

연구논문

# Evaluation of Groundwater Quality in Northern Bangladesh for Irrigation, Drinking and Industrial Uses

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북부 방글라데시에서 관개, 음용 및 공업용수로 사용되는 지하수의 수질

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## Abstract

방글라데시 북부에 위치한 풀바리 우파질라 지역의 지하수에서 pH, EC, 주요 양이온 ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Zn}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{3+}$ , and  $\text{As}^{3+}$ ), 주요 음이온 ( $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$ ) 그리고 total dissolved solids (TDS) 등의 용존물질 함량을 측정하였다. 또한 sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), 경도 등의 지표도 계산하였다. 전체적으로 지하수의 pH는 약알칼리성 (6.24 - 8.10)을 띠었으며, 주요 양이온은  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Na}^+$  이었고, 주요 음이온은  $\text{HCO}_3^-$  and  $\text{Cl}^-$  으로서 전형적인 담수의 이온조성을 보였다.  $\text{Cu}^{2+}$ ,  $\text{Mn}^{2+}$  and  $\text{Fe}^{3+}$  의 최대 농도는 각각 1.71, 0.606, 0.125 mg/L 이었다. 방글라데시의 여러 지역에서는 비소에 의한 지하수의 오염이 흔히 나타나고 있으나 이지역에서 비소의 최대농도가 0.41 mg/L로서 기준치인 0.05 mg/L 보다 낮은 오염도를 보였다. TDS와 SAR, SSP 등으로 볼 때 이 지역의 지하수는 대부분 양호한 수질을 가지는 담수인 것으로 평가된다.  $\text{As}^{3+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and  $\text{Cl}^-$  등의 농도는 음용수로 적합한 수준이었으나 일부 항목은 특정 산업용도로는 부적합한 농도를 보였다. 현재로서는 이지역의 지하수는 대부분 음용이 가능하고 일부 산업용에 대해서만 부적합성을 보였다. 그러나 앞으로 지하수의 이용과 산업활동이 증가하면 방글라데시의 많은 다른 지역의 지하수에서 발생한 사례와 같이 용존물질의 농도가 증가하여 물의 용도에 제한을 받게 될 우려가 있다.

주요어 : 방글라데시, 지하수, 수질, 전기전도도

## I. Introduction

Water of desirable quality is essential for irrigation, drinking and domestic uses, industrial uses, and functioning of both terrestrial and aquatic ecosystems. Water quality can also have a direct impact on crop production and soil properties. The quality of irrigation water can affect crops in different ways, depending upon soil properties, underlying geology, irrigation type, the specific crop grown, and the farming methods used. Although a large portion of irrigation water is used by plants or evaporates from the soil, a portion of the water is returned to the source. Depending on climatic regime, salts from the irrigation water can accumulate 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). Clay dispersion resulting in particle clogging within a soil column reduces the hydraulic conductivity (Felhendler *et al.*, 1974).

Groundwater is a critical source of water for irrigation, domestic and industrial uses in some rural areas of Bangladesh. Presently the cultivated land under irrigation with groundwater accounts for more than 70 % of the total irrigated area and contributes significantly to Bangladesh's grain production (Rashid and Islam, 2007). Phulbari Upazilla is a coal-mining area and the utilization of water from groundwater sources is gradually increasing for irrigation, domestic and industrial purposes. Yet few studies related to groundwater quality and irrigation practices are available for this region.

Some research in other regions has investigated the effect of irrigation water quality on crop production or soil properties. For example, Baumhardt *et al.*(1992) reported that the infiltra-

tion rate of soil was influenced by the chemical properties of irrigation water. Studies in Bangladesh have (Rahman and Zaman, 1995; Zaman and Majid, 1995; Quddus and Zaman, 1996) showed 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. In modern agriculture, assessment of water quality is essential for a better understanding and management of groundwater resources and future irrigation practices in Bangladesh. Better assessments of water quality are needed to prevent degradation of water and soil quality, in addition to human health concerns. Todd (1980) suggested that, among the many ions which might be considered important as related to groundwater quality,  $\text{Cl}^-$ ,  $\text{Fe}^{3+}$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Mn}^{2+}$ , pH, TDS and hardness are the important chemical constituents to assess the suitability of water for industrial purposes (Todd, 1980). 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.

