

Reconnaissance on the suitability of the available water resources for irrigation in Thakurgaon District of northwestern Bangladesh

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Abstract Reconnaissance on the suitability of the available groundwater resources for irrigation in Thakurgaon District of northwestern Bangladesh was done by determining pH, TDS, EC, hardness, alkalinity, major cations and anions. The pH values suggest that the water is slightly acidic to strongly basic. The dominant cation and anion in the study area are Ca^{2+} , Mg^{2+} and HCO_3^- , respectively. Calcium bicarbonate, calcium–magnesium–bicarbonate and calcium carbonate are the dominant hydrochemical facies among the water samples. The groundwater system in the study area may be recharged through infiltration of rain. The above statement is further supported by Gibbs plot where most of the samples fall within the rock-dominance zone. The evolution of these waters may be controlled by precipitation and dissolution of carbonate minerals. The USSL, SAR–EC classification schemes and Wilcox plot confirm that the groundwater samples are good to excellent as irrigation water. However, the groundwater evolution in this study is mainly the result of weathering of carbonate minerals and cation exchange within the aquifer materials, confirming the shallow porous groundwater hydrochemistry characteristics.

Keywords Hydrogeochemical character · Groundwater · Irrigation water quality · GIS · Bangladesh

Introduction

Groundwater quality is important for determining its use for domestic, irrigation and industrial purposes. It is however, degraded by several factors related to human activities and geochemical changes. In floodplain areas degradation generally occurs owing to hydrogeochemical processes, arsenic contamination, aerosols deposited on the top soil and interaction of groundwater with brines and sedimentary formation (Sanford et al. 2007). Hydrogeochemical processes that are responsible for changing the chemical composition of groundwater differ due to variation of time and space. In fact, interaction of groundwater with aquifer minerals significantly influences the groundwater chemistry. However, the study of hydrogeochemical processes of the groundwater system helps to obtain the contributions of rock/soil–water interaction in aquifer. The geochemical processes are responsible for the spatio-temporal variations in groundwater chemistry (Kelly 1940; Wilcox 1948; Matthes 1982; Kumar et al. 2006). Apart from the natural process, anthropogenic contaminations such as industrial effluents, agrochemicals, municipal wastewater, septic tank effluent and landfills are other major sources of water quality deterioration (Mondal et al. 2008, 2011; Selvam et al. 2013).

About one billion people are directly dependent upon groundwater resources in Asia alone (Foster 1995). The dependence on groundwater has increased tremendously in recent years in many parts of arid and semi-arid regions because of the changes of monsoon and the scarcity of surface water. Even though the quantity and quality of

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groundwater available for irrigation are variable from place to place in India and Bangladesh, many groundwater exploitation schemes in developing countries such as Bangladesh are designed without proper attention to quality issues.

In addition, due to interruption of trans-boundary river courses (Ganges and Tista rivers) of Bangladesh in the Indian corridor, the water flow in Bangladesh territory hampered significantly. Recently, there occurs some shortage of surface water for irrigation. Therefore, the agricultural activities in the northwestern part of the country face huge scarcity of surface water, and the people mostly depend on groundwater systems. This water crisis has been increased tremendously in the northern part of Bangladesh. The relative dependence on groundwater for irrigation in Bangladesh has notably increased with time. During 1969–1970, groundwater had been used only about 3.0 % of the total of 1.1 million irrigated hectares. However, 10 years later (i.e., in 1979–1980), the share of groundwater in the total irrigation activities had risen to 11.5 % when the total irrigated acreage grew to 1.60 million hectares (Bhuiyan 1984). However, recently this amount has been raised up to 30 % compared to the previous consumption. For that reason, it is necessary to know the hydrogeochemical characteristics of groundwater of the aquifer system and know how much suitable is this water for irrigation purposes. Previous studies on groundwater related issues in Bangladesh have not been focused sufficiently on irrigation purposes. The main objectives of the present research are to carry out the reconnaissance of groundwater quality in Thakurgaon District of northwestern Bangladesh for irrigation purposes. It is also intended to show the spatial distribution of hydrogeochemical constituents for selecting suitable irrigation schemes.

Geology and hydrogeology of the study area

The study area is a part of Tista Fan, located in the northwestern part of Bangladesh. It lies between 25°54' N to 26°12' N and 88°18' E to 88°38' E (Fig. 1). It is the extension of the Himalayan piedmont plain that slopes southward from a height of 96–33 m with a gradient of about 55 cm/km. The region consists of piedmont sand, gravel at the base, fine sand and silt at the top. These were deposited as alluvial fan of the Tista, Mahananda and Karatoya River. The distributaries of these rivers originate from the Terai area of the foothills of Himalayas. There was a major shift in the courses of these rivers in 1887 (LGRD 2002). In the northwest, a part of the delta has been classified as inactive. However, a major part in the south and southeast is very active by Tista and Brahmaputra River. In the Tista fan, major aquifer systems belong to the

Late Pleistocene to Holocene sediments. Most of the groundwater withdrawn for domestic or agricultural purposes in the Barind Uplands areas is from the Dupi Tila Sandstone. Parts of the Tista Fan area in northern Bangladesh (Fig. 1) and the Piedmont area along a narrow strip of the hills of the greater Mymensingh and Sylhet districts also withdraw all water from sediments older than Late Pleistocene. In all the groundwater studies undertaken in Bangladesh, the aquifer systems have not been divided stratigraphically. Conceptual models of hydrogeological conditions, based on simple lithology and depth rather than stratigraphic units, have been used to assess the engineering and hydraulic properties of aquifers and deep tube well designs at depth of 150 m (LGRD 2002).

