

## ASSESSING QUALITY AND ITS SUITABILITY OF GROUNDWATER IN A COAL-MINING AREA

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### ABSTRACT

An experiment was conducted to assess the ionic concentrations of groundwater of some parts of a coal mining area at Phulbari Upazilla in the District of Dinajpur for the suitability of irrigation, drinking, industrial and domestic uses. The chemical analyses of water included pH, EC, cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Zn}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{P}^{5+}$  and  $\text{As}^{3+}$ ), anions ( $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$ ), TDS (total dissolved solids). The computed variables were SAR (sodium adsorption ratio), SSP (soluble sodium percentage) and hardness. The pH value (pH = 6.60-8.11) indicated that the waters were slightly acidic to neutral or slightly alkaline. Waters contained  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{HCO}_3^-$ , and  $\text{Cl}^-$  predominantly along with  $\text{Zn}^{2+}$  in lesser amounts.  $\text{Cu}^{2+}$ ,  $\text{Mn}^{2+}$  and  $\text{Fe}^{3+}$  were found trace to very little amount.  $\text{As}^{3+}$  and  $\text{SO}_4^{2-}$  were found trace to very little amount. Arsenic content of 2 samples were above the permissible limit ( $>0.05 \text{ mgL}^{-1}$ ). Based on  $\text{As}^{3+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{NO}_3^-$  and  $\text{Cl}^-$  all waters were within the 'safe' limit for drinking but unsuitable for some industries for specific ions. TDS and SAR values reflected that all waters were under 'freshwater' and 'excellent' class respectively. SSP of most waters was under 'excellent', 'good', and 'permissible' classes. SAR and EC categorized the waters as C1-S1 and C2-S1 except one C3-S1 and one C4-S1.

*Keywords: Groundwater, Irrigation, Drinking, Industrial uses, Coal-mined area*

### INTRODUCTION

Groundwater is a critical source for irrigation, drinking and industrial uses in the northern Bangladesh especially in the Phulbari Upazilla under the district of Dinajpur. Though the groundwater are seems to be pure and free from suspended materials compared to surface water, the various ions are present in varying amounts. Sometimes, these ions are present in toxic levels and can be considered as pollutants. Water of desirable quality is absolutely essential for irrigation, drinking and domestic uses, and various industrial processes. Irrigation water affects in different ways depending upon original water quality, types of soil, underlying geology, types of irrigation, crops grown, and farming methods used. Soil properties, crop yield and quality will deteriorate if low quality water is used for irrigation (Prunty *et al.*, 1991). Most of the water available for irrigation shows a high electrical conductivity (EC) value that results in a very high salinity hazard and a sodium adsorption ratio (SAR) associated with Na hazard. Salts from the irrigation water are accumulated in soil profiles and lead to soil dispersion and surface seal development during irrigation, thus decreasing the infiltration rate and amount (Agassi *et al.*, 1981).

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The Phulbari coal deposits (approximately 400 Mt) are located in the low lying areas of the alluvial plain which are generally submerged under water. The peat occurs at the surface or at shallow depths below the surface. The mining area in the Phulbari Basin covers an area of 8 km (north-south) by 3 km (east-west) with coal seam(s) varying between 15-70 m thick at some 150-270 m beneath the surface, with average combined thickness of 38 m (Anonymous, 2008). Moreover, the Phulbari 'open pit' operation requires the mine area to be completely dewatered so that the hollow of the mine does not get immersed in water. When dewatering will start for the mining, the shallow and deep tube wells will not draw enough water for farmers in the larger area near the mine.

Several researchers (Rahman and Zaman, 1995; Zaman and Majid, 1995; Quddus and Zaman, 1996) reported that  $\text{HCO}_3^-$ ,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Cl}^-$  were the dominant ions in groundwater collected from different regions of Bangladesh. On the other hand, if the polluted waters are used for various industrial purposes, quality of products will be deteriorated. A substantial amount of Fe was present in groundwater which appeared unsuitable for baking, brewing and distilling, carbonated beverages, confectionery, paper and pulp, tanning, textile, laundering, synthetic rubber, ice manufacture sugar and dairy industries (Islam *et al.*, 1998).  $\text{Cl}^-$ ,  $\text{Fe}^{3+}$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Mn}^{2+}$ , pH, TDS and hardness are the important parameters among the chemical characteristics to assess the suitability of water for industrial purposes (Todd, 1980). The objective of the present research was to assess the concentrations of dissolved ions in order to classify the waters in accordance with their suitability for irrigation, drinking and industrial uses.

