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Assessing groundwater suitability for irrigation: A case study for Durgapur upazila of Bangladesh

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ABSTRACT

A study was carried out to evaluate the quality of groundwater and its suitability for irrigation in Durgapur upazila under Netrokona district of Bangladesh. Fifteen groundwater samples were collected from different tubewells and analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), major cations like Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and anions like Cl^{-}, SO_4^{2-}, PO_4^{3-}, CO_3^{2-}, HCO_3^{-}. Based on these analyses, irrigation water quality parameters like sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), magnesium adsorption ratio (MAR), total hardness (TH), Kelly's ratio (KR), permeability index (PI), potential salinity (PS) and salinity and alkalinity hazard were calculated. ArcGIS software was used to show the spatial distribution of different quality parameters across the study area. The groundwater of the study area was mildly acidic. Acidic water was observed in the north-eastern part of the study area. All the groundwater samples were found to be suitable for the irrigation in terms of EC, TDS, SAR, SSP, RSC, TH, KR, PI and PS, and whereas in terms of MAR, 5 samples were in 'dangerous' category. High MAR values of groundwater were observed in the north western part of the study area. However, in terms of salinity and alkalinity hazard, all of the water samples were categorized as 'good to excellent' class for irrigation. Piper diagram showed that Ca^{2+}–Cl^{-} type water was the dominant form of groundwater in the study area. Gibbs diagram indicated that most of the cations and anions had a precipitation dominance origin. Overall for the groundwater samples, PI-PS and SSP–KR had a very strong correlation with a correlation coefficient around 1, and whereas, Ca^{2+}, Mg^{2+}, K^{+} and MAR showed a negative correlation with most of the variables. The study revealed that the quality of the groundwater of the study area is suitable for irrigation.

Keywords: Groundwater, physico-chemical properties, spatial distribution, irrigation

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1 Introduction

The availability of Earth's water varies in space and time due to hydro-climatic momentum (WWAP, 2003). About 30% of all fresh water in the world is stored as groundwater (Shiklomanov and Rodda, 2003). Most of this has accumulated over millions of years with an average recharge rate of 0.1% to 3% per year (La Salle et al., 2001). Although groundwater is a limited resource, currently it meets a quarter of the world's water requirements (Pimentel et al., 2004).

Agriculture consumes, on an average, 70% of total water withdrawal across the world (WB, 2017). Irrigation constitutes a major share of total agricultural water withdrawal. However, all sorts of water are not equally suitable for irrigation. In order to achieve maximum crop yield, the desired irrigation water should pass some quality criteria. For groundwater sourced irrigation, extra attention to water quality must be paid because groundwater contains a relatively high content of various ions as dissolved chemical constituents compared to surface water. If low-quality groundwater is applied for irrigation, some ions may accumulate in soils as well as in crops and deteriorate soil environment ultimately affecting crop production (Ayers and Westcot, 1985).

During the dry season, irrigation systems in Bangladesh are largely dependent on groundwater resources due to an inadequate supply of surface water. It has been observed that the area under irrigation by surface water has remained more or less static since the early eighties, while the area under irrigation by shallow tube-wells has increased by five times (Bari and Anwar, 2000). In Bangladesh, the contribution of groundwater to the total irrigated area has been increased from 4% in 1971 to 85% in 2013 (Wang et al., 2013). For sustainable and environmentally friendly crop production, it is necessary to analyze various water quality parameters to detect whether these parameters are within the permissible limit. Water quality is a function of physical, chemical and biological properties of water. Evaluation of irrigation water is mainly performed with the aid of their chemical and physical characteristics (Mahmud et al., 2017).

There are a number of factors that contribute to the quality of irrigation water. Among those, four criteria are widely considered for the assessment of water quality for irrigation. These are (i) total soluble salt content in the water or salinity hazard, (ii) relative proportion of sodium cations to other cations or sodium hazard, (iii) excessive concentration of elements that causes ionic imbalance in plants or ion toxicity, and (iv) excessive presence of other miscellaneous elements like bicarbonate anion (Ayers and Westcot, 1985). However, the first two criteria are of major concern in water quality for irrigation in Bangladesh. In this study, the concentration of different chemical parameters of groundwater was measured and different irrigation water quality indices *viz*. sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), magnesium adsorption ratio (MAR), electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), Kelly's ratio (KR), permeability index (PI) and potential salinity (PS) were determined for judging the degree of suitability of groundwater for irrigation. Only a few research works have been conducted on the evaluation of the quality of groundwater for agricultural and domestic purposes in Bangladesh over the past years. Yasmin et al. (2019) conducted a study to evaluate the quality of groundwater in Barishal district of Bangladesh for both irrigation and drinking purposes, where they explored that most of the water samples were found as acceptable limit in terms of TDS, EC, SAR and TH values, but unacceptable based on pH, and also found that the quality of groundwater for most of the locations in the area was permissible and good for irrigation and drinking purposes.

In Netrokona district of Bangladesh, no specific research work relating the quality of groundwater for irrigation purpose has been conducted yet. Therefore, this study was conducted to assess the quality of groundwater of Durgapur upazila of Netrokona district in Bangladesh by analyzing different quality parameters important for the suitability of groundwater for irrigation.