Methodology

Sample Collection

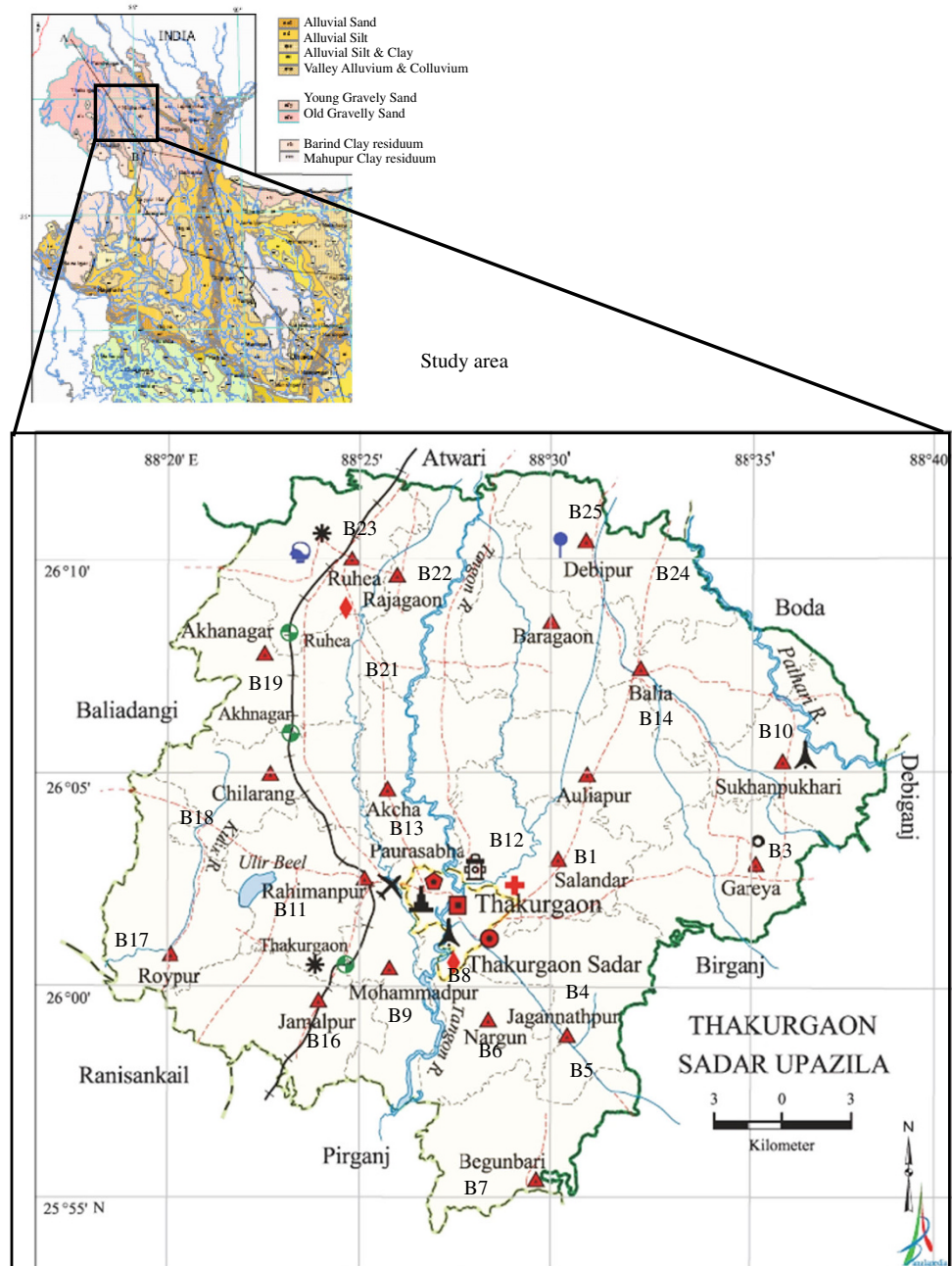
Twenty-five groundwater samples (one at each well) were collected from the shallow tube wells and irrigation pumps (depths of wells are approximately 90–120 m) during winter season in Thakurgaon Sadar Thana of Thakurgaon district in Bangladesh following the standard procedures of Bhattacharya et al. (2002). The geographic positions of the sample sites were recorded by GPS (Explorist model: 200). The stagnant water in the hand-dug wells was pumped out for 15 min prior to sample collection. The pre-sterilized plastic bottles were washed three times with sample water. The samples were collected after filtering through 0.45- μ m filters and acidified with HNO₃ for trace elements analysis. However, the samples collected for bicarbonate and major ions analysis were filtered but not acidified.

Physicochemical parameters and elemental analyses

Physicochemical parameters were measured using available field kits. The pH of water samples was determined using microprocessor pH meter (HANNA Instruments model: pH 211). Electrical conductivity (EC) was measured using conductivity meter (HANNA Instruments model: HI 8033). Microprocessor turbidity meter (HANNA Instruments model: HI 93703) was used for recording spot turbidity. Alkalinity was determined using titrimetric method. Anions (SO₄²⁻, PO₄³⁻, Cl⁻ and NO₃⁻) were measured following the standard procedures of Michael (1975). Fluoride concentrations were measured by F⁻ electrode using the EPA standard method 430.2 for fluoride measurement (Skoog and Leary 1992).

Elemental analysis was performed by a Perkin-Elmer Atomic Absorption Spectrophotometer (AAS: Model 3110). The accuracy and precision of the AAS method

Fig. 1 Map showing the sample locations and surface geology of the study area



were verified by triplicate analyses of NIST standard reference material, SRM-1640. The precision was better than 8 % for all analyzed elements. The instrumental detection limits (IDL) (in mg/l) of heavy metals in the analyzed samples were: 0.05 (K), 0.03 (Ca), 0.1 (Ti, V, Cr, Ni, Cu, Pb), 0.01 (Mn), 0.038 (Fe), and 0.026 (Zn). An Orion AAS (Model: AA240) coupled with a hydride generation system was used for arsenic analysis. The IDL of arsenic was 0.1 mg/l and precision was 5 %. Bore logs of the respective wells were collected from the Bangladesh Government local branch of public health engineering and irrigation extension office.