## MATERIALS AND METHODS

Water samples were collected randomly from some parts of the Phulbari Upazilla under the district of Dinajpur. The study was conducted during the period February, March and April, 2006. From each sampling site, sample was collected in each month. The time schedule for sampling was chosen as the groundwater levels lower down due to heavy abstraction of groundwater and low/no precipitation during this period. Within the study area, 40 sites were selected for collecting representative water samples of which 35 shallow tubewells, 3 deep tubewells and 2 hand tubewells. Details of the sampling sites for different sources of waters have been shown in Figure 1 and Table 1. Water samples were collected following the techniques outlined by Hunt and Wilson (1986) and APHA (1998). The water samples were collected in 2 liter plastic bottles. These bottles were cleaned with dilute hydrochloric acid (1:1) and then washed with tap water followed by distilled water. Before sampling, containers were again rinsed 3 to 4 times with water to be sampled. The water carried to the laboratory of the department of Agricultural Chemistry and Biochemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh for testing. The samples were analyzed as quickly as possible on arrival at the laboratory.

In order to assess the suitability for irrigation, drinking and industrial uses, the important chemical constituents of surface water like pH, (EC), (TDS),  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Zn}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{PO}_4^{3-}$ ,  $\text{As}^{3+}$ ,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and  $\text{Cl}^-$  were considered. All bottles and glasswares used were cleaned with P-free detergent (Extrans), rinsed three times with ultra-pure water (Milli-Q), soaked in 10% (v/v) HCl for at least 24 h, and finally rinsed three times with ultra-pure water. The

Table 1. Information regarding of sampling site; location, well type, depth, and the duration of uses

Sl. No.	Location	Upazilla	Depth of sink (m)	Well type	Duration of uses (year)
1.	Baraipara	Phulbari	24.38	Shallow tube well	5
2.	Maddhapara	Phulbari	18.28	Shallow tube well	10
3.	Garpillai	Phulbari	13.71	Shallow tube well	2
4.	Lalmati	Phulbari	18.28	Shallow tube well	1
5.	Baraipara	Phulbari	30.48	Deep tube well	7 months
6.	Kholapara	Phulbari	24.38	Shallow tube well	10
7.	Polypara	Phulbari	30.48	Deep tube well	20
8.	Harharia	Phulbari	18.28	Shallow tube well	2
9.	Maddampara	Phulbari	24.38	Shallow tube well	10
10.	Daulatpur	Phulbari	9.14	Hand tube well	6
11.	Daulatpur	Phulbari	36.57	Deep tube well	12
12.	Maddampara	Phulbari	24.38	Shallow tube well	2
13.	Siriharipur	Phulbari	19.81	Shallow tube well	2 months
14.	Aladipur	Phulbari	12.19	Shallow tube well	2 months
15.	Jiadgaram	Phulbari	22.86	Shallow tube well	5
16.	Rangamati	Phulbari	18.89	Shallow tube well	13
17.	Aladipur	Phulbari	24.38	Shallow tube well	2 months
18.	S. Ragnagpur	Phulbari	24.38	Shallow tube well	4
19.	Kurmut	Phulbari	22.86	Shallow tube well	8
20.	Rangamati	Phulbari	21.33	Shallow tube well	7
21.	Senera	Phulbari	27.43	Shallow tube well	10
22.	Shatpur	Phulbari	19.81	Shallow tube well	3
23.	Rangamati	Phulbari	19.81	Shallow tube well	7
24.	Barai	Phulbari	19.81	Shallow tube well	7
25.	Rangamati	Phulbari	10.66	Hand tube well	19
26.	Sonkarpur	Phulbari	51.81	Deep tube well	7
27.	Nandigaram	Phulbari	60.96	Deep tube well	1
28.	Daldalia	Phulbari	51.81	Deep tube well	1
29.	Nandigaram	Phulbari	57.91	Deep tube well	20
30.	Khandakhui	Phulbari	51.81	Deep tube well	6
31.	Daldalia	Phulbari	57.91	Deep tube well	24
32.	Nurkhanpur	Phulbari	54.86	Deep tube well	20
33.	Anaatpur	Phulbari	54.86	Deep tube well	16
34.	Khandakhui	Phulbari	30.48	Deep tube well	20
35.	Kamalpur	Phulbari	85.34	Deep tube well	28
36.	Baronagar	Phulbari	85.34	Deep tube well	18
37.	Gangapur	Phulbari	53.03	Deep tube well	5
38.	Nandigaram	Phulbari	22.86	Shallow tube well	6
39.	Jorotpur	Phulbari	51.20	Deep tube well	23
40.	Middle Rudrani	Phulbari	21.33	Shallow tube well	8