2 Materials and Methods

2.1 Study area

The study area is located at Durgapur upazila under Netrokona District near Bangladesh-India border. It is bordered by the Meghalaya state of India on the north. Kulagora union was selected as the study site. The surface geology of the study area comprises of Madhupur Tract. Climate is one of the most important factors for the occurrence and movement of groundwater (CGWB, 2009). The annual rainfall of the study area is 2235 mm, and the temperature ranges from 12.5 °C to 34.2 °C. Agriculture is the largest source of income of the people comprising 73.01%, and main crops cultivated in that area include paddy, jute, wheat and mustard, etc. (BBS, 2018).

2.2 Groundwater sample collection

Fifteen groundwater samples were collected from different locations of Kulagora union. The samples were collected in bottles of 500 mL according to the standard methods mentioned in APHA (1998). Two sets of water samples from each site were collected. One set of the sample was kept under the non-acidified condition and another set of the sample was kept under acidified condition by adding 0.01 M HNO_3. At the time of sampling, bottles were thoroughly rinsed two to three times with groundwater to be sampled. The bottles were kept airtight and labeled properly. Groundwater samples were filtered through filter paper to remove undesirable solids and suspended materials before chemical analysis.

2.3 Water quality parameters

Chemical analysis of collected groundwater samples was performed in the laboratory of the Department of Agricultural Chemistry, Bangladesh Agricultural University (BAU) and Humbolt Soil Testing Laboratory of the Department of Soil Science, BAU. The pH values of groundwater samples were measured following methods mentioned by Singh and Narain (1980). The electrical conductivity (EC) of water was determined according to the technique described by Tandon (1993). Total dissolved solids were measured following the method as suggested by Chopra and Kanwar (1980). The following water quality indices were considered in assessing the quality of groundwater for irrigation:

Sodium adsorption ratio (SAR) describes the relationship between soluble sodium (Na^+) and soluble divalent cations, calcium (Ca^{2+}) and magnesium (Mg^{2+}) (Alrajhi et al., 2015). The SAR was calculated by the following equation given by Richards (1954) as:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \tag{1}$$

Soluble sodium percentage (SSP) is used to evaluate sodium hazard. SSP was calculated by the following equation as developed by Todd (1980):

$$SSP = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \tag{2}$$

The presence of Mg^{2+} in groundwater to a great extent will reduce the overbearing effect of Na^+ in groundwater. The Mg^{2+} adsorption ratio (MAR) was calculated by the equation of Raghunath (1987) as:

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \tag{3}$$

Residual sodium carbonate (RSC) was calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose and was expressed by the equation (Eaton, 1950):

$$RSC = (CO_3^- + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \tag{4}$$

All the ions in Equation (1) to Equation (4) are expressed in meq L^{-1} or epm (equivalents per million).

The total hardness was calculated by the following equation (Sawyer and McCarty, 1967):

$$TH = (2.5 \times Ca^{2+}) + (4.1 + Mg^{2+}) \tag{5}$$

where all the ions are expressed in mg L^{-1} or ppm (parts per million).

Kelly's ratio (KR) is also an important parameter for irrigation water quality which was calculated using the equation (Kelley, 1963) as:

$$KR = \frac{Na}{Ca^{2+} + Mg^{2+}} \tag{6}$$

Doneen (1964) has evolved a criterion for assessing the suitability of water for irrigation based on permeability index (PI). PI was calculated according to Doneen (1964) by the following equation:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \tag{7}$$

Potential salinity (PS) is defined as the chloride concentration plus half of the sulfate concentration. Doneen (1954) gave the following equation:

$$PS = Cl^- + \frac{1}{2} SO_4^{2-} \tag{8}$$

All the ions in Equation (6) to Equation (8) are expressed in meq L^{-1} or epm (equivalents per million).

Spatial distribution of different groundwater quality parameters was mapped using ArcGIS software. The groundwater was also classified based on Piper (Piper, 1944) and Gibbs (Gibbs, 1970) diagrams.

3 Results and Discussion

Understanding the groundwater chemistry is important as it is one of the vital factors in determining its suitability for drinking, domestic, agricultural and industrial purposes (Subramani et al., 2005). The physico-chemical parameters of the collected 15 groundwater samples are presented and broadly discussed in the subsequent sections.

