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Assessing groundwater stoichiometric composition and its suitability in Northwestern Bangladesh

Avaliação de lençol de água quanto a composição estioquiométrica e a sua conveniência do Noroeste do Bangladesh

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ABSTRACT

Groundwater quality analyses included pH, EC, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Zn^{2+}, Cu^{2+}, Mn^{2+}, Fe^{3+} and As^{3+}), anions (CO_3^{2-}, HCO_3^{-}, NO_3^{-}, SO_4^{2-}, PO_4^{3-} and Cl^{-}) and TDS of northwestern Bangladesh. The samples contained Ca^{2+}, Mg^{2+} and Na^{+} as the dominant cations and HCO_3^{-} and Cl^{-} were the dominant anions. Ratios of major cations and anions of water samples suggest the predominance of Ca and Mg-containing minerals over Na-containing minerals. According to TDS and SAR values, all samples were classed as 'freshwater' and 'excellent' categories. The SSP of all waters was under 'excellent' and 'good' classes. All samples were within 'soft' class regarding hardness with 'suitable' RSC. Based on As^{3+}, Zn^{2+}, Mn^{2+}, Fe^{3+}, SO_4^{2-}, NO_3^{-} and Cl^{-} all groundwater samples were within the 'safe' limit for drinking but unsuitable for some industries for specific ions.

Key words: *groundwater, suitability, northwestern Bangladesh.*

RESUMO

As análises de qualidade de Lençol de Água incluíram pH, EC, e os cations,(Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Zn^{2+}, Cu^{2+}, Mn^{2+}, $Fe^{3+\ e}$ As^{3+}), aníons (CO_3^{2-}, HCO_3^{-}, NO_3^{-}, SO_4^{2-}, PO_4^{3-} e Cl^{-}e TDS do noroeste do Bangladesh. As amostras continham Ca^{2+}, Mg^{2+} e Na^{+} e como o cations dominante HCO_3^{-} e Cl foram os aníons dominantes. Segundo o TDS e valores de SAR, todas as amostras foram classificadas como categorias 'de água doce' e 'excelentes'. O SSP de todas as águas foi nas classes 'excelentes' e 'boas'. Todas as amostras foram dentro da classe 'suave' quanto à dureza com RSC 'conveniente'. Baseado As^{3+}, Zn^{2+}, Mn^{2+}, Fe^{3+}, SO_4^{2-}, NO_3^{-} e Cl^{-} - todas as amostras de lençol de água foram dentro do limite 'seguro' como água de bebida mas impróprias para algumas indústrias que emprega íons específicos.

Palavras-chave: *lençol de água, conveniência, o Bangladesh do noroeste.*

INTRODUCTION

Groundwater resources support urban and rural communities in Bangladesh. As industrial and agricultural development of Bangladesh increases, the demand for water also steadily grows. Changes in groundwater quality are due to variation in climatic conditions, residence time of water, aquifer materials, and inputs from soil during percolation of water (KRISHNA KUMAR et al., 2009). Many hydrogeochemical processes have been highlighted in the control of the chemical composition of groundwater like carbonates and silicates weathering, and ion exchange (KRISHNA KUMAR et al., 2009; SUBBA RAO, 2008).

Groundwater contains a variety of chemical constituents at different concentrations. The greater part of the soluble constituents in groundwater comes from soluble minerals in soils and sedimentary rocks (WANTM, 2005). A much smaller part has its origin in the atmosphere and surface water bodies. For most groundwaters, 95% of the ions are represented by only a few major ionic species: the positively charged cations sodium (Na^{+}), potassium (K^{+}), calcium (Ca^{2+})

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and magnesium (Mg^{2+}), and the negatively charged anions chloride (Cl^-), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-) and nitrate (NO_3^-). TODD & MAYS (2005) suggested that, among the many ions which might be considered important as related to groundwater quality, Cl^-, Fe^{3+}, SO_4^{2-}, NO_3^-, Mn^{2+}, pH, TDS and hardness are the important chemical constituents to assess the suitability of water for industrial purposes. Therefore, the objective of the present research was to examine the concentrations of selected dissolved ions in groundwater and classify the waters according to their suitability for irrigation, drinking and industrial uses.