Methods for hydrochemical and water quality evaluation

The total hardness (TH) in ppm (Todd 1980; Hem 1985; Ragunath 1987) was determined by following equation: $TH = 2.497 Ca^{2+} + 4.115 Mg^{2+}$. The Na % is computed as equation:

$$Na\% = \frac{Na}{Na + Ca + Mg} \times 100.$$

where the concentrations of the individual species are in milli-equivalents per liter. The RSC is computed taking the

alkaline earths and weak acids in milli-equivalents per liter (Rao et al. 2012) as follows (Ragunath 1987): $RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$. The permeability index (PI) indicated suitability of groundwater for irrigation, as the soil permeability is affected by long-term use of irrigation water, influenced by the Na^+ , Ca^{2+} , Mg^{2+} , and HCO_3^- contents of the soil. For assessing the suitability of water for irrigation, Doneen (1964) and Ragunath (1987) evolved a criterion based on PI where water can be classified classes I, II, and III. The PI can be written as follows: $PI = (Na^+ + \sqrt{HCO_3}) \times 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$, where the concentrations are reported in milli-equivalents per liter.

For evaluating the water quality for irrigation purpose, the sodium or alkali hazard expressed by sodium adsorption ratio (SAR) is widely used (Devadas et al. 2007; Simsek and Gunduz 2007). If water sample is high in Na^+ and low in Ca^{2+} , the ion exchange complex may become saturated with Na^+ which destroys the soil structure (Todd 1980). The SAR value of irrigation water quantifies the relative proportion of Na^+ to Ca^{2+} and Mg^{2+} and is computed as:

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}] + [Mg^{2+}]}{2}}}$$

where $[Na^+]$, $[Ca^{2+}]$ and $[Mg^{2+}]$ are defined as the concentrations of Na, Ca and Mg ions in water, respectively (Ayers and Westcot 1985). In this equation, the concentrations are expressed as milli-equivalents per liter and are computed by dividing the aqueous concentrations of the corresponding ion expressed in milligrams per liter by the product of its atomic weight and the ionic charge (Simsek and Gunduz 2007). A combined EC–SAR criterion is usually used to assess the potential infiltration hazard that might develop in a soil. Water with $EC < 700 \mu S/cm$ is said to be good irrigation water. The EC values of the analyzed samples vary from 129 to 288 $\mu S/cm$ and are within the acceptable range. SAR values range from 0.064 to 0.274 and are within the acceptable range.

Techniques for spatial analysis

Kriging in one form or another is becoming a standard practice for local estimation in regional surveys of the environment, generally, and in hydrogeology, in particular (Gaus et al. 2003). It is a group of geostatistical techniques employed to interpolate the value of a random field at an unobserved location from observations of its value at nearby locations. Kriging provides the best linear unbiased estimation for spatial interpolation. However, it is widely known that the key tool of most geostatistical analyses is the variogram. The variogram can be described as half the expected squared difference between paired random functions separated by the distance and direction vector. The

important features of the variogram are range, sill, and nugget effect. The variogram function can be expressed as follows:

$$\hat{\gamma}(h, x) = \frac{1}{2m(h)} \sum_{i=1}^{m(h)} [Z(x_i) - Z(x_i + h)]$$

where $m(h)$ is number of pairs observations, $Z(x_i)$ represents the regionalized variable at position x_i . For the traditional variogram, which is a function of one variable h , the model for the variogram can be acquired by the use of mathematical models for instance exponential, spherical, Gaussian, and linear variogram. These models may be fitted to the variogram, and the coefficients of the model may be employed to assign optimal weights for interpolation using kriging. In this study the applied form of kriging is ordinary kriging, which assumes an unknown constant trend: $\mu(x) = \mu$. In this case, the estimate method is linear weighted moving averages of the n available observations. The interpolation by ordinary kriging is given by:

$$\hat{Z}(x_0) = \sum_{i=1}^n \lambda_i Z(x_i)$$

$$\sum_{i=1}^n \lambda_i = 1$$

where $\hat{Z}(x_0)$ is estimated the value at x_0 , and the kriging weights of ordinary kriging fulfill the unbiasedness condition. The weighting factors can be determined by solving a non-linear optimization problem involving the minimization of the estimated error to the constraint using the Lagrange multiplier (Shyu et al. 2011).

Results and discussions

General hydrochemistry

Statistics of the various hydrochemical parameters are presented in Table 1. The pH of the groundwater has a wider range varying from slightly acidic (6.21) to strongly alkaline (12.2). Elevated pH levels beyond the permissible limit (pH 8.5) occur only in samples B5, B6 and B23 which are evident by carbonate content in the borehole rocks. However, the pH value of water is controlled by the amount of dissolved CO_2 , CO_3^{2-} and HCO_3^- concentrations. The EC varies from 134 to 295 $\mu S/cm$ with a mean of 203.5 $\mu S/cm$ with the standard deviation of 37.72 (Table 1). However, EC of the groundwater samples in this study is generally low and below the WHO (2004) stipulated maximum permissible limit (1,500 $\mu S/cm$) for drinking and domestic purposes. This is attributable to low content of dissolved ions in the groundwater. The TDS