## II. Materials and Methods

### 1. Location, climate and geological setting

The study area is located ( $25^{\circ}31' 0.12''$ ,  $88^{\circ}52' 59.88''$ ) in Phulbari Upazilla in the northern part of Bangladesh, and has an area of approximately 230 km<sup>2</sup>. Bangladesh has a tropical monsoon climate characterized by heavy seasonal rainfall, high temperatures and high humidity. The average rainfall during monsoon ranges from 1194 mm to 3454 mm.

The lithology of most northern region of Bangladesh, especially this study area, consists

predominantly of medium to coarse grained, poorly sorted sands and gravels with thin surface clays. A coal deposit in this Upazilla is one of the largest coal basins in Bangladesh. The coal-bearing sediments are comprised of Permian-age sandstones, silt stones, subordinate carbonaceous shales, and six coal seams (Islam and Hayashi, 2008). A previous UNDP study classified the groundwater aquifers of Bangladesh into three zones, namely the upper aquifer, main aquifer and deep aquifer (UNDP, 1982). We collected the water samples from the main aquifer. This is the main water bearing zone and occurs at depths ranging from less than 5 m in the northwest region of Bangladesh. This aquifer is either semi-confined or leaky, and consists of stratified interconnected, unconfined water bearing zones. The aquifer is comprised of medium and coarse grained sediments, in places inter-bedded with gravel (UNDP, 1982). These sediments occur to depths of about 140 m below ground surface.

## 2. Collection of water sample and sampling techniques

Well water samples were collected during February, March and April 2006 during the time period when groundwater levels are generally lower relative to other seasons of the year (Shamsudduha *et al.*, 2009). Water samples were collected monthly from 35 shallow tube wells, 1 hand tube well, 1 shallow well and 3 deep tube wells (Figure 1). Samples were collected in two liter plastic bottles that had been cleaned with hydrochloric acid (1:1) and then rinsed with tap water followed by rinsing with distilled water. Before collecting each sample, bottles were rinsed 3 to 4 times with sample. Samples were analyzed in Department of Agricultural Chemistry & Bio-

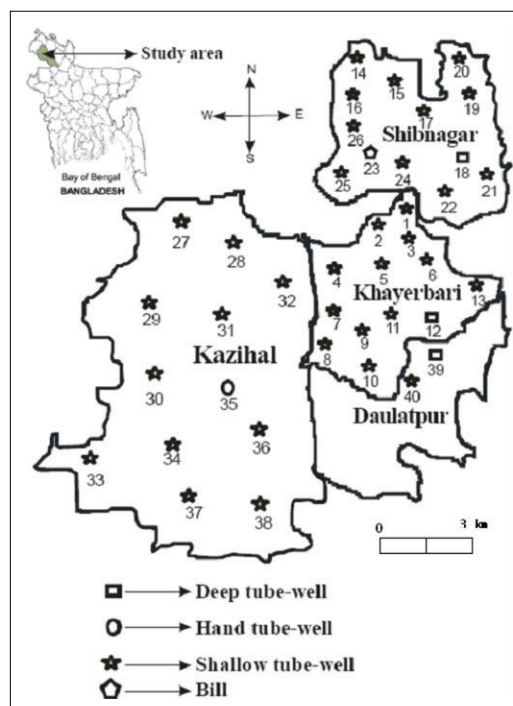


Figure 1. Map of the sampling sites of the Phulbari Upazilla under the District of Dinajpur along with the map of Bangladesh

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## 3. Analytical procedures

In order to assess the suitability classes for irrigation, domestic and industrial uses, we measured 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  $\text{Cl}^-$ . The 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).  $\text{K}^+$  and  $\text{Na}^+$  were estimated by flame emission spectrophotometry (Ghosh *et al.*, 1983).  $\text{SO}_4^{2-}$  was determined turbidimetrically (Wolf, 1982).  $\text{CO}_3^{2-}$  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 spectrophotometry (APHA, 1998) in the Soil Science Division Laboratory, 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 arsenic measurements. All samples for arsenic determination were pre-reduced with concentrated HCl (1 ml), 5 % KI and ascorbic acid mixture prior to hydride generation.