3.1 Irrigation water quality

pH The pH value of all water samples varied from 5.34 to 6.32 (Table 1) which indicates that the sampled groundwater is mildly acidic. Most of the groundwater samples were suitable for irrigation with respect to pH values, as the acceptable pH for agricultural use ranges between 6.0 and 8.5 (Ayers and Westcot, 1985). The spatial distribution of groundwater pH across the study area is shown in Fig. 1a. Slightly acidic water (pH 5.9-6.1) was observed in the southern and north-western part of the study area and acidic water (pH 5 -5.7) was observed in the north-eastern part of the area. It might be caused due to the presence

Table 1. Chemical composition and quality parameters of groundwater samples

Quality parameters	Average	Range
pH	5.90	5.34∼6.32
EC (μS cm^{-1})	266.7	115.7∼459
TDS (ppm)	74.1	44.0∼120.0
Ca (ppm)	12.772	2.405∼24.048
Ca (epm)	0.639	0.120∼1.202
Mg (ppm)	8.636	0.972∼31.596
Mg (epm)	0.720	0.081∼2.633
K (epm)	0.012	0.008∼0.019
Na (epm)	0.081	0.025∼0.165
Cl (epm)	0.596	0.171∼1.156
SO_4 (epm)	0.012	0.004∼0.024
PO_4 (epm)	0.00012	0.00004∼0.00024
HCO_3 (epm)	0.029	0.020∼0.043
SAR	0.154	0.045∼0.367
SSP (%)	7.753	2.087∼18.115
MAR	48.015	6.732∼88.992
RSC (epm)	−1.330	−3.809∼−0.646
TH (ppm)	67.339	33.958∼189.664
KR	67.339	33.958∼189.664
PI (%)	20.865	5.971∼40.476
PS (epm)	0.602	0.172∼1.169

EC = electrical conductivity, TDS = total dissolved solids, SAR = sodium adsorption ratio, SSP = soluble sodium percentage, MAR = magnesium adsorption ratio, RSC = residual sodium carbonate, TH = total hardness, KR = Kelly's ratio, PI = permeability index, and PS = potential salinity

of low alkalinity in groundwater as lack of alkaline substances in the groundwater system helps in the accumulation of acidity in the groundwater (Zhou et al., 2015).

Electrical conductivity (EC) The range of EC of all water samples varied from 115.7 to 459.0 μS cm^{-1} with the mean value of 266.7 μS cm^{-1}. The EC of the samples were compared with that of the standard classified values (Table 2) and it was found that 7 groundwater samples were in 'excellent class' and 8 samples were in 'good class'. Only two sampling sites fell under the areas of relatively higher EC (Fig. 1b). Overall, a moderate EC value persisted across the study area.

Total dissolved solids (TDS) In this study, TDS varied from 44 to 120 ppm (Table 1), and it was found that all the samples were in excellent class (Table 2). On the basis of TDS values (44 to 120 ppm), all the groundwater samples were rated as 'fresh' and found suitable for growing crops as recommended by Freeze and Cherry (1979). The spatial distribution of TDS is shown in Fig. 1c. Overall, a low TDS signature of groundwater persisted across the study area.

Sodium adsorption ratio (SAR) SAR is an estimate of the extent to which sodium ion present in the water that would be absorbed by the soil. In irrigation water with high SAR values, the sodium in the water can displace the calcium and magnesium in the soil. Water having inadequate SAR value causes a decrease in the ability of soil to form stable aggregates and loss of soil structure, and also lead to a decrease in infiltration and permeability of the soil to water, leading to problems with crop production (Chandrasekar et al., 2013). The SAR ranged from 0.045 to 0.367 with an average value of 0.154 in the study area (Table 1). It was found that all water samples were in 'excellent' class (Table 2). A low EC value and high SAR means there is a high potential for permeability or water infiltration problems. They can act separately or collectively to disperse soil aggregates, which in turn reduces the number of large pores in the soil. These large pores are hence responsible for aeration and drainage (Grattan, 2002). The distribution of SAR values in the study area is shown in Fig. 1d. It was observed that samples of low SAR were mainly located in the eastern and north-western parts of the study area.

Soluble sodium percentage (SSP) The sodium concentration of irrigation water is of prime importance and plays a significant role in determining the permeability of the soil. Sodium adsorbed on the clay surface, as a substitute for Ca and Mg, may damage

Table 2. Classification of groundwater samples based on different parameters

Parameters (range)	Water class and its developer	No. of sample	% of sample
EC (μS cm^{-1})	Wilcox (1955)		
<250	Excellent	7	47
250∼750	Good	8	53
750∼2250	Doubtful	–	–
>2250	Unsuitable	–	–
TDS (ppm)	WHO (1996a) and WHO (1996b)		
<300	Excellent	15	100
300∼600	Good	–	–
900∼1200	Fair	–	–
>1200	Unacceptable	–	–
SAR	Richards (1954)		
<10	Excellent	15	100
10∼18	Good	–	–
18∼26	Doubtful	–	–
>26	Unsuitable	–	–
SSP (%)	Wilcox (1955)		
<20	Excellent	15	100
20∼40	Good	–	–
40∼60	Permissible	–	–
60∼80	Doubtful	–	–
RSC (epm)	WHO (1989)		
<1.25	Safe	15	100
1.25∼2.50	Marginal	–	–
>2.50	Unsuitable	–	–
TH (ppm)	Sawyer and McCarty (1967)		
0∼75	Soft	13	86
75∼150	Moderately hard	1	7
150∼300	Hard	1	7
>300	Very Hard	–	–

EC = electrical conductivity, TDS = total dissolved solids, SAR = sodium adsorption ratio, SSP = soluble sodium percentage, RSC = residual sodium carbonate, and TH = total hardness

the soil structure making it compact and impervious (Singh et al., 2008). Percentage of Na content is a parameter to assess its suitability for agriculture purpose (Wilcox, 1948). The range of SSP in the samples varied from 2.087 to 18.115% with an average value of 7.753 (Table 1). While comparing with the Wilcox (1955) classification, it was found that 100% of the samples were in the 'excellent' class (Table 2). The results are in the conformity with the findings of Nizam et al. (2014). The Indian standards suggest a maximum of 60% Na is permissible for irrigation water. Percent Na plotted on Wilcox diagram indicates that all the groundwater samples were in excellent category (Fig. 2a). Spatial distribution of SSP is shown in Fig. 3a. The SSP values gradually decreased in the Western region while there is an increasing trend in the northern part.