Table 1 Chemical concentration of major ions and other water quality parameters

Sample	pH	EC (uS/cm)	TDS (mg/l)	CO ₃ ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	F ⁻ (mg/l)	Cl ⁻ (mg/l)	NO ₃ ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	Na ⁺ (mg/l)	K ⁺ (mg/l)	Ca ²⁺ (mg/l)	Fe ⁻ (mg/l)	Mg ²⁺ (mg/l)	Mn (mg/l)	%Na	SAR	RSBC	RSC	PI	TH
B1	6.6	235	184	0.1	78	0.1	4.3	0.05	1.7	1.7	0.2	14	1.2	5.2	0.3	9.13	0.1	64.5	0.17	42.6	55.61
B2	6.4	205	204	0.1	68	0.1	4.7	5.2	3	1.8	0.3	18	0.4	3.2	0.1	8.97	0.1	49.9	-0.05	35.32	58.36
B3	7.7	200	208	0.1	79	0.1	3.4	0.05	5.4	2.6	1.7	6.5	0.1	1.1	0.1	36.13	0.25	72.3	0.88	74.81	20.76
B4	7.3	200	24	0.1	97	0.1	8.5	0.05	3.6	1.9	0.4	34	0.4	4.9	0.1	5.56	0.08	62.8	-0.52	23.84	105.6
B5	12.2	134	404	303	25	1.4	1.5	0.05	54	2.6	2.5	116	0.7	5	0.1	4.04	0.06	-91.1	0.26	3.98	310.2
B6	11	285	188	50	22	0.8	12	0.05	38	3.2	0.9	10	0.4	0.1	0.1	28.57	0.27	11.8	0.85	32.91	25.68
B7	7.5	200	164	6.9	100	0.5	4.2	5.6	2.8	1.8	0.3	18	0.5	3.3	0.1	9.01	0.1	82	0.61	42.97	58.28
B8	8.7	200	180	0.1	87	0.1	4.1	3.9	2.8	1.8	0.3	19	0.1	3.1	0.1	8.75	0.1	68.2	0.23	38.94	59.7
B9	6.5	195	192	0.1	104	0.1	4.2	3.9	2.7	1.9	0.3	18	0.3	3.3	0.1	9.32	0.11	86	0.53	43.31	58.78
B10	6.4	200	156	0.1	108	0.1	4.1	5.1	3	1.9	0.3	18	0.5	3.3	0.1	9.24	0.11	90	0.59	43.81	59.27
B11	6.5	190	168	1.1	102	0.6	4.1	4.1	2.6	1.9	0.3	17	0.7	3.2	0.1	9.91	0.11	85.1	0.59	45.56	55.12
B12	6.6	235	124	0.1	152	0.1	2.7	0.05	1.7	1.8	0.3	22	0.3	5.9	2.5	6.95	0.09	130.2	0.9	40.94	79.71
B13	6.9	200	228	0.1	112	0.6	4.2	4.3	2.8	1.9	0.3	19	0.8	3.4	0.1	9.02	0.11	93.5	0.62	43.51	60.93
B14	7.8	200	212	0.1	72	0.5	3.2	0.05	5.7	2.8	0.4	6.9	0.4	1.1	0.1	28.57	0.26	65.1	0.75	76.01	21.76
B15	7.1	280	237	0.1	151	0.4	7.7	0.05	3.4	1.7	0.4	33	0.9	5.1	0.1	5.2	0.07	118.2	0.4	30.5	103.9
B16	8.4	235	144	0.1	149	0.4	4	0.05	3.1	1.8	0.4	20	0.4	5.5	0.5	7.89	0.09	129.1	0.98	43.86	73.07
B17	6.3	190	55	0.1	110	0.1	3.8	3.4	2.7	1.4	0.3	18	0.3	3.4	0.1	7.3	0.08	91.5	0.61	45.01	59.44
B18	7.6	200	258	0.1	101	0.1	3.6	0.9	3	1.7	0.4	21	0.5	4.2	0.1	7.84	0.09	80.5	0.28	37.56	68.47
B19	6.5	170	188	0.1	104	0.1	3.9	0.05	2.6	1.6	0.3	15	0.2	3.8	0.1	9.22	0.1	89.4	0.65	49.65	52.84
B20	6.9	175	96	0.1	108	0.4	3.5	0.05	2.5	1.7	0.3	18	0.8	3.4	0.1	8.7	0.1	90.3	0.61	45.24	57.94
B21	6.4	160	92	0.1	91	0.1	3.3	0.05	1.5	1.4	0.2	13	0.7	3.7	0.1	8.7	0.09	77.4	0.52	51.78	47.94
B22	6.6	165	92	0.1	81	0.5	6.9	0.05	2.2	1.7	0.2	13	0.4	3.6	0.1	10.16	0.11	67.8	0.37	48.22	47.77
B23	11	295	144	89	13	0.5	6.8	0.05	18	1.8	0.6	20	0.3	0.1	0.1	10.55	0.11	-7.2	0.97	15.99	50.89
B24	6.4	160	60	0.1	93	0.1	1.8	0.05	0.7	1.5	0.2	12	0.4	4.4	0.1	9.66	0.1	81	0.58	54.73	46.82
B25	6.3	180	56	0.1	105	0.1	4	0.05	1.2	1.7	0.1	14	0.6	5.6	0.2	8.61	0.1	91.7	0.59	49.16	56.75
Min	6.3	134	24	0.1	13	0.1	1.5	0.05	0.7	1.4	0.1	6.5	0.1	0.1	0.1	4.04	0.07	-91.1	-0.05	3.98	20.76
Max	12.2	295	404	303	152	1.4	7.7	5.6	54	3.2	2.5	116	1.2	5.9	2.5	36.13	0.27	130.2	0.98	76.01	310.2
Mean	7.53	203.5	166	152	93	0.3	4.6	1.49	6.8	1.9	0.5	21	0.49	1.9	0.2	11.08	0.12	71.2	0.52	42.41	67.82

%Na percent sodium, SAR sodium absorption ratio, RSBC residual sodium bicarbonate, RSC residual sodium carbonate, PI permeability index

values range from 24 to 404 mg/l with a mean of 165.64 mg/l, which exhibit the similar picture of EC. Freeze and Cherry (1979) also stated that TDS values of groundwater within the range of 0–1,000 mg/l are considered as fresh. On the basis of EC and TDS, groundwater samples in the study area falls on fresh group. The dominant cation in the area is Ca^{2+} and varies from 6.5 to 116 mg/l with a mean value of 21 mg/l. HCO_3^- , the dominant anion concentration varies from 13 to 152 mg/l with a mean of 93 mg/l. The dominance of this ion in the groundwater samples indicates that the rocks in the aquifer area are composed of carbonate minerals notably calcite, dolomite and gypsum. The Na^+ , Mg^{2+} , K^+ , Cl^- , SO_4^{2-} and CO_3^{2-} occur in very low concentrations. However, high Ca^{2+} and CO_3^{2-} concentrations in groundwater samples imply a predominant calcite mineral in the aquifer that is being tapped. The range of NO_3^- is 0.05–5.6 mg/l with the mean value of 1.49 mg/l falling below the FAO (1972) standard limits. Fluoride ion varies from 0.1 to 1.4 mg/l with a mean of 0.49 mg/l. The F^- concentrations are generally low with respect to WHO (2004) limit of 1.5 mg/l. However, the content of F^- indicates the presence of fluorite mineral in the aquifer. Fe varies from 0.11 to 1.22 mg/l with a mean value of 0.55 mg/l. Most of the samples show elevated Fe concentrations which is above the WHO (2004) recommended value of 0.3 mg/l.