pH and electrical conductivity (EC) were determined electrometrically (APHA, 1998). TDS was estimated after Chopra and Kanwar (1980).  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  were analyzed by complexometric titration (Page *et al.*, 1982) whereas  $\text{K}^+$  and  $\text{Na}^+$  were estimated by flame emission spectrophotometer (Ghosh *et al.*, 1983).  $\text{SO}_4^{2-}$  was determined turbidimetrically (Wolf, 1982) while  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$ , were analyzed titrimetrically (Chopra and Kanwar, 1980; Ghosh *et al.*, 1983). Chloride was estimated by argentometric titration (APHA, 1998; Ghosh *et al.*, 1983) and  $\text{PO}_4^{3-}$  and  $\text{NO}_3^-$  were determined colorimetrically (APHA, 1998). Arsenic was determined by atomic absorption spectrophotometer equipped with hydride generator (APHA, 1998).  $\text{Zn}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Mn}^{2+}$  and  $\text{Fe}^{3+}$  were analyzed by atomic absorption spectrophotometer (APHA, 1998) in the laboratory of Soil Chemistry Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. A Perkin–Elmer Analyst 100 atomic absorption spectrophotometer equipped with a FIAS-100-flow injection hydride generation system was used for all arsenic determination. All samples were pre-reduced with concentrated HCl (1 ml), 5% KI and ascorbic acid mixture prior to hydride generation.

The following formulae related to the irrigation water classes rating were computed from the data obtained by chemical analyses of water samples.

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

$$\text{b) Soluble Sodium Percentage (SSP): } SSP = \frac{\text{Soluble Sodium Percentage}}{\text{Total Calcium Concentration}} \times 100$$

$$\text{c) Hardness or Total Hardness (H}_T\text{): } H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$$

Where, concentrations of ionic constituents for calculating all parameters are in  $\text{meq L}^{-1}$  except hardness ( $\text{mg L}^{-1}$ ).

## RESULTS AND DISCUSSION

**Suitability for irrigation uses based on pH, EC, SAR and SSP:** The concentration and composition of the dissolved salts varied depending on the location and sources of irrigation water. Some waters contained low concentrations of chemical component while others high concentrations. Most of the samples were alkaline in nature as the pH values were above 7 which might be due to the presence of relatively significant amounts of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  in the water (Michael, 1978; Rao *et al.*, 1982). In the present study, the higher concentrations of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  confirmed the higher pH value of the water. Depending on pH, all the waters were suitable for irrigation since the accepted limit is in the range of 6.0-8.5 for agriculture (Ayers and Westcot, 1985). A significant variation in the EC values detected ranging from 217-1384  $\mu\text{S cm}^{-1}$  at 25 to 28°C (Table 2). Higher EC values reflected the higher salt concentrations that may affect the irrigation water quality in relation to salinity hazard (Agarwal *et al.*, 1982). Table 4 indicated that out of 40 samples 29 samples were rated as good, 7 were as 'permissible' and 4 were as 'excellent' for irrigation purposes according to Wilcox (1955).