Residual sodium carbonate (RSC) A relation of alkaline earth with weak acid is expressed in terms of RSC for assessing the quality of water for irrigation (Richards, 1954). RSC values ranged from −3.809 to −0.646 epm with an average value of −1.330 in the study area (Table 1). All the groundwater samples were in the 'safe' category (Table 2). The spatial distribution of RSC is shown in Fig. 3b. A negative RSC value indicates that total CO_3^{2-} and HCO_3^- concentration is lower than the sum of Ca^{2+} and Mg^{2+} concentrations, reflecting that there is no residual carbonate present to react with Na^+ to increase sodium hazard in the soil (Islam et al., 2014). A value range of −1.5 to −0.5 dominated over the study area. A small area in the western part showed relatively low RSC values. Overall, the groundwater of the study area was suitable for irrigation in terms of RSC.

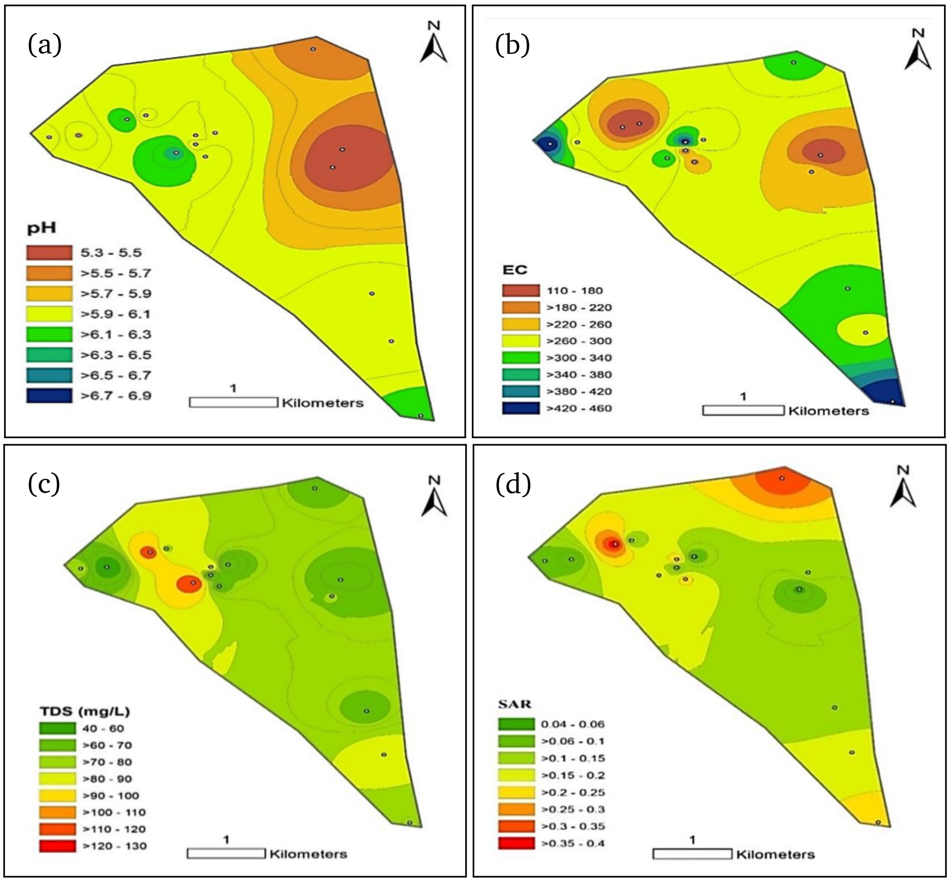

Figure 1. Spatial distribution of (a) pH, (b) electrical conductivity (EC), (c) total dissolved solids (TDS), and (d) sodium adsorption ratio (SAR) of groundwater in the study area

Magnesium adsorption ratio (MAR) MAR expresses the relationship between Mg and Ca concentration in groundwater (Raghunath, 1987; Ayuba et al., 2013). The presence of a large amount of Mg in water adversely affects soil quality by converting the soil into alkaline in nature thus reducing the crop yield (Khan and Abbasi, 2013). MAR greater than 50 is considered harmful and unsuitable for irrigation purposes (Kaçmaz and Nakoman, 2009). In this study, the MAR of the groundwater varied from 6.732 to 88.992 with an average value of 48.015 (Table 1). Among 15 groundwater samples, 5 water samples were in 'dangerous category' (>50). The results are in partial agreement with the findings of Nizam et al. (2014) and Hasan et al. (2016). The spatial distribution of MAR of groundwater shows that high MAR values prevailed in the north-western part of the study area (Fig. 3c). Therefore, caution must be taken before using groundwater for irrigation in this area.