MATERIAL AND METHODS

Water sampling and analysis

Well water samples were collected in March and April 2012. Our sampling sites were 14 shallow tubewells, 15 hand tubewells and 15 deep tubewells. Samples were collected in two liter plastic bottles that had been cleaned with hydrochloric acid (1:1) and then rinsed with distilled water. Before collecting each sample, bottles were rinsed 3 to 4 times with sample. All reagents used in chemical analysis were of analytical grade. Samples were analyzed in Department of Agricultural Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur. For assessing the suitability classes for irrigation, domestic and industrial uses, we measured pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Zn^{2+}, Cu^{2+}, Mn^{2+}, Fe^{3+}, PO_4^{3-}, As^{3+}, CO_3^{2-}, HCO_3^-, SO_4^{2-}, NO_3^- and Cl^-All measured by the method of APHA, 1998 in the Soil Resources Development Institute, Dinajpur, Bangladesh. The ion-balance-error was computed, taking the relationship between the total cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and the total anions (HCO_3^-, Cl^-, SO_4^{2-}) for each set of complete analysis of water samples. Only samples which fall within ±5% were reported in this work.

Equations used in calculating water class rating parameters

The following formulae related to the irrigation water classes rating were used to classify water samples using the chemical data.

a) Sodium Adsorption Ratio (SAR), $SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$

b)Soluble Sodium Percentage (SSP),

$$SSP = \frac{\text{Soluble Na concentration (meq/L)}}{\text{Total cation concentration (meq/L)}} \times 100$$

c) Residual Sodium Carbonate (RSC) , $RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$

d) Hardness or Total Hardness (H_T), $H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$

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

f) Permeabili ty index $(P.I) = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+}$

RESULTS

Chemical composition of water samples

Some summary results from our survey of groundwater are shown in tables 2A and 2B. Details of the sampling sites are presented in table 1. Groundwater pH is a fundamental property that describes the acidity and alkalinity and largely controls the amount and chemical form of many organic and inorganic substances dissolved in groundwater. The pH of samples ranged from 5.4 to 5.9 (Table 2A). The EC and TDS ranged from 160 to 460 µS/cm and 95 to 287 mg/L, respectively. Concentrations of Na^+ and K^+ ranged from 0.36 to 1.17 meq/L and 0.17 to 0.48 meq/L, respectively. K^+ concentrations were generally lower than Na^+ concentrations. Ca^{2+} and Mg^{2+} were major cations in groundwater and ranged from 0.64 to 2.32 meq/L and 1.05 to 3.81 meq/L, respectively. NO_3^- and SO_4^{2-} concentrations were 0.10 to 1.65 mg/L and 0.007 to 0.096 meq/L, respectively. An appreciable amount of HCO_3^- was present in all water samples, though CO_3^{2-} was negligible in most cases. The range for HCO_3^- were 1.50 to 3.48 meq/L while Cl^- concentrations ranged from 0.65 to 2.25 meq/L. The order of the relative abundance of major cations, expressed in percent of meq/L, was Mg^{2+}(47.52%) > Ca^{2+}(30.63%) > Na^+(15.22%) > K^+(6.64%) while that of the anions was HCO_3^-(63.13%) > Cl^-(35.83%) > SO_4^{2-}(1.04%). The concentration of earth alkalis elements (Ca and Mg) represents 78.15% of total cations; this shows a high rock/water interaction in dry season. Fe^{3+}, Cu^{2+}, Zn^{2+} and Mn^{2+} concentrations varied from 0.0006 to 1.31 mg/L, 0.072 to 0.21 mg/L, 0.0006 to 0.048 mg/L and 0.0017 to 2.02 mg/L, respectively (Table 2B). The computed variable, hardness, varied from 100 to 300 mg/L. The potential salinity and permeability index values ranged from 0.66 to 2.30 meq/L and 0.37 to 0.74, respectively (Table 2A).