#### 4. Equations used in calculating water class rating parameters

Whether groundwater is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that specific use. 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)

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

- b) Soluble Sodium Percentage (SSP)

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

- c) Residual Sodium Carbonate (RSC)

$$\text{RSC} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})$$

- d) Hardness or Total Hardness (HT)

$$\text{HT} = 2.5 \times \text{Ca}^{2+} + 4.1 \times \text{Mg}^{2+}$$

(Freeze and Cherry, 1979)

where concentrations of ionic constituents for

calculating all parameters are in meq/L except hardness (mg/L).

### III. Results and Discussion

#### 1. Chemical composition of water samples

Details of the sampling sites are presented in Figure 1 and Table 1. Some summary results from our survey of groundwater are shown in Tables 2 and 3. The pH of the samples ranged from neutral to alkaline (pH ranged from 6.24 to 8.10; Table 2). The EC and TDS ranged from 209 to 1667 *mS/cm* and 107 to 1044 mg/L, respectively. The EC values were distinctly dissimilar among the samples. Ground water contain higher TDS due to appreciable amount of dissolved bicarbonate, chloride and sulfate compounds containing  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$  (Karanth, 1994).  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  concentrations were 0.10 to 1.22 mg/L and trace to 0.54 meq/L, respectively. Concentrations of  $\text{Na}^+$  and  $\text{K}^+$  ranged from 0.13 to 9.00 meq/L and 0.10 to 1.50 meq/L, respectively. Potassium concentrations were generally lower than Na concentrations.  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  were major cations in groundwater and ranged from 0.70 to 5.30 meq/L and 0.95 to 4.60 meq/L, respectively. An appreciable amount of  $\text{HCO}_3^-$  was present in all water samples, though  $\text{CO}_3^{2-}$  was negligible in most cases. The range for  $\text{HCO}_3^-$  were 0.64 to 5.61 meq/L while  $\text{Cl}^-$  concentrations ranged from 0.09 to 10.24 meq/L.  $\text{Fe}^{3+}$  and  $\text{Mn}^{2+}$  concentrations varied from trace to 0.125 mg/L and trace to 0.606 mg/L, respectively (Table 3). Arsenic concentrations ranged from trace to 0.041 mg/L. The computed variable, hardness, varied from 84 to 491 mg/L.