Total hardness (TH) Hardness is an important criterion for determining the suitability of groundwater for domestic, agricultural and industrial uses (Vandenbohede et al., 2010). The hardness of water results from the abundance of divalent cations like Ca and Mg (Todd, 1980). The calculated TH of all the groundwater samples ranged from 33.958 to 189.664 ppm with a mean value of 67.339 ppm (Table 1). Among 15 samples, one sample was in moderately hard, one in hard and the remaining samples were in the soft category (Table 2). Fig. 3d demonstrates the spatial distribution of TH across the study area. The occurrence of hard groundwater was seen in the north-western part of the area and a decreasing trend in TH was evident from west to north-eastern part of the study area.

Kelly's ratio (KR) The level of Na measured against Ca and Mg is known as KR, based on which irrigation water can be rated (Kelley, 1963). The concentration of Na in irrigation water is considered to be in excess if KR is greater than 1, thereby making the water unsuitable. Hence water with KR <1 is suitable for irrigation. In this study, the value of KR varied from 0.019 to 0.204 (Table 1). Thus the groundwater of the study area was suitable for irrigation purpose.

Permeability index (PI) The PI of the groundwater samples ranged from 5.971 to 40.476% with a mean value of 20.865% (Table 1). Analytical data of PI values plotted on Donnen's diagram and revealed that

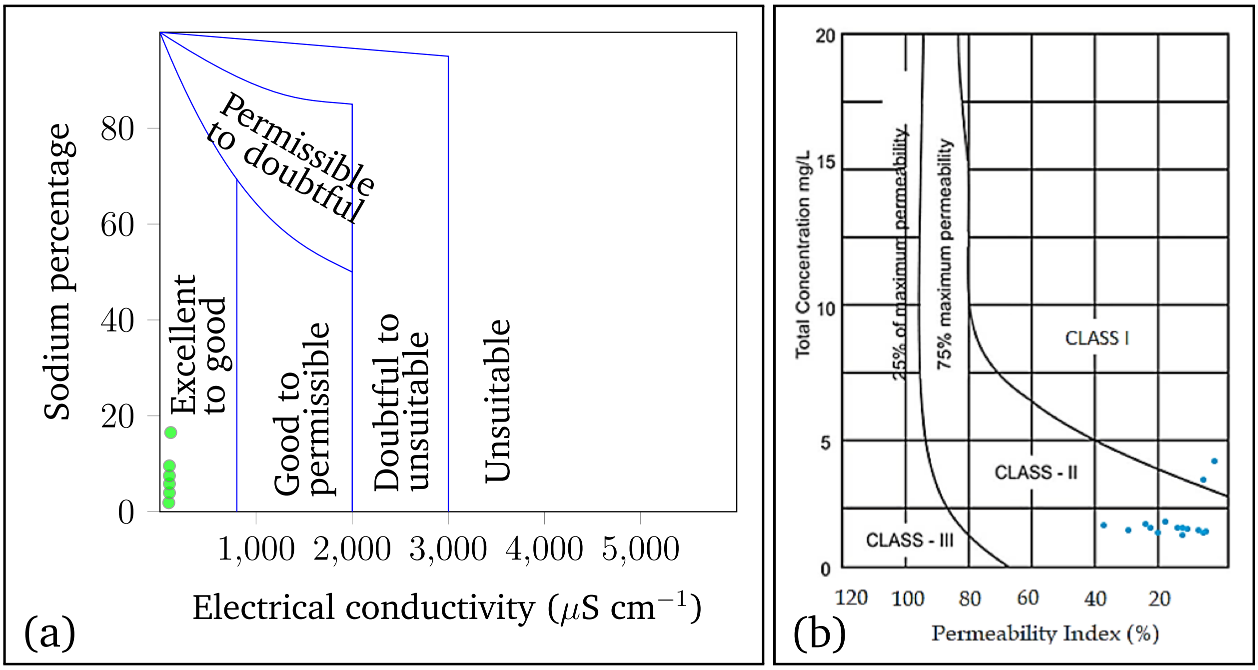

Figure 2. (a) Wilcox (Wilcox, 1955) diagram, and (b) Doneen's diagram (Doneen, 1964) for the classification of groundwater quality in the study area