Stoichiometric relations

The Na-Cl relationship has often been used to identify the mechanisms for acquiring salinity and saline intrusions (JALALI, 2007). Most groundwater samples in this study had Na^+:Cl^- ratio lower than unity, while a few had Na^+:Cl^- ratio equal

Table 1- Information regarding of sampling sites of the Dinajpur Sadar Upazilla under the District of Dinajpur, Bangladesh; location, well type, depth, and the duration of uses

Sample	-------------------------------Sampling sites-------------------------------		Depth of sink (m)	Well type	Duration of uses (year)
No.	Location	Union (Small administrative unit)			
1	Daksin Balubari	Sadar	18	STW	10
2	Uttar Gobindapur	Chehelgazi	23	STW	15
3	Uttar Mohespur	Fazilpur	50	STW	12
4	Raniganj	Fazilpur	60	STW	14
5	Godabari	Sundarban	45	STW	20
6	Dighon	Sekhpura	73	STW	22
7	Nayanpur	Sadar	23	STW	14
8	Kismat Madhabpur	Shashara	43	STW	9
9	Masimpur	Auliapur	40	STW	15
10	Karimullapur	Auliapur	45	STW	14
11	Daksin Gosaipur	Uthrail	30	STW	20
12	Maligram	Uthrail	43	STW	24
13	Mollapara	Kamalpur	35	STW	17
14	Purba Mohonpur	Shankarpur	40	STW	18
15	Pourashova	Sadar	125	DTW	20
16	Daksinnagar	Sekhpura	125	DTW	15
17	Uttar Bhabanipur	Chehelgazi	125	DTW	17
18	Belbari	Sundarban	125	DTW	20
19	North Fazilpur	Fazilpur	110	DTW	14
20	Mahatulyapur	Shashara	135	DTW	10
21	Kaugan	Shashara	113	DTW	15
22	Mohabbatpur	Auliapur	110	DTW	17
23	Saidpur	Auliapur	85	DTW	20
24	Mohorampur	Auliapur	110	DTW	14
25	Gauripur	Askarpur	113	DTW	20
26	Daksin Gobindapur	Askarpur	155	DTW	15
27	Ramchandrapur	Uthrail	115	DTW	14
28	Daksin Bhabanipur	Kamalpur	115	DTW	10
29	Shankarpur	Shankarpur	125	DTW	18
30	Auliapur	Auliapur	75	HTW	19
31	Daskin Auliapur	Auliapur	70	HTW	15
32	Deotair	Sekhpura	60	HTW	14
33	North Chehelgazi	Chehelgazi	50	HTW	12
34	South Chehelgazi	Chehelgazi	48	HTW	9
35	East Sundarban	Sundarban	60	HTW	7
36	East Fazilpur	Fazilpur	53	HTW	14
37	West Fazilpur	Fazilpur	65	HTW	12
38	South Shashara	Shashara	50	HTW	13
39	Daksin Sadipur	Uthrail	30	HTW	14
40	East Shankarpur	Shankarpur	45	HTW	10
41	Muradpur	Uthrail	75	HTW	11
42	Jamalpur	Askarpur	60	HTW	12
43	Baragram	Kamalpur	62	HTW	14
44	West Shankarpur	Shankarpur	20	HTW	8

STW=Shallow tubewell, DTW= Deep tubewell, HTW= Hand tubewell

to one (Figure 1c). The weathering of silicates with carbonic acid (H_2CO_3) formed from interaction of atmospheric CO_2 with water or CO_2 coming from the decomposition of organic matter in the soil (SUBBA RAO, 2008), can be written as follows:(Na^+, Mg^{2+}, Ca^{2+}, K^+) silicates + $H_2O \rightarrow H_4SiO_4 + HCO_3^- + Na^+ + Mg^{2+} + Ca^{2+} + K^+$ + clays (1). In this study, all the groundwater samples had a ratio of Ca^{2+}: HCO_3^- +

Table 2 - A. pH, EC, TDS, hardness, potential salinity (PS), permeability index (PI) and anionic constituents of groundwater. B. Concentrations of cationic constituents of groundwater. C. Stoichiometric ratios of different major ions.

A	pH	EC	TDS	Hardness	Cl^-	PS	PI	HCO_3^-	SO_4^{-2}	NO_3^-	PO_4^{3-}
		µS /cm	mg/L	mg/L	meq/L	meq/L		meq/L	meq/L	mg/L	mg/L
Min	5.4	160	95	100	0.65	0.66	0.37	1.5	0.007	0.10	0.004
Max	5.9	460	287	300	2.25	2.30	0.74	3.48	0.096	1.65	0.275
Mean	5.6	280	171	177	1.40	1.42	0.56	2.46	0.040	0.57	0.057
SD	0.12	75	51	60	0.49	0.50	0.11	0.53	0.024	0.46	0.049