Geochemical classification

The values obtained from the groundwater samples are plotted on Piper (1944) trilinear diagram (Fig. 2) to

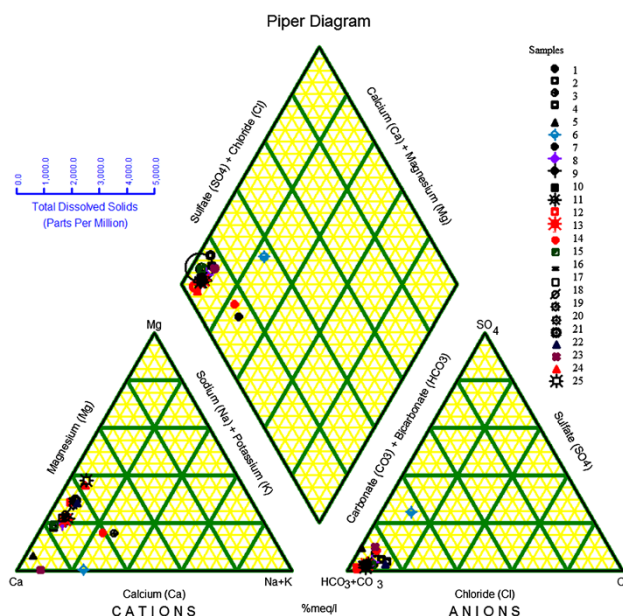
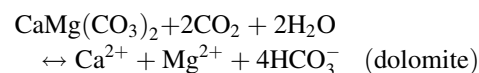
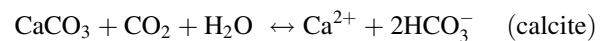


Fig. 2 The Piper (1944) diagram for the groundwater samples of the study area

recognize the hydrogeochemical facies which are able to provide clues how groundwater quality changes within and between aquifers (Sivasubramanian et al. 2013). From the samples plotting on the Piper (1944), trilinear diagram (Fig. 2) shows that HCO_3^- , Ca^{2+} and Mg^{2+} play a dominating role for characterizing groundwater, other than Cl^- or SO_4^{2-} . The Fig. 2 shows HCO_3^- – Ca – Mg are the major chemical types, clustering at the left corner of the diamond on the plot and confirming the shallow porous groundwater hydrochemistry characteristic in carbonate sediments. The release of HCO_3^- from rocks weathered by the carbonic acid in rainwater is the important part of carbon cycle. Geologically, the term “carbonate” refers equally to carbonate minerals and carbonate rocks and both are dominated by the CO_3^{2-} ion. Carbonate minerals are enormously varied and everywhere in chemically precipitated sedimentary rock. Preferably, Ca^{2+} and Mg^{2+} might have been contributed through dissolution of carbonate minerals (Zhou et al. 2012). The most common are calcite, the chief constituent of limestone (as well as the main component of mollusc shells and coral skeletons); dolomite and siderite, an important iron ore. These water types may have evolved from the dissolution of calcite and dolomite minerals in the rocks according to equations,



However, the CO_3 – HCO_3 system is apparently the most significant chemical system in natural waters. The vital role of the carbonate system is that it provides the buffering capacity essential for maintaining the pH of natural water systems, and is responsible in a great measure for the alkalinity of water in the range which is needed by bacteria and other aquatic species.

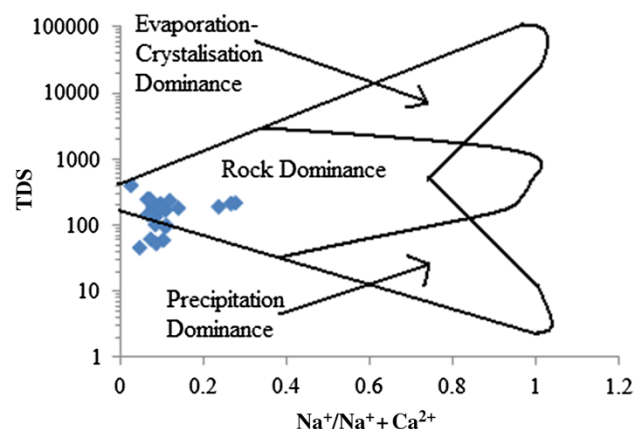
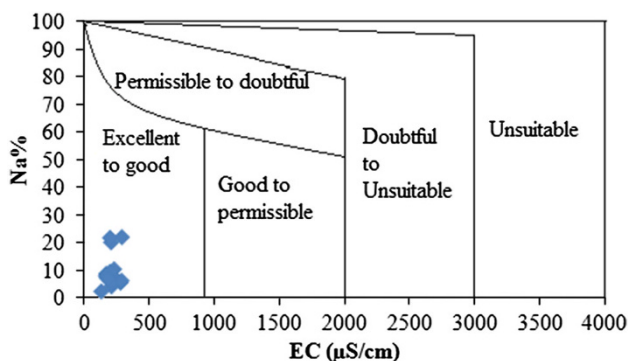
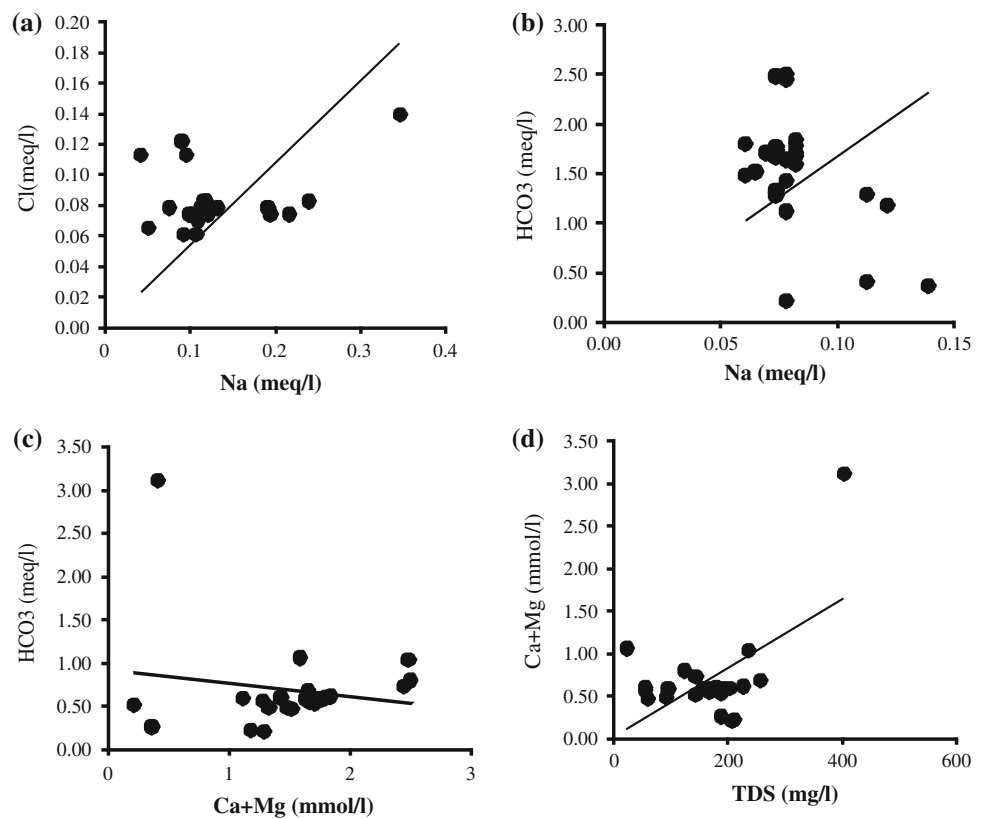