If high salinity water is used for a long period of time, the soil profile, especially the root zone might be affected by the accumulation of salts which would ultimately reduce yields. As the total

concentration of salts increases into the saline sodic range, concentrations of  $\text{Ca}^{+2}$  are adequate for most plants and osmotic effects begin to predominate. However, some species are susceptible to salinity induced by  $\text{Ca}^{+2}$  deficiencies. Some cultivars of corn, sorghum, rice, wheat and barley exhibit a severe deficiency in  $\text{Ca}^{+2}$  at a high  $\text{Na}^+/\text{Ca}^{+2}$  ratios (Grieve and Fujiyama, 1987). SSP is an important criterion of the soil physical properties and can affect plant growth. Water with a SSP greater than 60 percent may result in sodium accumulations that will cause a breakdown in the soil's physical properties. Among the collected waters 32 were rated as excellent, 7 were rated as good and 1 was rated as doubtful in Table 4 according to Wilcox (1955). Water belonging to the excellent, good and permissible categories may be used for irrigation purposes. Doubtful waters were considered to be harmful and unsuitable for crop cultivation. Doubtful water contained as much as 60 to 80% soluble Na. Natural occurrence of Na enriched minerals in the parent and geochemical process during the course of flow may account for the high Na concentration since there was an absence of point and non-point sources in this location. As a result, the soil environment may undergo deterioration due to the accumulation of a high concentration of soluble Na resulting in crust formation and seal development on the soil surface over a long period of time. Thus, if such waters are used for irrigation, they are likely to be polluted. Sodium toxicity is often modified and reduced if Ca and Mg are also present. Moderate amounts of Ca and Mg may reduce Na damage and higher amounts even prevent it. Since the effect of Na is dependent on the Na, Ca and Mg concentrations, a reasonable evaluation of the potential toxicity is possible using the adjusted sodium adsorption ratio (SAR), which is a ratio of the Na vs. Ca and Mg in the irrigation water (Sawyer and McCarty, 1967).

According to Richards (1968), all irrigation waters were under C2S1 with two C1S1, one C3S1 and one C4S1 categories. C1 indicated 'low' salinity ( $\text{EC} < 250 \mu\text{Scm}^{-1}$ ), C2 indicated 'medium' salinity ( $\text{EC} = 250\text{-}750 \mu\text{S cm}^{-1}$ ), C3 indicated 'high' salinity ( $\text{EC} = 750\text{-}2250 \mu\text{S cm}^{-1}$ ), and C4 indicated 'very high' salinity ( $\text{EC} > 2250 \mu\text{Scm}^{-1}$ ), and S1 indicated 'low Na' 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. Considering the SAR values, all the samples were classified as excellent for crop irrigation and would not affect the soil environment. Both a low salt content (low EC) and high SAR can mean 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 responsible for aeration and drainage (Grattan, 2002). If these waters were used for irrigation purposes, alkali hazard might not occur and crops may grow without any deleterious effect on the soil. In our study all waters were suitable based on SAR value (Table 2).

#### **b) Suitability for irrigation uses based on TDS, $\text{H}_\text{T}$ , $\text{Cl}^-$ and $\text{NO}_3^-$ , $\text{PO}_4^{-3}$ and semi-heavy metals**

The TDS values ranged from 107-831 with an average value of  $286.78 \text{ mg L}^{-1}$ . All the waters except one were graded as fresh, based on the criteria of Freeze and Cherry (1979). It may be difficult for plants to absorb water containing more than  $1,000 \text{ mgL}^{-1}$  TDS. Several processes may lead to a higher content of dissolved solids in groundwater such as flow through rocks containing soluble mineral matter or concentration by evaporation (Karanth, 1994). In our study, almost all