B	--------Ca^{2+}--------	Mg^{2+}	Na^+	K^+	Cu^{2+}	Zn^{2+}	Mn^{2+}	Fe^{3+}	As^{5+}
	meq/L	meq/L	meq/L	meq/L	mg/L	mg/L	mg/L	mg/L	mg/L
Min	0.64	1.05	0.36	0.17	0.072	0.0006	0.0017	0.0006	0.005
Max	2.32	3.81	1.13	0.48	0.21	0.05	2.02	1.31	0.032
Mean	1.40	2.18	0.70	0.30	0.14	0.02	0.26	0.06	0.018
SD	0.52	0.74	0.18	0.07	0.03	0.01	0.38	0.20	0.007

C

Ratios	Min	Max	Mean	SD
$(Ca^{2+}+Mg^{2+})$/Tcations	0.63	0.88	0.77	0.06
(Na^++K^+)/Tcations	0.12	0.36	0.23	0.06
Ca^{2+}/Mg^{2+}	0.46	1.91	0.66	0.22
Na^+/Ca^{2+}	0.20	1.08	0.55	0.21
$Na^+/(Na^+ + Cl^-)$	0.19	0.51	0.34	0.34
HCO_3^-/Na^+	1.92	7.42	3.70	3.69
$(HCO_3^- + SO_4^{2-})$/Tanions	0.55	0.73	0.65	0.05
Cl^-/Tanions	0.26	0.45	0.35	0.06

CO_3^{2-} and Mg^{2+}: HCO_3^- + CO_3^{2-} greater than unity while the ratio of Na^+: HCO_3^- + CO_3^{2-} were far below the unity suggesting the predominance of Ca and Mg-containing minerals over Na-containing minerals in the study area. As a result, the ratios of Ca^{2+} + Mg^{2+}: total cations of most of the water samples had ratios approaching unity while the ratios of Na^+ + K^+: total cations were far below unity (Figure 1a, 1b). In order to confirm the ion exchange process taking place, Na^+/Ca^{2+} and $Na^+/(Na^+ + Cl^-)$ ratios are also computed. In the study area, the groundwater showed Na^+/Ca^{2+} ratio between 0.20-1.08. The ratio of $Na^+/(Na^+ + Cl^-)$ varied in the range of 0.19-0.51 (Table 2C).

Water class ratings

Table 3 shows that out of 44 samples, 27 were rated as ‘good’ and 17 were as ‘excellent’ for irrigation purposes based on Wilcox requirement. According to Richards (RICHARDS, 1968), all irrigation waters were classified as C2S1 (27 samples) and C1S1 (17 samples) categories. C1 indicated ‘low’ salinity (EC < 250 µS/cm), C2 indicated ‘medium’ salinity (EC= 250-750 µS/cm), and S1 indicated ‘low sodium’ with respect to SAR. Irrigation with C1 and C2 class waters is unlikely to affect the osmotic pressure of the soil solution and the cell sap of the crop plants. Among the groundwater samples we collected, 39 were rated as ‘excellent’ and 5 were rated as ‘good’ according to Wilcox. Among the samples, 25 samples were classified as ‘hard’ and 19 samples were grouped as ‘moderately hard’ waters.

DISCUSSION

Stoichiometric evaluation of water samples

The sources of major cations, such as Ca^{2+} and Mg^{2+}, in groundwater can be the weathering of calcium and magnesium minerals (KRISHNA