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

Sample No.	Sampling sites		Depth of sink (m)	Well type	Duration of uses (year)
	Location	Union (Small administrative unit)			
1	Balupara	Khayerbari	13.71	STW	2.5
2	Lakhipur	Khayerbari	27.43	STW	5
3	Fhakhirpara	Khayerbari	13.71	STW	0.4
4	Jailapara	Khayerbari	18.28	STW	12
5	Napitpara	Khayerbari	12.19	STW	1
6	Balupara	Khayerbari	21.33	STW	6
7	Naldange	Khayerbari	12.19	STW	1.5
8	Boiragipara	Khayerbari	13.71	STW	4
9	Akhillahpara	Khayerbari	25.9	STW	18
10	Phakhirpara	Khayerbari	13.71	STW	4
11	Muktarpur	Khayerbari	29.14	STW	5
12	Khaarbari	Khayerbari	69.62	DTW	1
13	Kasmatlalpur	Khayerbari	18.28	STW	4
14	Rajarampur	Sibnagar	19.81	STW	12
15	Sibnagar	Sibnagar	19.81	STW	15
16	North Gopalpur	Sibnagar	18.28	STW	7
17	Amdungirhat	Sibnagar	10.66	STW	2
18	Ghatpara	Sibnagar	60.48	DTW	5
19	South Gopalpur	Sibnagar	21.33	STW	2
20	MiddleSibnagar	Sibnagar	24.38	STW	3
21	Sibnagar	Sibnagar	21.33	STW	4
22	Rajarampur	Sibnagar	21.33	STW	8
23	Rajarampur	Sibnagar	4.00	SW	5
24	Gopalpur	Sibnagar	18.28	STW	4
25	Dangapara	Sibnagar	16.76	STW	8
26	Samsernagar	Sibnagar	18.28	STW	8
27	Rashidpur	Kazihal	19.81	STW	1
28	Rasulpur	Kazihal	18.28	STW	13
29	Ramchandrapur	Kazihal	15.24	STW	20
30	Hajratpur	Kazihal	20.3	STW	12
31	Amra	Kazihal	18.28	STW	8
32	South Veram	Kazihal	18.89	STW	4
33	Joyanty	Kazihal	12.19	STW	15
34	Pukuri	Kazihal	18.28	STW	3
35	Kakuldanga	Kazihal	14.04	HTW	5
36	Pukuri	Kazihal	18.28	STW	3
37	Dadul	Kazihal	21.33	STW	22
38	Amra	Kazihal	18.28	STW	4
39	Joynagar	Daulatpur	85.34	DTW	20
40	Daulatpur	Daulatpur	24.38	STW	10

STW=Shallow tube well, DTW= Deep tube well, SW= Shallow well, HTW= Hand tube well

Table 2. pH, EC, TDS, hardness and anionic constituents of groundwater during the study period

	pH	EC μS/cm	TDS mg/L	Hardness mg/L	Cl <sup>-</sup> meq/L	HCO <sub>3</sub> <sup>-</sup> meq/L	SO <sub>4</sub> <sup>-2</sup> meq/L	NO <sub>3</sub> <sup>-</sup> mg/L	PO <sub>4</sub> <sup>3-</sup> mg/L
Min	6.24	209	107	84	0.09	0.640	Trace	0.10	Trace
Max	8.10	1667	1044	491	10.24	5.61	0.54	1.22	0.672
Mean	7.2	652	399	87	2.90	2.59	0.14	0.39	0.050
SD	0.48	402	63	42	2.87	1.27	0.13	0.28	0.110

Traces for sulfate and phosphate were considered <0.001meq/L and <0.001mg/L, respectively

Table 3. Concentrations of cationic constituents of groundwater during the study period

	Ca <sup>2+</sup> meq/L	Mg <sup>2+</sup> meq/L	Na <sup>+</sup> meq/L	K <sup>+</sup> meq/L	Cu <sup>2+</sup> mg/L	Zn <sup>2+</sup> mg/L	Mn <sup>2+</sup> mg/L	Fe <sup>3+</sup> mg/L	As <sup>5+</sup> mg/L
Min	0.70	0.95	0.13	0.10	Trace	Trace	Trace	Trace	Trace
Max	5.30	4.60	9.00	1.50	1.710	0.464	0.606	0.125	0.041
Mean	1.72	2.43	1.78	0.53	0.050	0.010	0.090	0.010	0.035
SD	0.83	0.97	2.74	0.36	0.270	0.070	0.160	0.030	0.006

Traces for Fe, Zn, Cu, Mn and As were considered <0.01, <0.01, <0.01, <0.01 and <0.01 mg/L, respectively

