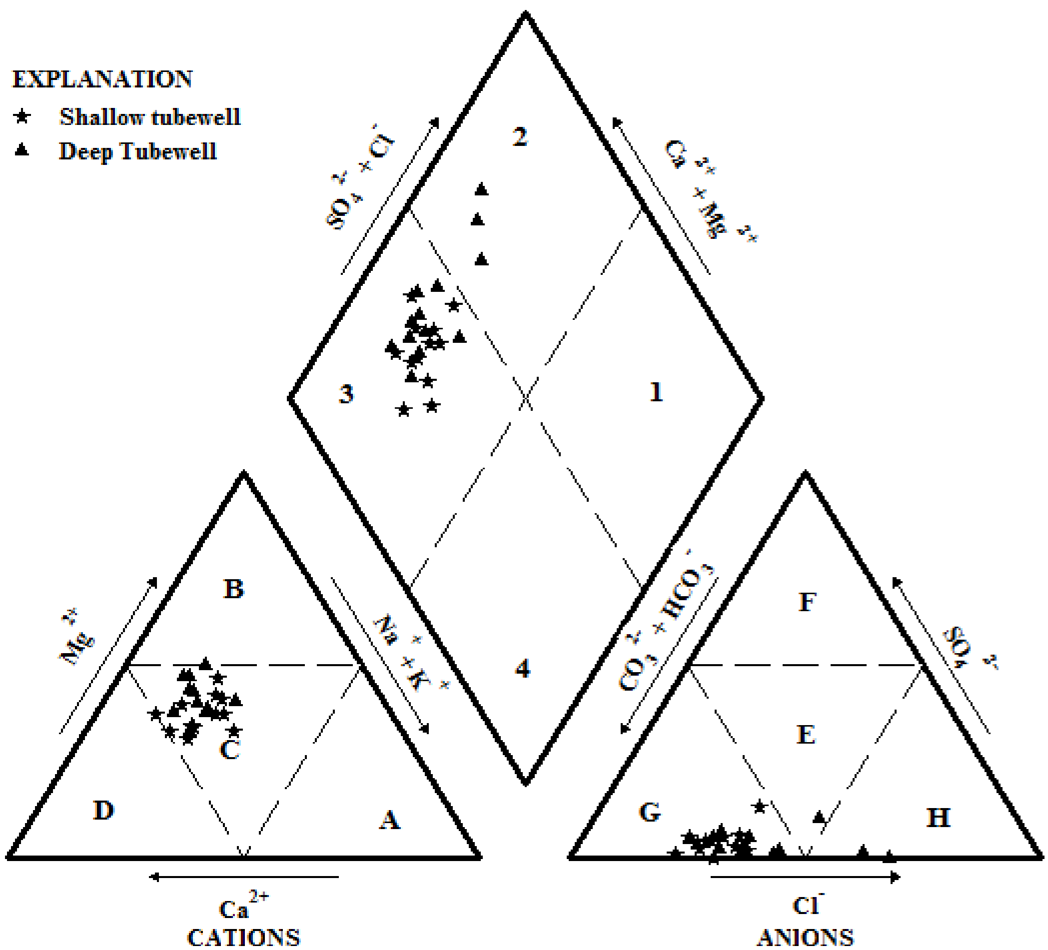

Figure 4: Piper diagram of the groundwater samples in the study area(1) Na^+-K^+-SO_4^{2-}-Cl^- type, (2) Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^- type, (3)Ca^{2+}-Mg^{2+}-CO_3^{2-}-HCO_3^- type, and (4) Na^+-K^+-CO_3^{2-}-HCO_3^- type

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Groundwater classifications are used to understand the groundwater body that differs in their chemical properties and compositions (Mahlnecht et al. 2004). Depending on lithology, regional flow patterns of water and resident time hydrochemical properties of groundwater vary. From the viewpoint of chemical compounds, all waters are divided into three main categories: chloride, sulfate and bicarbonate types (Chebotarev 1955). The Piper diagram can be used to identify the type of water. It consists of three parts: one diamond shaped diagram in the middle and two trilinear diagrams along the bottom. The relative concentrations of cations (left diagram) and anions (right diagram) in each sample is shown in the trilinear diagram. For the purpose of a piper diagram, the cations are grouped into three major divisions: sodium (Na+) plus potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). The anions are likewise grouped into three main categories: bicarbonate (HCO_3^-) plus carbonate (CO_3^{2-}), chloride (Cl^-), and sulfate (SO_4^{2-}). Each sample is represented by a point in each trilinear diagram; the type of water samples will qualify according to the symbolic area in piper diagram. The high variability of major ion chemistry is shown in Fig. 4. For the study area, approximately 12 % of the samples were Na^+-K^+-SO_4^{2-}-Cl^- and nearly 88 % samples were Ca^{2+}-Mg^{2+}-CO_3^{2-}-HCO_3^- type. Most of the samples were in the left corner of the diamond shape rich in $Ca^{2+} + Mg^{2+}$ and HCO_3^- and is the region of water of temporary hardness.

CONCLUSION

The collected water samples of Saidpur upazila are slightly acidic to alkaline and almost suitable for drinking and other purpose. In respect of TDS the samples were ‘desirable’ limit for drinking and fresh water for irrigation and suitable for livestock consumption. The Ca, Mg, Na and K contents were within safe limit for drinking and irrigation. All samples were ‘excellent’ for sensitive, semi-tolerant and tolerant crops and were suitable for livestock consumption in respect of Cl. HCO_3 and P was found in safe limit. Finally, measurements of different water quality parameters indicate that these groundwater samples were suitable for irrigation, drinking and livestock consumption in the study area.

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