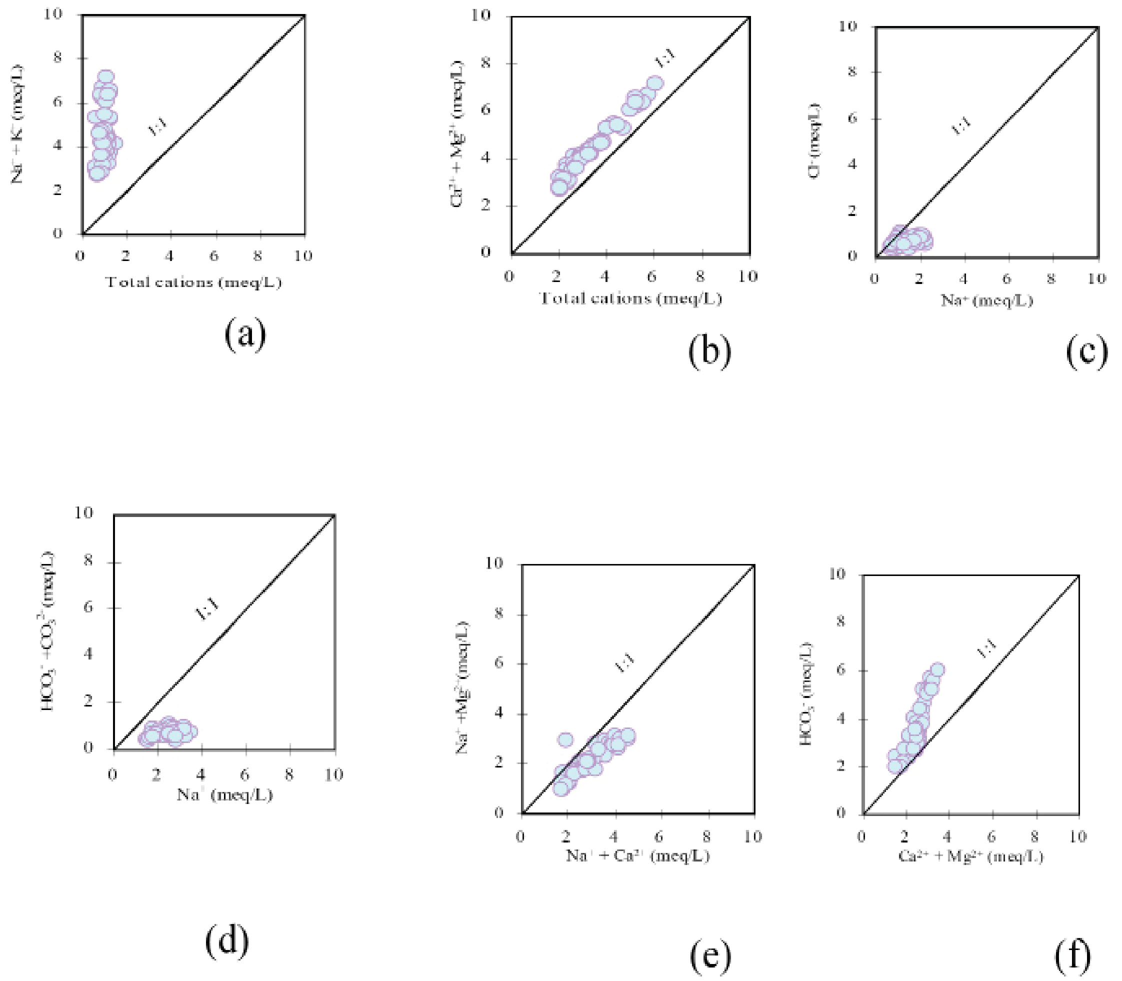

Figure 1 - Ratios of the major anions and cations in groundwater from Dinajpur Sadar Upazilla, Bangladesh.

KUMAR et al., 2009). In the areas of increased clay-rich soil dispersed and where Na^+ concentration is higher (YOUSAF et al., 1987), the Mg^{2+} concentration is relatively higher than that of Ca^{2+}. The ratio HCO_3^-: Na^+ can also be used to assess the weathering process (KRISHNA KUMAR et al., 2009) that occurs in groundwater. When the HCO_3^-: Na^+ ratio is greater than 1, carbonate weathering occurs, while a ratio A ratio of $Na^+/(Na^+ + Cl^-)$ higher than 0.5 had only one samples, suggesting that ion exchange process is very low. On the whole, the groundwater samples have the concentration of Na^+ higher than that of K^+ (Table 2A), because of the greater resistance of K^+ to chemical weathering and its adsorption on clay minerals (SUBBA RAO, 2008). This suggests that when there is lack of rain, the decomposition of organic matter by bacterial organisms in the soil would not provide the appropriate CO_2 to the rock/water interaction in dry season.

Suitability for irrigation

Plants intake water from soil by osmosis and osmotic pressure is proportional to the salt content, which affects the growth of plants, soil structure and permeability (GUPTA et al., 2009). SAR is an important parameter for the determination of the suitability of irrigation water because it is responsible for the sodium hazard (TODD AND MAYS, 2005). In our study, all water samples were suitable for growing crops according to TDS values (Table 2C). In addition to TDS, the relative abundance of sodium with respect to alkaline earths, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation. This excess is denoted by 'Residual sodium carbonate' (RSC). A negative

Table 3 - Quality classification of water samples for irrigation.