## 2. Factors controlling the composition of groundwater

Most groundwater samples in this study had Na:Cl ratio lower than unity, while a few had Na:Cl ratio equal to one (Figure 2). A ratio equal to one is sometimes attributed to dissolution of NaCl while a Na:Cl ratio greater than one might reflect release of Na<sup>+</sup> from silicate weathering (Meyback, 1987). Among the anions, HCO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup> are often dominant anions in groundwater. Precipitation of salts can cause a decline in the concentration of HCO<sub>3</sub><sup>-</sup> and thereby anions in groundwater are dominated by Cl<sup>-</sup>. The precipitation of CaCO<sub>3</sub> might result in a decline in Ca<sup>2+</sup> concentration, supporting our finding of higher concentrations of Na<sup>+</sup> in groundwater. As a result, the ratio of Mg<sup>2+</sup>:Ca<sup>2+</sup> was greater than unity in the groundwater showed in Figure 2 (e). In the areas of increased clay-rich soil dispersed and where Na<sup>+</sup> concentration is higher [20], the Mg<sup>2+</sup> concentration is relatively higher than that of Ca<sup>2+</sup>. The Na<sup>+</sup> hazard can be greater, where the groundwater is dominated by Na<sup>+</sup> + Mg<sup>2+</sup>

ions rather Na<sup>+</sup> + Ca<sup>2+</sup> ions (Yousaf *et al.*, 1987). The higher concentrations of Na decrease the hydraulic conductivity of soil/weathered materials, thus reducing the drainage conditions. In this study, all the groundwater samples had a ratio of Ca<sup>2+</sup>:HCO<sub>3</sub><sup>-</sup>+CO<sub>3</sub><sup>2-</sup> and Mg<sup>2+</sup>:HCO<sub>3</sub><sup>-</sup>+CO<sub>3</sub><sup>2-</sup> greater than unity while the ratio of Na<sup>+</sup>:HCO<sub>3</sub><sup>-</sup>+CO<sub>3</sub><sup>2-</sup> were approximately 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<sup>2+</sup>+Mg<sup>2+</sup>: total cations of most of the water samples had ratios approaching unity while the ratios of Na<sup>+</sup>+K<sup>+</sup>: total cations were far below unity (Figure 2).

Because our study area has a higher rate of evapotranspiration characterized by tropical climate and restricted fresh water exchange, salt layers may form near the evaporating surface (Karanth, 1994). On the other hand, human activities in areas of groundwater withdrawal might lead to future changes in groundwater chemical composition. For instance, intensive and long-term irrigation can leach salts from the