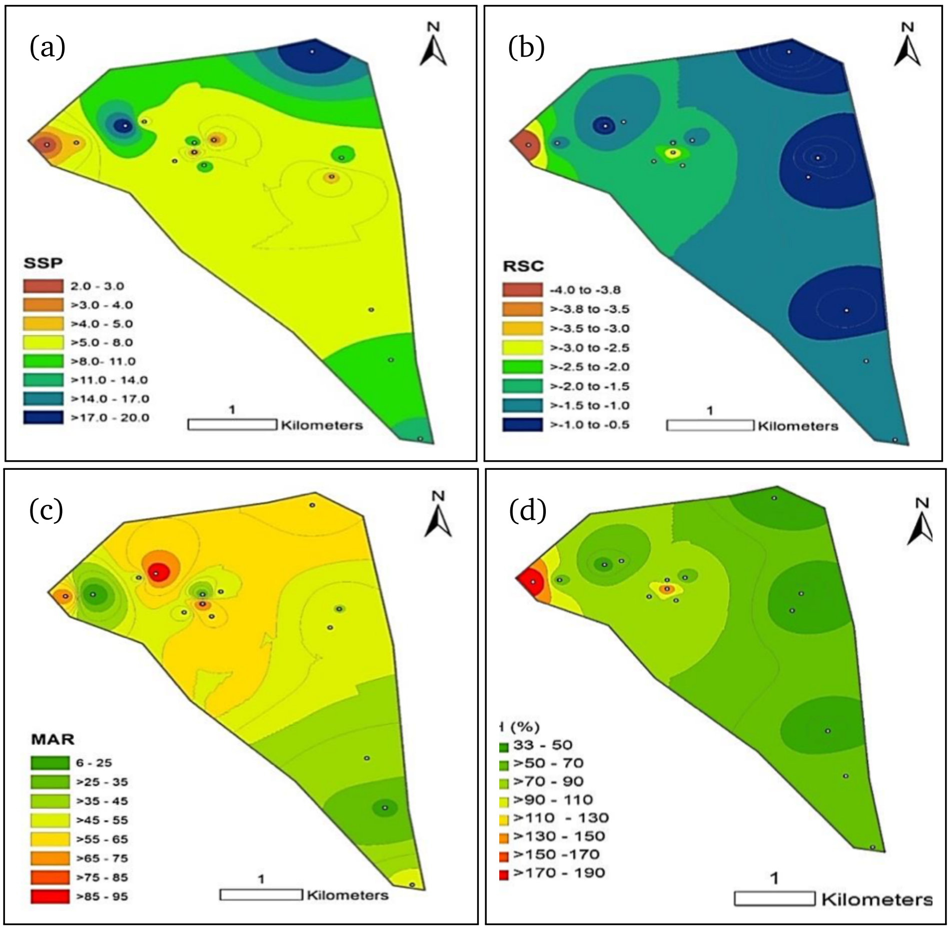

Figure 3. Spatial distribution of (a) soluble sodium percentage (SSP), (b) residual sodium carbonate (RSC), (c) magnesium adsorption ration (MAR), and (d) total hardness (TH) of groundwater in the study area

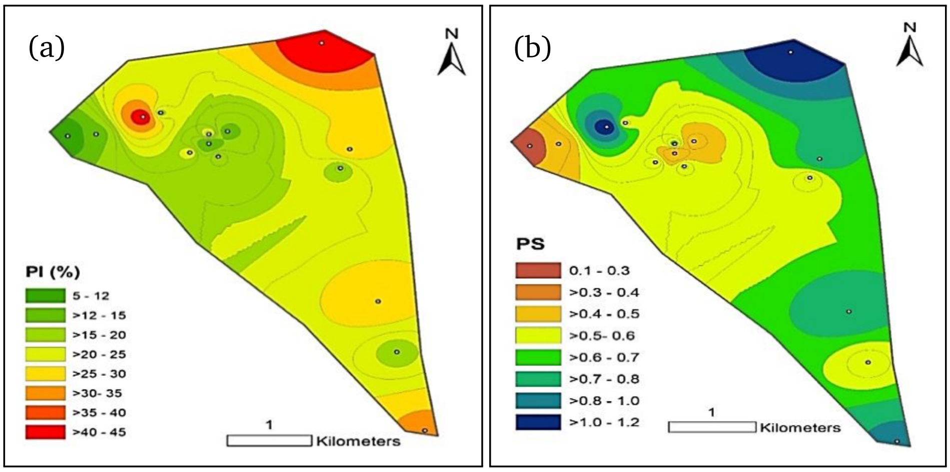

Figure 4. Spatial distribution of (a) permeability index (PI), (b) potential salinity (PS) of groundwater in the study area