Sl	EC	Hardness	TDS	SAR	SSP	RSC	---------------------Water class based on---------------------						Alkalinity-
No	µS /cm	mg/L	mg/L				EC		TDS	SAR	SSP	RSC	salinity class
1	310	200	174	0.70	17	-2.83	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
2	160	120	98	0.59	15	-1.87	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
3	180	116	126	0.54	11	-4.27	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
4	190	132	106	0.98	18	-1.41	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
5	300	272	186	0.34	13	-4.49	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
6	240	172	168	0.57	11	-2.17	Ex	Hard	Fre	Ex	Ex	Suit	C1-S1
7	200	148	116	0.82	16	-2.34	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
8	210	116	130	0.33	5	-1.06	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
9	190	120	95	0.41	6	-0.77	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
10	340	260	163	0.40	8	-3.79	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
11	310	284	161	0.32	8	-4.48	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
12	310	232	174	0.25	5	-3.68	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
13	380	260	247	0.40	12	-4.27	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
14	450	300	284	0.43	13	-5.40	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
15	280	116	172	0.79	22	-1.79	Good	MH	Fre	Ex	Good	Suit	C2-S1
16	260	100	179	0.69	23	-1.37	Good	MH	Fre	Ex	Good	Suit	C2-S1
17	320	128	202	0.50	8	-1.35	Good	MH	Fre	Ex	Ex	Suit	C2-S1
18	180	100	103	0.37	5	-0.64	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
19	310	276	208	0.32	7	-4.04	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
20	390	260	269	0.59	9	-4.26	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
21	300	108	204	0.55	6	-0.63	Good	MH	Fre	Ex	Ex	Suit	C2-S1
22	210	160	118	0.67	23	-2.65	Ex	Hard	Fre	Ex	Good	Suit	C1-S1
23	200	144	128	0.68	10	-2.15	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
24	390	164	245	0.58	13	-2.35	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
25	270	132	153	0.55	13	-1.66	Good	MH	Fre	Ex	Ex	Suit	C2-S1
26	310	180	175	0.41	10	-2.55	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
27	330	216	191	0.53	14	-3.71	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
28	270	136	162	0.55	8	-1.46	Good	MH	Fre	Ex	Ex	Suit	C2-S1
29	220	100	142	0.48	6	-0.77	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
30	260	156	148	0.52	9	-1.60	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
31	230	148	122	0.62	11	-1.54	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
32	240	200	163	0.67	14	-3.19	Ex	Hard	Fre	Ex	Ex	Suit	C1-S1
33	220	148	146	0.56	12	-2.04	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
34	230	136	147	0.50	7	-2.09	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
35	290	188	203	0.54	23	-3.14	Good	Hard	Fre	Ex	Good	Suit	C2-S1
36	370	248	237	0.53	29	-4.35	Good	Hard	Fre	Ex	Good	Suit	C2-S1
37	260	192	159	0.45	7	-2.31	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
38	360	260	205	0.62	14	-3.86	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
39	460	258	287	0.53	14	-3.96	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
40	180	100	115	0.55	6	-1.04	Ex	MH	Fre	Ex	Ex	Suit	C1-S1
41	340	220	238	0.48	9	-3.19	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
42	250	164	130	0.54	17	-2.73	Good	Hard	Fre	Ex	Ex	Suit	C2-S1
43	210	160	111	0.51	12	-2.25	Ex	Hard	Fre	Ex	Ex	Suit	C1-S1
44	390	188	222	0.42	11	-2.81	Good	Hard	Fre	Ex	Ex	Suit	C2-S1

Ex = Excellent, Fre = Fresh, Suit = Suitable, MH=moderately hard.

RSC value indicates that the total concentration of CO_3^{2-} and HCO_3^- is lower than the sum of the Ca^{2+} and Mg^{2+} concentrations, reflecting that there is no residual carbonate to react with Na^+ to increase the Na hazard in the soil. Trace metals including Cu^{2+}, Zn^{2+}, Fe^{3+}, As^{3+}, Mn^{2+} were concentrations were low and considered to be suitable for crop production and the soil environment (AYERS AND WESTCOT, 1985).