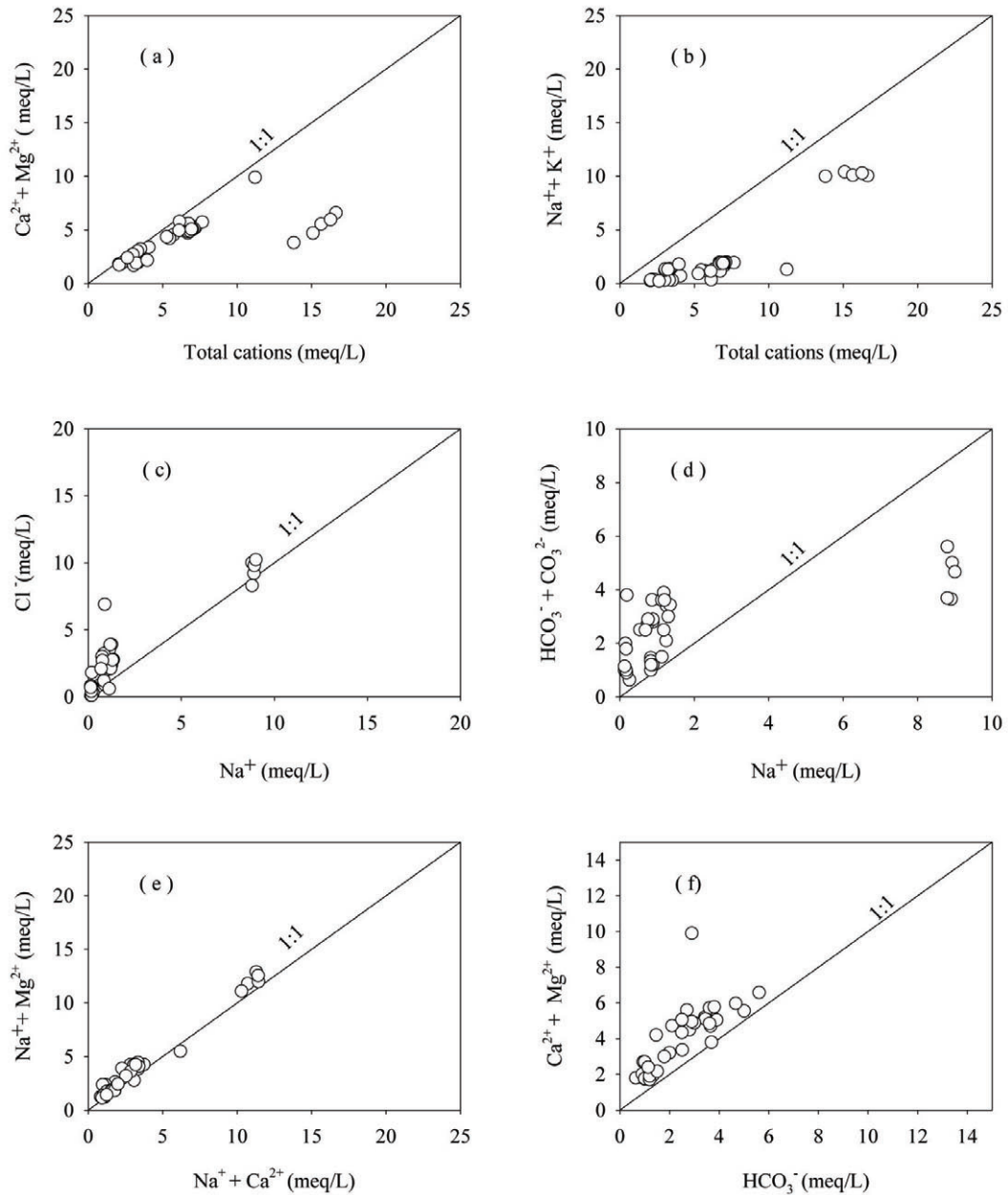


Figure 2. Ratios of the major anions and cations in groundwater from Phulbari Upazilla, Bangladesh

soil/weathered rock zone, because of the availability of water (Hem, 1991).

### 3. Suitability for irrigation based on pH, EC, SAR and SSP

Irrigation water quality can have a profound

impact on crop production. In this study, 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  $\text{HCO}_3^{-}$  (Michael, 1978; Rao *et al.*, 1982). The major factors that influence the

substrate solution pH during plant production: 1) pre-plant materials such as dolomitic limestone put into the substrate and substrate components themselves, 2) the alkalinity of the irrigation water, 3) the acidity / basicity of the fertilizers used during production, and 4) the plant species being grown. All the groundwater samples were suitable for irrigation according to the results for pH since the acceptable pH for agricultural use ranges from 6.0 to 8.5 (Ayers and Westcot, 1985).

We found significant variability in EC values, with the values ranging from 209 to 1667  $\mu\text{S}/\text{cm}$ . This result of EC was in close agreement in the groundwater of neighboring country Nepal reported by Chapagain *et al.* (2009). Higher EC values reflected higher concentrations of dissolved constituents that may affect the irrigation water quality in relation to salinity hazard (Agarwal *et al.*, 1982). Table 4 shows that out of 40 samples, 29 were rated as 'good', 7 were as 'permissible' and 4 were as 'excellent' for irrigation purposes based on Wilcox requirement (Wilcox, 1955). Salts can accumulate in the root zone by two processes; the upward movement of a shallow saline-water table and salts left in the soil due to insufficient leaching. According to Richards (1968), all irrigation waters were classified as C2S1 with one C3S1 (sample no. 25) and one C4S1 (sample no. 3) categories. C1 indicated 'low' salinity ( $\text{EC} < 250 \mu\text{S}/\text{cm}$ ), C2 indicated 'medium' salinity ( $\text{EC}=250\text{-}750 \mu\text{S}/\text{cm}$ ), C3 indicated 'high' salinity ( $\text{EC}=750\text{-}2250 \mu\text{S}/\text{cm}$ ), and C4 indicated 'very high' salinity ( $\text{EC} > 2250 \mu\text{S}/\text{cm}$ ), 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. If water with a high salinity level 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 crop 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). With respect to the SAR values, all the groundwater samples were classified as excellent (S1) for crop irrigation and would not be expected to negatively affect soil quality. 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). In this study, all groundwater samples were suitable based on SAR values (Table 4).