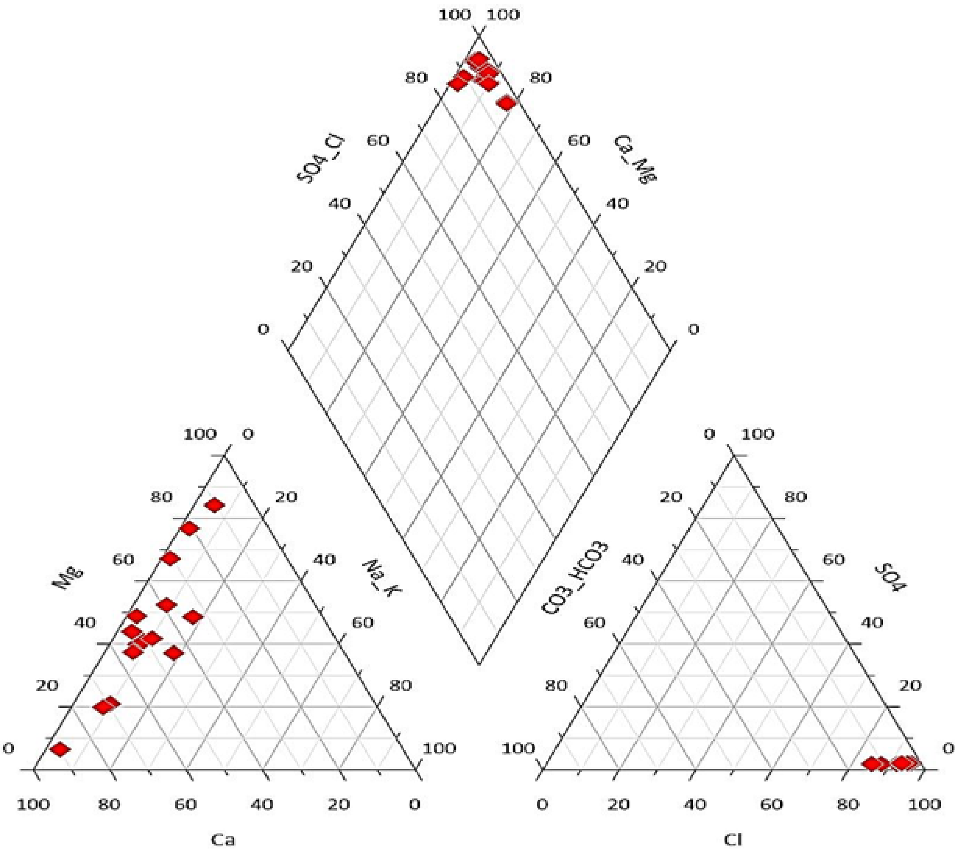

Figure 5. Piper diagram (Piper, 1944) of groundwater in the study area

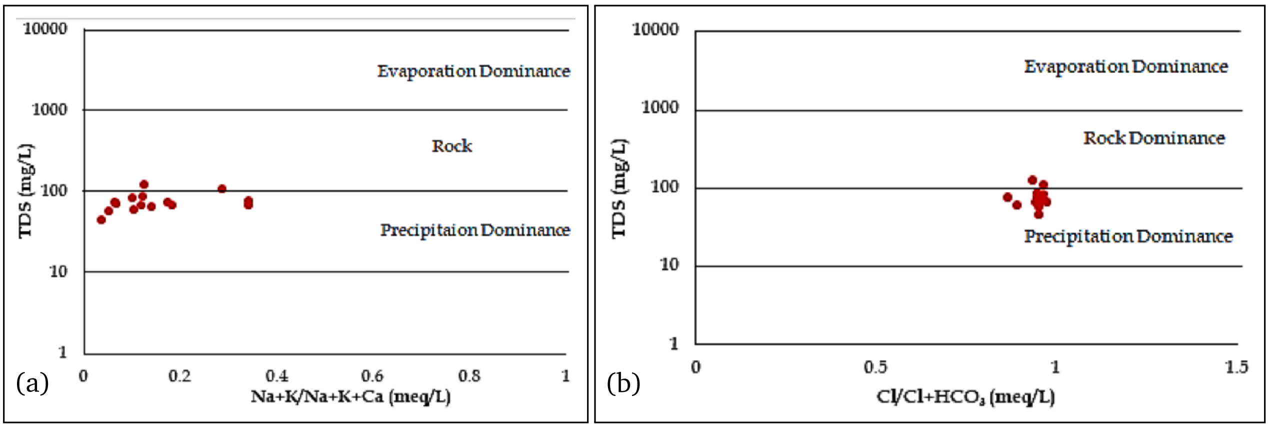

Figure 6. Gibbs diagram (Gibbs, 1970) for (a) cations and (b) anions of groundwater in the study area

87% of the groundwater samples fell in Class II and 13% fell under Class I categories (Fig. 2b). The waters of Classes I and II in the Doneen's diagram are generally good for irrigation purposes. So, the groundwater of the study area is good for irrigation. Spatial distribution of PI was shown in Fig. 4a. Relatively low PI values were observed in the north-western part of the study area.

Potential salinity (PS) The PS of the groundwater samples varied from 0.172 to 1.169 epm (Table 1). Doneen (1954) classified the PS of groundwater as following 3 classes: 'Excellent to Good (<5)', 'Good to Injurious (5-10)', 'Injurious to Unsatisfactory (>10)'. Based on the above classification, all the groundwater samples belong to the 'Excellent to Good' category. Results found by Islam et al. (2014) were in partial agreement with the present findings. Spatial distribution of PS is shown in Fig. 4b. The north-eastern part of the study area showed relatively high PS values.

Salinity hazard and alkalinity hazard Salinity hazard based on EC value can be classified into four groups: low salinity hazard, medium salinity hazard, high salinity hazard and very high salinity hazard. The alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations. According to the classification of irrigation waters (Richards, 1954), 7 groundwater samples were classified as C1-S1 (Excellent-Excellent) and 8 samples were classified as C2-S1 (Good-Excellent). The result revealed that no salinity or alkalinity hazard was found in the study area.