Table 4 - Correlation matrix of different chemical constituents of groundwater, n=50, units of each parameter are in Table 2 and Table 3

	EC	TDS	Cl^-	HCO_3^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	SAR	SSP	H_T
EC	1.00											
TDS	0.95	1.00										
Cl^-	0.70	0.64	1.00									
HCO_3^-	0.66	0.60	0.75	1.00								
NO_3^-	0.02	0.06	-0.11	-0.06	1.00							
Ca^{2+}	0.77	0.69	0.92	0.81	-0.11	1.00						
Mg^{2+}	0.67	0.59	0.85	0.90	-0.02	0.82	1.00					
Na^+	0.13	0.16	0.34	0.32	-0.03	0.19	0.14	1.00				
K^+	0.03	0.11	-0.10	-0.16	-0.29	-0.09	-0.20	-0.08	1.00			
SAR	-0.26	-0.21	-0.20	-0.15	0.00	-0.30	-0.39	0.81	0.05	1.00		
SSP	0.10	0.13	0.14	0.18	-0.04	0.08	0.05	0.61	-0.02	0.57	1.00	
H_T	0.74	0.66	0.92	0.90	-0.06	0.94	0.97	0.17	-0.16	-0.37	0.07	1.00

Italic values are significant at p =0.05 where r ≥ 0.29

Based on permeability index (DONEEN, 1964), all waters were under Class I and Class II orders. Class I and Class II waters are categorized as good for irrigation with 75% or more of maximum permeability.

Correlations among the parameters

The correlation matrix of 12 parameters, for the 44 samples in the study area is indicated in table 2C. The high correlations between Cl^- and HCO_3^- (r= 0.75), and between Mg^{2+} and HCO_3^- (r= 0.90), between Mg^{2+} and Cl^- (r= 0.85) and between Ca^{2+} and Cl^- (r= 0.92) indicating that they most likely derive from the same source of water (Table 4). There was a good correlation between the conductivity and, Ca^{2+}, Mg^{2+}, Cl^- and HCO_3^-. The high correlation between EC and TDS reflects the interdependency of these measurements as general measures of the amount of total dissolved solutes.

Suitability for drinking and domestic uses

The pH of all groundwater samples was not within the safe limits prescribed for drinking water by WHO (2004). Higher concentration of SO_4^{2-} in drinking water is associated with respiratory problems (SUBBA RAO, 1993). Excess NO_3^- can cause methemoglobinemia, gastric cancer, birth malformations and hypertension. However, the concentrations of Na, Cl^- , SO_4^{2-} and NO_3^- of the studied groundwater samples were far below the recommended limits (Na^+= 200 mg/L, Cl^- =250 mg/L, SO_4^{2-}=150 mg/L, NO_3^-=10 mg/L) for drinking according to WHO (2004). In this study, all waters were under 'moderately hard' (43%) and 'hard' categories (57%).

Industrial rating of groundwater samples

The waters of the study area might not be suitable for brewing, tanning and laundering, where the recommended limits of pH are 6.5-7.0, 6.0-6.8 and 6.0-8.0, respectively (TODD AND MAYS, 2005). Based on chloride concentration, the percent suitability for brewing, carbonated beverage, dairy, sugar and textile industries were 100, 100, 9, 0 and 100, respectively. The TDS concentrations were not suitable for confectionery as the recommended limits of TDS for the above industry is 50-100 mg/L (USEPA, 1975). However, for confectionary and paper and pulp industries, the percent suitability were 5 and 70, respectively (Figure 2) while for brewing, carbonated beverage, dairy and ice manufacture industries, all waters were suitable. The allowable limits of Mn for various industries range from 0.05 to 1.0 mg/L except for sugar manufacture (TODD AND MAYS, 2005).

CONCLUSION

The water in the study area shows enrichment of magnesium and calcium among cations and of bicarbonate among anions. Based on the patterns we observed, it can be concluded that all the shallow tube well and deep tube well water samples of the Dinajpur Sadar Upazilla in the district of Dinajpur, Bangladesh were suitable for irrigation, drinking, domestic and industrial uses; although some samples were rated to be unsuitable for some specific industries for some specific ions.