Soluble sodium percentage (SSP) is an important criterion for soil physical properties and can affect plant growth. Water with a SSP greater than 60 percent may result in accumulation of Na that will cause a breakdown in the soil physical properties (<http://agnewsarchive.tamu.edu/drought/DRGHTEPAK/SALINITY.HTM>). Among the groundwater samples we collected, 30 were rated as 'excellent', 5 were rated as 'good', 3 were rated as 'permissible', and 1 was rated as 'doubtful' according to Wilcox (1955). Water belonging to the excellent, good and permissible categories may be used for irrigation purposes. Doubtful waters are considered to be harmful

Table 4. Quality classification of water samples for irrigation

Sl No	EC $\mu\text{S/cm}$	TDS mg/L	SAR	SSP	RSC	Water class based on					Alkalinity-salinity class
						EC	TDS	SAR	SSP	RSC	
1	573	342	0.50	15.64	-1.70	Good	Fre	Ex	Ex	Suit	C2-S1
2	705	450	0.59	16.40	-1.67	Good	Fre	Ex	Ex	Suit	C2-S1
3	1667	1044	4.13	52.91	-0.97	Permi	Bra	Ex	Permi	Suit	C4-S1
4	692	449	0.59	16.27	-1.38	Good	Fre	Ex	Ex	Suit	C2-S1
5	726	466	0.60	16.34	-1.60	Good	Fre	Ex	Ex	Suit	C2-S1
6	723	440	0.65	17.38	-1.78	Good	Fre	Ex	Ex	Suit	C2-S1
7	633	410	0.46	13.83	-1.35	Good	Fre	Ex	Ex	Suit	C1-S1
8	673	405	0.67	18.68	-2.62	Good	Fre	Ex	Ex	Suit	C2-S1
9	770	501	0.55	14.75	-2.11	Permi	Fre	Ex	Ex	Suit	C2-S1
10	1514	888	4.93	58.94	-1.05	Permi	Fre	Ex	Permi	Suit	C2-S1
11	1568	995	4.45	57.09	-0.54	Permi	Fre	Ex	Permi	Suit	C2-S1
12	697	433	0.62	17.02	-2.56	Good	Fre	Ex	Ex	Suit	C1-S1
13	713	445	0.71	19.04	-1.66	Good	Fre	Ex	Ex	Suit	C2-S1
14	1631	994	4.39	55.31	-1.30	Permi	Fre	Ex	Permi	Suit	C2-S1
15	549	313	0.46	15.22	-2.74	Good	Fre	Ex	Ex	Suit	C1-S1
16	1384	831	5.40	63.76	-0.11	Permi	Fre	Ex	Dou	Suit	C2-S1
17	678	404	0.37	10.97	-2.90	Good	Fre	Ex	Ex	Suit	C2-S1
18	410	271	0.35	13.30	-0.86	Good	Fre	Ex	Ex	Suit	C2-S1
19	703	458	0.62	16.88	-1.15	Good	Fre	Ex	Ex	Suit	C2-S1
20	675	443	0.65	17.88	-1.24	Good	Fre	Ex	Ex	Suit	C2-S1
21	1125	626	0.32	7.93	-7.00	Permi	Fre	Ex	Ex	Suit	C2-S1
22	688	418	0.69	19.00	-1.88	Good	Fre	Ex	Ex	Suit	C2-S1
23	617	397	0.09	3.09	-1.98	Good	Fre	Ex	Ex	Suit	C1-S1
24	355	222	0.10	4.27	-1.22	Good	Fre	Ex	Ex	Suit	C2-S1
25	337	214	0.68	24.92	-0.61	Good	Fre	Ex	Good	Suit	C3-S1
26	614	387	0.40	12.45	-2.05	Good	Fre	Ex	Ex	Suit	C2-S1
27	531	325	0.39	13.09	-1.85	Good	Fre	Ex	Ex	Suit	C2-S1
28	209	113	0.12	6.82	-0.70	Ex	Fre	Ex	Ex	Suit	C2-S1
29	335	199	0.12	5.13	-1.21	Good	Fre	Ex	Ex	Suit	C2-S1
30	301	163	0.10	5.05	-1.76	Good	Fre	Ex	Ex	Suit	C2-S1
31	304	160	0.09	4.33	-1.70	Good	Fre	Ex	Ex	Suit	C2-S1
32	217	107	0.22	11.92	-1.16	Ex	Fre	Ex	Ex	Suit	C2-S1
33	241	140	0.15	7.59	-1.12	Ex	Fre	Ex	Ex	Suit	C2-S1
34	211	124	0.15	8.21	-0.74	Ex	Fre	Ex	Ex	Suit	C2-S1
35	306	168	0.74	27.48	-0.77	Good	Fre	Ex	Good	Suit	C1-S1
36	309	177	0.80	29.18	-0.50	Good	Fre	Ex	Good	Suit	C2-S1
37	326	203	0.70	26.08	-0.70	Good	Fre	Ex	Good	Suit	C2-S1
38	400	215	0.91	28.53	-0.67	Good	Fre	Ex	Good	Suit	C2-S1
39	697	433	0.62	17.02	-2.56	Good	Fre	Ex	Ex	Suit	C1-S1
40	267	154	0.09	4.94	-1.26	Good	Fre	Ex	Ex	Suit	C1-S1