Table 2. Quality classification of water samples for irrigation

Sl. No.	EC $\mu\text{Scm}^{-1}$	TDS $\text{mgL}^{-1}$	SAR	SSP	Alkalinity and salinity hazard class				
					EC	TDS	SAR	SSP	
1	217	107	0.22	11.92	Ex	Fre	Ex	Ex	C2-S1
2	692	449	0.59	16.27	Good	Fre	Ex	Ex	C2-S1
3	295	203	0.66	26.11	Good	Fre	Ex	Good	C2-S1
4	379	250	0.55	20.00	Good	Fre	Ex	Good	C2-S1
5	242	156	0.10	5.46	Ex	Fre	Ex	Ex	C2-S1
6	294	176	0.67	26.20	Good	Fre	Ex	Good	C2-S1
7	749	481	0.83	21.34	Good	Fre	Ex	Good	C1-S1
8	273	155	0.12	5.88	Good	Fre	Ex	Ex	C2-S1
9	228	140	0.14	7.58	Ex	Fre	Ex	Ex	C2-S1
10	617	397	0.09	3.09	Good	Fre	Ex	Ex	C2-S1
11	241	140	0.15	7.59	Ex	Fre	Ex	Ex	C2-S1
12	299	177	0.64	24.40	Good	Fre	Ex	Good	C2-S1
13	258	146	0.19	9.84	Good	Fre	Ex	Ex	C2-S1
14	550	324	0.40	13.00	Good	Fre	Ex	Ex	C2-S1
15	411	246	0.31	11.54	Good	Fre	Ex	Ex	C2-S1
16	564	327	0.42	13.39	Good	Fre	Ex	Ex	C1-S1
17	439	250	0.24	8.96	Good	Fre	Ex	Ex	C2-S1
18	508	278	0.38	12.89	Good	Fre	Ex	Ex	C2-S1
19	473	284	0.24	8.52	Good	Fre	Ex	Ex	C2-S1
20	424	231	0.21	8.33	Good	Fre	Ex	Ex	C2-S1
21	464	255	0.16	6.08	Good	Fre	Ex	Ex	C2-S1
22	504	296	0.27	9.06	Good	Fre	Ex	Ex	C2-S1
23	550	324	0.40	13.00	Good	Fre	Ex	Ex	C2-S1
24	502	291	0.25	9.03	Good	Fre	Ex	Ex	C2-S1
25	571	341	0.39	12.52	Good	Fre	Ex	Ex	C3-S1
26	1384	831	5.40	63.76	Permi	Fre	Ex	Dou	C4-S1
27	427	271	0.28	10.40	Good	Fre	Ex	Ex	C2-S1
28	559	343	0.38	12.61	Good	Fre	Ex	Ex	C2-S1
29	481	276	0.38	12.99	Good	Fre	Ex	Ex	C2-S1
30	337	214	0.68	24.92	Good	Fre	Ex	Good	C2-S1
31	306	168	0.74	27.48	Good	Fre	Ex	Good	C2-S1
32	242	156	0.10	5.46	Ex	Fre	Ex	Ex	C2-S1
33	538	320	0.41	13.48	Good	Fre	Ex	Ex	C2-S1
34	571	341	0.39	12.52	Good	Fre	Ex	Ex.	C2-S1
35	481	282	0.40	13.83	Good	Fre	Ex	Ex	C2-S1
36	487	312	0.41	14.07	Good	Fre	Ex	Ex	C2-S1
37	642	415	0.51	15.04	Good	Fre	Ex	Ex	C2-S1
38	710	417	0.34	10.19	Good	Fre	Ex	Ex	C2-S1
39	504	296	0.27	9.60	Good	Fre	Ex	Ex	C2-S1
40	614	387	0.40	12.45	Good	Fre	Ex	Ex	C2-S1

Legend: Ex = Excellent; Fre = Fresh; Suit = Suitable; Bra = Brackish; Permi = Permissible