Fig. 3 Gibbs plot showing the mechanism controlling groundwater chemistry of the study area

Fig. 4 Ionic scatter diagram of groundwater in the study area**Fig. 5** Na% vs. EC plots of the groundwater samples of the study area and its suitability for irrigation

In addition to the Piper diagram, Gibbs (1970) plots (Fig. 3) were also employed to gain better insight into hydrochemical processes such as precipitation, rock water interaction and evaporation on groundwater chemistry in the study area. Gibbs (1970) suggested that a simple plot of TDS vs. the weight ration of $\text{Na}^+(\text{Na}^+ + \text{Ca}^{2+})$ (Fig. 3) could provide information on the mechanism controlling the chemistry of waters (i.e., atmospheric precipitation, rock weathering and evaporation and precipitation). The Fig. 3 demonstrates that groundwater samples were plotted both in the rock-dominance zone and precipitation zone, which are influenced by chemical weathering of rock-

forming minerals (mostly carbonate minerals). The samples falling in the precipitation dominance are collected from dug wells from the barren areas (area lacking of surface water) of semi-arid climatic condition, which addressed the similar observation of Jeevanandam et al. (2012).

Geochemical process

The Na/Cl is used to identify the mechanism for acquiring salinity, rock–water interaction and saline intrusions (Sivasubramanian et al. 2013). Most water samples plotted close to the line (Fig. 4a) defined by NaCl showing a continuum from precipitation and uncontaminated groundwater (Panno et al. 1999a). The few samples are exceptions, which contain little Cl^- and show an enrichment of Na^+ because of rock–water interaction within the aquifer (Panno et al. 1994; Hackley 2002) or origin from animal and human waste in rural areas (Panno et al. 1999a). Increased concentration of Na^+ compared to HCO_3^- concentration (Fig. 4b) in groundwater suggests that carbonate weathering occurred in the aquifer sediments. The evolution of the slopes of $\text{Ca}^{2+} + \text{Mg}^{2+}$ with HCO_3^- gives valuable information about the sources of Ca^{2+} and Mg^{2+} in groundwater (Richter et al. 1993). $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. HCO_3^- plot (Fig. 4c) illustrates a relatively gentle slope line indicating $\text{Ca}^{2+} + \text{Mg}^{2+}/\text{HCO}_3^-$ ratio reflects some changes during the increase of HCO_3^- .

Table 2 Sawyer and McCarthy (1967) classification for groundwater based on hardness

TH as CaCO ₃ (mg/l)	Water class	Range (no. of samples)	Percent
<75	Soft	21 Samples	84
75–150	Moderately hard	3 Samples	12
150–300	Hard	Nil	Nil
>300	Very hard	1 Sample	4

This phenomenon indicates the contribution of Ca²⁺ + Mg²⁺ and HCO₃⁻ is preferably from dissolution of carbonate minerals and some other sources (Zhou et al. 2012; Sivasubramanian et al. 2013). Higher HCO₃⁻ may exist due to the higher evaporation. Enrichment of HCO₃⁻ and depletion of Ca²⁺ + Mg²⁺ may be due to cation exchange within the aquifer materials (Spears 1986). The plot of Ca²⁺ + Mg²⁺ vs. TDS demonstrates that the data falls on the 1:1 trend line, reflecting Na and K as the major contributor for the increase of TDS (Sivasubramanian et al. 2013) (Fig. 4d).

Groundwater quality assessment for irrigation

The suitability of groundwater for irrigation mostly depends on relative concentrations of EC and Na⁺ in relation to other cations and anions (Todd 1980; Hem 1991). In the studied samples, the groundwater quality was good to excellent for irrigation (Fig. 5).

Total hardness

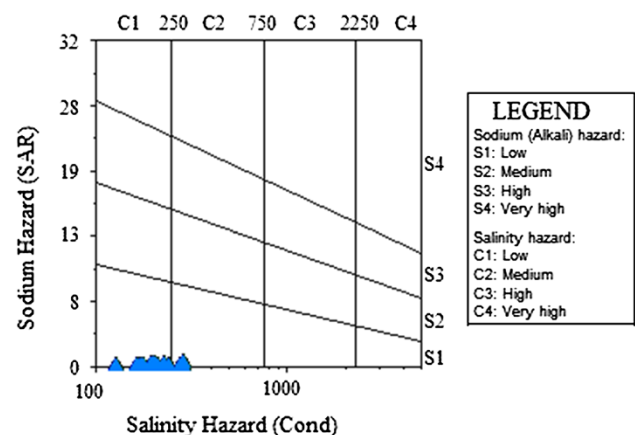
Hardness is an important criterion for determining the suitability of groundwater for domestic and industrial uses. The classification of the groundwater of the study area based on hardness (Sawyer and McCarthy 1967) has been carried out and is presented in Table 2. Accordingly, 21 samples (84 %) fall under the soft class.