3.2 Interrelationship among the indices

The correlation coefficient (r) was calculated to find out the relationship between the quality parameters of the groundwater samples and between irrigation water quality indices, presented in Table 3 and Table 4, respectively. The value of r around zero reveals no relationship between the parameters (Srivastava and Ramanathan, 2007). The value around 1 shows a very strong correlation between the parameters. If the value of r is more than 0.7, it is considered as strongly correlated, whereas if its value ranges from 0.5 to 0.7, the parameters are moderately correlated, and in case of negative value, it implies that the value of one parameter is decreasing with the increase in another parameter (Giridharan et al., 2007).

A strong correlation was found between EC and TDS ($r = 0.863$). EC was also strongly correlated with Na^+ ($r = 0.816$) and HCO_3^- ($r = 0.75$). Ca^{2+}, Mg^{2+} and K^+ showed negative correlation with most of the parameters. Na^+ showed positive correlation with all of the parameters but strongly with HCO_3^- ($r = 0.839$). Cl^- showed a perfect correlation ($r = 1$) with SO_4^{2-} and PO_4^{3-}, might be caused due to the very low constituents of SO_4^{2-} and PO_4^{3-}. PI and PS demonstrated a perfect relationship ($r = 1$) and SSP showed strong correlations with KR ($r = 0.996$), PI ($r = 0.945$) and PS ($r = 0.945$). Overall, SAR-SSP, SAR-KR, SAR-PI, SAR-PS, KR-PI and KR-PS were strongly correlated with correlation coefficient value of greater than 0.8. MAR showed negative correlation with most of the parameters. The remaining other pairs showed moderately strong to weak correlation.

3.3 Classification of groundwater

Piper diagram The Piper diagram (Piper, 1944) was used to classify groundwater based on the distribution of cations and anions in groundwater. The concentrations of major cations and anions of collected water samples were plotted on a Piper diagram as shown in Fig. 5. It revealed that the dominance of the concentration of Ca^{2+} and Cl^- ions was found in the groundwater of the study area.

Gibbs diagram Gibbs diagram (Gibbs, 1970) was used to find the origin of ions in groundwater by fo-

Table 3. Correlation matrix of the chemical composition of groundwater samples

Variables	EC	pH	TDS	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}	PO_4^{3-}	HCO_3^-
EC	1										
pH	0.677	1									
TDS	0.863	0.501	1								
Ca^{2+}	−0.037	0.384	−0.006	1							
Mg^{2+}	−0.063	0.187	−0.102	0.223	1						
K^+	0.167	0.055	−0.132	0.066	−0.038	1					
Na^+	0.816	0.41	0.623	−0.04	−0.135	0.192	1				
Cl^-	0.4	−0.145	0.341	−0.544	−0.607	−0.008	0.654	1			
SO_4^{2-}	0.4	−0.145	0.341	−0.544	−0.607	−0.008	0.654	1	1		
PO_4^{3-}	0.4	−0.145	0.341	−0.544	−0.607	−0.008	0.654	1	1	1	
HCO_3^-	0.75	0.48	0.576	−0.171	−0.04	−0.049	0.839	0.592	0.592	0.592	1

Table 4. Correlation matrix of the irrigation water quality indices

Variables	EC	pH	TDS	SAR	SSP	RSC	MAR	KR	PI	PS
EC	1									
pH	0.677	1								
TDS	0.863	0.501	1							
SAR	0.708	0.208	0.548	1						
SSP	0.576	0.029	0.446	0.971	1					
RSC	0.074	−0.293	0.095	0.391	0.54	1				
MAR	0.074	−0.045	−0.02	−0.1	−0.127	−0.393	1			
KR	0.585	0.053	0.457	0.977	0.996	0.488	−0.095	1		
PI	0.4	−0.145	0.341	0.857	0.945	0.72	−0.137	0.931	1	
PS	0.4	−0.145	0.341	0.857	0.945	0.72	−0.137	0.931	1	1

cusing on the correlation between the concentrations of cations (Na^+, Ca^{2+}) and anions (Cl^-,HCO_3^-), and TDS. Fig. 6 shows that most of the cations and anions in groundwater had a precipitation dominance origin.

4 Conclusions

This study demonstrated that concentrations of the major ions and important physical parameters were within the permissible limits for irrigation. With some exception, the groundwater of the study area was suitable for irrigation in terms of pH. In respect of EC, groundwater was categorized as excellent to good class. The concentration of TDS in groundwater was in the acceptable limit for irrigation and the water remained between excellent to good class. In SAR scale, all of the samples were in excellent class, and the groundwater was safe in respect of residual sodium carbonate. The groundwater was classified as soft to the moderately hard category depending on total hardness. No salinity or alkalinity hazard was anticipated to the crops for using the groundwater for irrigation. The form of groundwater found in the study area was Ca^{2+} – Cl^- type. Therefore, it is finally inferred that the groundwater of the study area is suitable for irrigation purpose.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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