the water samples were suitable for growing crops. Sawyer and McCarty (1967) classified irrigation water into four categories on the basis of hardness. According to this classification, 'very hard' (>300 mgL<sup>-1</sup> as CaCO<sub>3</sub>), 'hard' (150-300 mgL<sup>-1</sup> as CaCO<sub>3</sub>) and 'moderately hard' (75-150 mgL<sup>-1</sup> as CaCO<sub>3</sub>) samples were observed in the study area (data not shown). Natural enrichment of significant amounts of soluble Ca<sup>+2</sup> and Mg<sup>+2</sup> in the water samples may be the possible cause of very hard water and polluted water bodies with excessive amounts of dissolved Ca<sup>+2</sup> and Mg<sup>+2</sup> waters can be considered to be suitable for irrigation. Dissolved Ca<sup>+2</sup> in water is responsible for water hardness since it reduces the soil acidity and replenishes Ca<sup>+2</sup> for crop nutrition (Tan, 1994). Chloride is not adsorbed by soils but moves readily with the soil water. It is taken up by the roots and moves upward to accumulate in the leaves. According to Ayers and Westcot (1985) the recommended concentration of chloride is 4.0 me L<sup>-1</sup>. But in study area the chloride ranges from 0.09-8.30 meL<sup>-1</sup> (Table 2). In these samples 6 samples exceeded this limit and may threaten for crop production which can produce the typical symptoms of leaf burn or drying of leaf tissues at the extreme leaf tip of older leaves and progress back along the edges as severity increases. Excessive leaf burn is often accompanied by abnormal early drop and defoliation. The NO<sub>3</sub>-N contained in underground water ranges from 0.1-1.65 mgL<sup>-1</sup> in collected water samples. Nitrogen in the irrigation water acts the same as fertilizer N and excess will cause problems just as fertilizer excesses cause problems. NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>3-</sup> are considered to be important parameters because of their synergistic effect on plant nutrition and potential adverse effect on water contamination. In the study area, the concentration of semi-heavy metal and NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>3-</sup> were within the safety limits for irrigation. Some semi-heavy metals like Cu<sup>2+</sup>, Zn<sup>2+</sup>, Fe<sup>3+</sup>, As<sup>3+</sup> and Mn<sup>2+</sup> were examined but their relative distribution was very low (Table 3) and considered to be suitable for crop production and the soil environment (Ayers and Westcot, 1985).

**Correlation matrix among the chemical constituents with depth:** There were no good relations of different water quality parameters with depth but highly significant correlations of EC and TDS with other water quality parameters reflects the proportionality of different anions and cations (Table 4). Significant positive correlation ( $r = 0.91$ )

Table 5 Correlation matrix among the different water quality parameters

	Depth	EC	TDS	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	SAR
EC	0.082									
TDS	0.090	<i>0.992</i>								
Cl	0.085	<i>0.885</i>	<i>0.890</i>							
HCO <sub>3</sub>	0.073	<i>0.813</i>	<i>0.837</i>	<i>0.532</i>						
Ca	-0.061	<i>0.677</i>	<i>0.675</i>	<i>0.336</i>	<i>0.888</i>					
Mg	-0.077	<i>0.676</i>	<i>0.672</i>	<i>0.335</i>	<i>0.878</i>	<i>0.924</i>				
Na	0.174	<i>0.791</i>	<i>0.778</i>	<i>0.921</i>	<i>0.350</i>	0.109	0.099			
K	0.120	<i>0.747</i>	<i>0.773</i>	<i>0.845</i>	<i>0.465</i>	0.228	0.176	<i>0.813</i>		
SAR	0.179	<i>0.734</i>	<i>0.722</i>	<i>0.894</i>	0.277	0.024	0.014	<i>0.995</i>	<i>0.805</i>	
SSP	0.197	<i>0.548</i>	<i>0.550</i>	<i>0.746</i>	0.142	-0.134	-0.179	<i>0.871</i>	<i>0.836</i>	<i>0.906</i>
H <sub>T</sub>	-0.072	<i>0.689</i>	<i>0.685</i>	<i>0.342</i>	<i>0.898</i>	<i>0.972</i>	<i>0.988</i>	0.105	0.199	0.018

Italic values are significant at  $p = 0.05$  where  $r \geq 0.325$

observed between SSP and SAR reflects that the sodium adsorption ratio by soil particles may or will increase with the amount of soluble Na and will create alkali hazard in soil and hinder successful crop production. The correlation between EC and TDS ( $r = 0.99$ ) is due to the fact that conductivity depends TDS. However, the relationship between EC and TDS indicates the increase of one element will or may increase the concentration of the other and synergistic behavior amongst the dissolved ions in water.