Salinity, sodium hazard and SAR

In order to diagnosis and classification, the total concentration of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance (Ravikumar et al. 2011). Salinity signifies leaching of salts into groundwater. Salinity hazard (C) has been classified as four groups: (a) low salinity hazard (C1), when the EC is less than 250 μS/cm; (b) medium salinity hazard (C2), when it varies from 250 to 750 μS/cm; (c) high salinity hazard (C3), when it is in between 750 and 2,250 μS/cm; and (d) very high salinity hazard (C4), when it is more than 2,250 μS/cm (Table 3). The values of EC measured from the groundwater samples

Table 3 Quality of irrigation water based on electrical conductivity followed by WHO (2004 standard)

EC (μS/cm)	Water salinity	Samples	Percent of samples
0–250	Low salinity (excellent quality)	B1–B5, B7–B14, B16–B22, B24, B25	88
251–750	Medium salinity (good quality)	B6, B15, B23	12
751–2,250	High salinity (permissible quality)		
2,251–6,000	Very high salinity		
6,001–10,000	Extensively high salinity		
10,001–20,000	Brines weak concentration		
20,001–50,000	Brines moderate concentration		
50,001–100,000	Brines high concentration		
>100,000	Brines extremely high concentration		

**Fig. 6** US salinity diagram showing the sodium adsorption ratio and salinity for the classification of groundwater for irrigation purposes (Wilcox 1948)

vary from 134 to 295 μS/cm (Table 1). According to the classification of salinity hazard, most of the groundwater sampling points (Fig. 6) fall in the low (C1) classes for irrigation. The spatial distribution of EC (Fig. 7) shows that groundwater salinity increases in the middle and southern part of the basin (especially Sadar Upazila, Paurasava, Salanar and Targun areas). However, some heterogeneity in salinity distribution is observed. The spatial distribution of EC primarily reflects the influence of geology, groundwater residence time and recharge processes on groundwater quality. Hot water spring

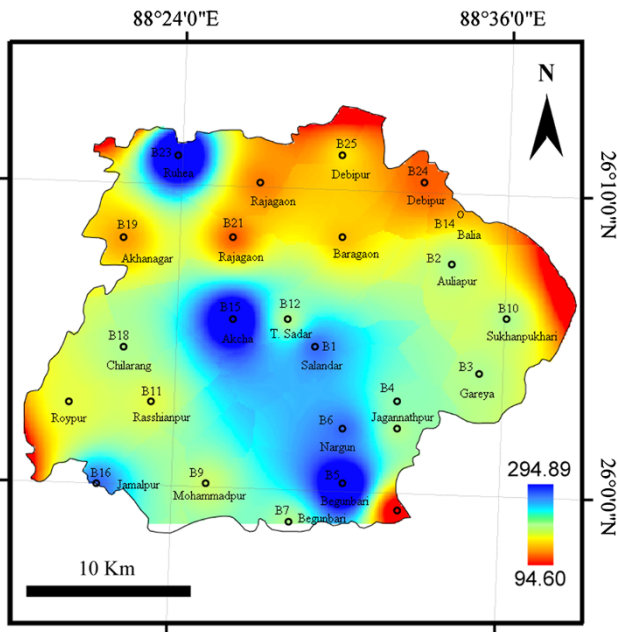


Fig. 7 Spatial distribution of EC (salinity) in groundwater samples in the study area

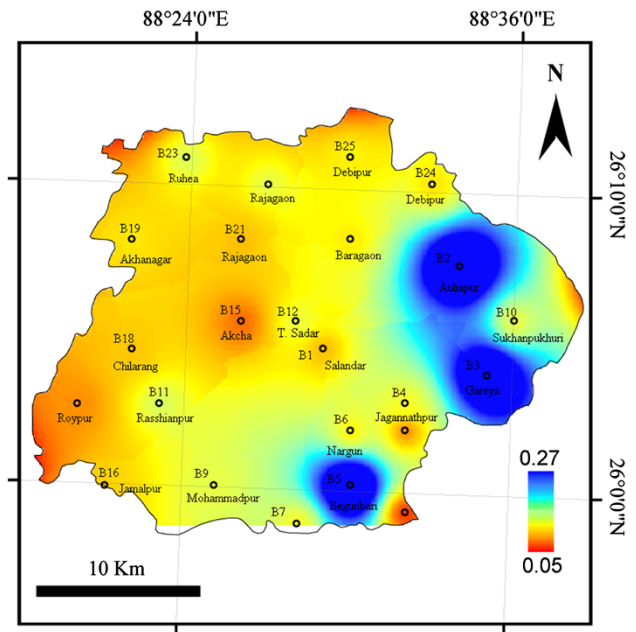


Fig. 8 The distribution of SAR values in the study area

Table 4 The classification of groundwater for irrigation purpose based on sodium hazard

Zone	SAR	Sample no.	% of samples	Water class
S1	<10	1–25	100	Excellent
S2	10–18	–	–	Good
S3	18–26	–	–	Permissible
S4	>26	–	–	Unsuitable

(geothermal water) in the southeastern part of the study area influences the salinity level of groundwater. Salinity level showed in the southern part due to infiltration of the upper Tangon River into the aquifer. A higher concentration of EC in the central part of the basin was observed. This is the area acting as the outlet for drainage of upstream land with a shallow water table. In general, a considerable increase in the degree of water mineralization was observed in the direction of Tangon River flow and the least mineralized water was found closest to the main recharge area.