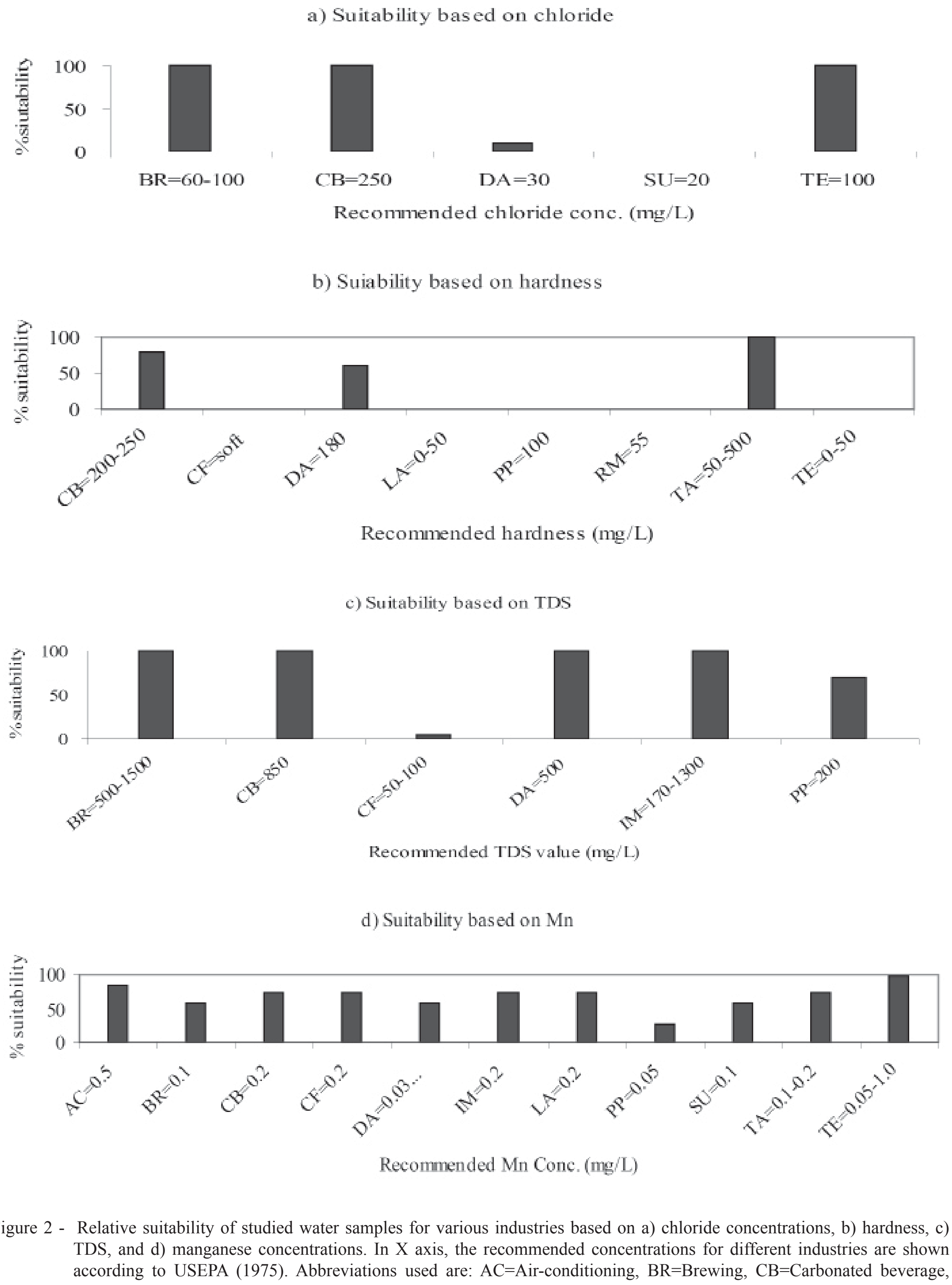

Figure 2 - Relative suitability of studied water samples for various industries based on a) chloride concentrations, b) hardness, c) TDS, and d) manganese concentrations. In X axis, the recommended concentrations for different industries are shown according to USEPA (1975). Abbreviations used are: AC=Air-conditioning, BR=Brewing, CB=Carbonated beverage, CF=Confectionary, DA=Dairy, IM=Ice manufacture, LA=Laundering, PP=Paper & pulp, SU=Sugar, TA=Tanning, TE=Textile, RM=Rayon manufacture.

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