### **Suitability for drinking and domestic uses**

The  $p^H$  (6.60-8.11) of the samples is within the safe limits prescribed for drinking water by WHO (1984). The recommended concentration of TDS is  $500 \text{ mg L}^{-1}$  (WHO, 1984) and 1 sample was above the recommended limit (Table 4). Concentrations of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions increase total hardness. Such waters can develop scales in water heaters, distribution pipes and well pumps, boilers and cooking utensils, and require more soap for washing clothes (Todd, 1980; Karanth, 1994). In drinking water, excess concentration of some nutrients can cause health hazard. For example, the concentration  $\text{Na}^+$  should not exceed  $200 \text{ mgL}^{-1}$ . A Na-restricted diet is recommended to patients suffering from hypertension or congenial heart diseases and also from kidney problems. For such people, extra intake of  $\text{Na}^+$  through drinking water may prove critical (Holden, 1971). Excess concentration of  $\text{Cl}^-$  gives a salty taste and has a laxative effect in people not accustomed to it. Higher concentration of  $\text{SO}_4^{2-}$  in drinking water is associated with respiratory problems (Maiti, 1982; Subba Rao, 1993). In combination with  $\text{Na}^+$  and  $\text{Mg}^{2+}$ ,  $\text{SO}_4^{2-}$  also exerts a cathartic effect on digestive tracts. Excess  $\text{NO}_3^-$  can cause methemoglobinemia, gastric cancer, birth malformations and hypertension. However, the concentrations of  $\text{Na}^+$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  of the studied groundwater samples were far below the recommended limits ( $\text{Na}^+ = 200 \text{ mgL}^{-1}$ ,  $\text{Cl}^- = 250 \text{ mgL}^{-1}$ ,  $\text{SO}_4^{2-} = 150 \text{ mgL}^{-1}$ ,  $\text{NO}_3^- = 10 \text{ mgL}^{-1}$ ) for drinking according to WHO (1984) and ISI (1983).

### **Industrial rating of waters based on $\text{Cl}^-$ , $\text{Fe}^{3+}$ , $\text{Mn}^{2+}$ , $p^H$ , TDS and hardness**

Based on  $\text{Cl}^-$  concentration, the percent suitability for brewing, carbonated beverage, dairy, sugar and textile industries were 12, 97, 50, 17 and 97 (Fig. 2). The water samples also contained traces amount of  $\text{Mn}^{2+}$ . The allowable limits of Mn for various industries range from  $0.05\text{-}1.0 \text{ mgL}^{-1}$  except sugar manufacture (Todd, 1980). For sugar manufacture water should be free from Mn. The status of Fe ( $\text{Fe}^{+3}$ ) in the present study ranged from traces to  $0.089 \text{ mgL}^{-1}$  and may be suitable for almost all industries. The acceptable range of Fe is from  $0.10\text{-}0.30 \text{ mgL}^{-1}$  (Todd, 1980). The  $p^H$  of the samples might not be suitable for brewing and laundering but could safely be used for tanning. For brewing, laundering and tanning, the recommended limits of  $p^H$  are 6.5-7.0, 6.0-6.8 and 6.0-8.0, respectively (Todd, 1980). The detected TDS values ( $107\text{-}831 \text{ mgL}^{-1}$ ) were not found suitable for confectionery as the recommended limits of TDS is  $50\text{-}100 \text{ mgL}^{-1}$  (USEPA, 1975). However, none of the sample was suitable for brewing and confectionery. But for carbonated beverage, dairy, ice manufacture, and paper and pulp industries, the percent suitability were 100, 97, 80 and 25, respectively. Hardness was due to the sufficiency of divalent cations like  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  (Todd, 1980). As regards to hardness, all waters were unsuitable for confectionery, textile and laundering while the suitability were for tanning (100 %), paper and pulp industries (80 %), carbonated beverage (37 %) and dairy (37 %) in this studied sample.

## CONCLUSION

In conclusion, it can be concluded that all the shallow tube well and deep tube well water samples of the Phulbari Upazilla under the district of Dinajpur were found suitable for irrigation, drinking, domestic and industrial uses; although some samples were rated to be toxic for all the above purposes. However, in case of drinking and industrial uses, bacteriological and radiological analyzes are equally important before using these waters.

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