According to the US Department of Agriculture (Wilcox 1955), the Na hazard (S) is classified as (a) low Na hazard (S1), when the SAR is less than 10; (b) medium Na hazard (S2), when it is in between 10 and 18; (c) high Na hazard (S3), when it varies from 18 to 26; and (d) very high Na hazard (S4), when it is more than 26 (Table 4). The SAR values calculated from the groundwater samples of the study area are in between 0.064 and 0.274 (Table 1), which classified the groundwater samples in the excellent category (S1) for irrigation (Table 4). The higher the SAR

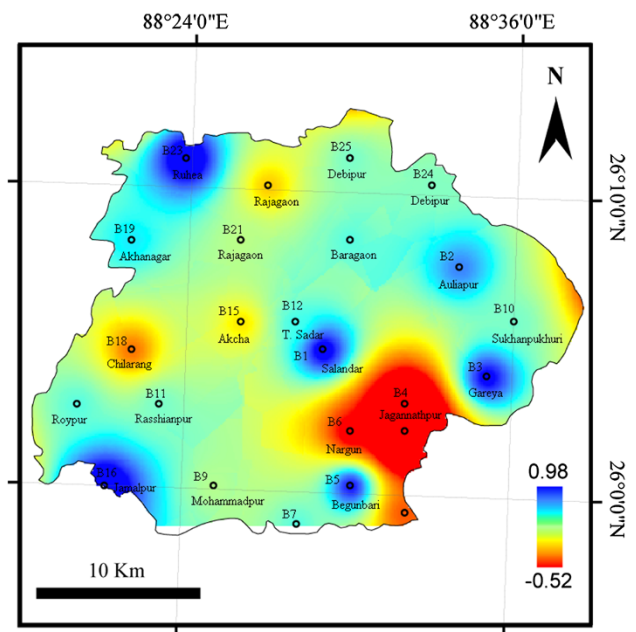


Fig. 9 RSC distribution in the study area

values, the greater is the risk of Na on plant growth. The distribution of SAR values in the study area is shown in Fig. 8. It is observed that samples of low SAR are mainly located in the northern–western part of the area, while high SAR dominated the southern part. The spatial distributions of EC and SAR showed nearly a similar pattern which dominates in the southern part of the study area (Table 1). However, some heterogeneity was observed in the basin. Variations in SAR are larger in the southeastern part of

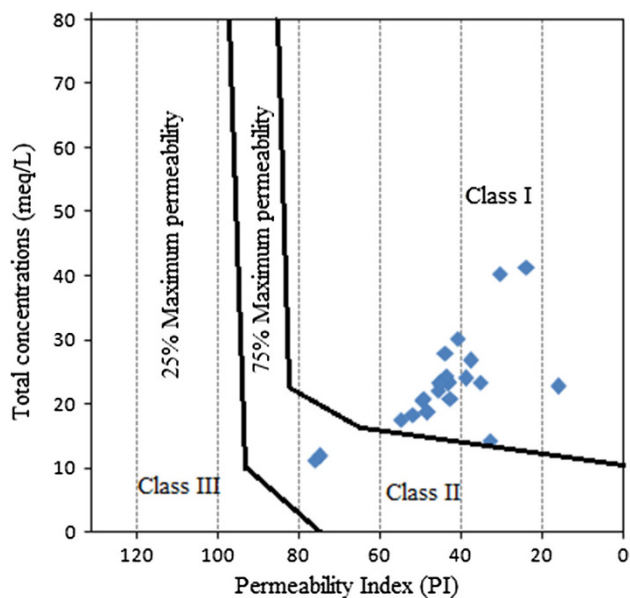


Fig. 10 The permeability index of the groundwater samples in the study area

study area (Fig. 8). Whereas southwestern part of the study area is dominated with higher EC values.

Residual sodium carbonate (RSC)

A relation of alkaline earths with weak acids is expressed in terms of RSC for assessing the quality of water for irrigation (Richards 1954). When the weak acids are greater than the alkaline earths, a precipitation of alkaline earths occurs in soils, which damages the permeability of soil (Rao et al. 2012). On the basis of RSC values, water quality is generally classified as (a) safe, when the RSC is less than 1.25 milli-equivalents per liter; (b) marginally safe, when it is between 1.25 and 2.50 milli-equivalents per liter; and (c) unsafe, when it is more than 2.50 milli-equivalents per liter for irrigation (Richards 1954). The values of computed RSC from groundwater samples of the study area vary from 0.17 to 0.984 (Table 1). Hence, all the groundwater samples are safe for irrigation. Spatial analysis showed that there is no significant variation of RSC distribution in studied samples. The lowest value of RSC was found in the northeastern part (Jaganathpur/Nargun area) of the study area (Fig. 9).

Permeability index

The permeability index of the groundwater samples ranges from 4 to 76 % (Fig. 10) with an average value of 42 %. Hence, all the samples fall in class 1 of Doneen's chart (Domenico and Schwartz 1990). WHO (1998) uses a criterion for assessing the suitability of water for irrigation

based on the permeability index. According to the permeability index values, 98 % of the samples fall under class 1 (PI > 75 %) and about 2 % belong to class 2 (PI ranged from 25 to 75 %) (Fig. 10).

Conclusion

The quality of groundwater resources in the central Thakurgaon Sadar of Thakurgaon District was evaluated to reconnaissance the suitability for irrigation uses. The order of abundance of ions in groundwater samples are $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and $\text{HCO}_3^- > \text{CO}_3^{2-} > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^- > \text{F}^-$. Trace metals concentration in groundwater samples were below the detection limit. The chemical analyses of groundwater samples indicate that the water is chemically characterized by Ca-HCO₃, Ca-Mg-HCO₃ and CaCO₃ with low TDS. The groundwaters from these groups are recharged through direct infiltration of rain. However, the groundwater evolution in this study is mainly the result of weathering of carbonate minerals and cation exchange within the aquifer materials, confirming the shallow porous groundwater hydrochemistry characteristics.

Gibbs plots showed that most of the samples fall in rock-dominance zone. The evolution of these waters may be controlled by precipitation and dissolution of carbonate minerals. The plot of Ca + Mg/HCO₃ showed enrichment of HCO₃ than Ca + Mg suggesting both were from different sources. SAR, RSC, and %Na imply that the water samples fall in excellent, suitable and safe for irrigation. The Na⁺ hazards in all samples are low, indicating that these waters are suitable for irrigation in almost all soils with small danger of the development of Na⁺ problem. Permeability index of the water samples recommends that the water from the Thakurgaon area, belonging to class 1 is suitable for irrigation. USSL graphical geochemical representation of irrigation water quality suggests that all the samples fall under low salinity with low alkali hazards.

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