Ex = Excellent, Fre = Fresh, Dou = Doubtful, Suit = Suitable, Bra = Brackish, Permi = Permissible

and unsuitable for crop cultivation. Natural occurrence of Na enriched minerals in parent materials and geochemical processes during interaction with groundwater may account for elevated Na concentration. As a result, soils may undergo deterioration due to the accumulation of Na, resulting in crust formation and seal development on the soil surface over a long period of time. Sodium toxicity is often modified and reduced if Ca and Mg are also present (Clemson University, <http://www.clemson.edu/agrvlb/IRRWAT.htm>). Moderate amounts of Ca and Mg may reduce sodium damage and higher amounts even prevent it.

#### 4. Suitability for irrigation based on TDS, RSC, $H_T$ , $Cl^-$ , $NO_3^-$ and metals

The TDS values ranged from 107 to 1044 mg/L with an average value of 399 mg/L. All the waters except one were rated as 'fresh' according to the guidelines given in Freeze and Cherry (1979). In our study, almost all the water samples were suitable for growing crops (Table 4). The Residual sodium carbonate (RSC) is the most important criterion to examine the water quality as suggested by Eaton (1950). A negative 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. As for the RSC values, all the water samples were graded as 'suitable' and these waters may be used safely. Sawyer and McCarty (1967) classified irrigation water into four categories on the basis of hardness ( $H_T$ ). In our study, according to this classification, 2 groundwater samples were classified as very hard (data not shown). Natural concentra-

tions of significant amounts of soluble  $Ca^{2+}$  and  $Mg^{2+}$  might be the possible cause of very hard water. For the remaining samples, 26 samples were classified as hard and 12 samples were grouped as moderately hard waters these can be considered to be suitable for irrigation.

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 meq/L. Our results showed that chloride concentration ranged from 0.09 to 10.24 meq/L. In these samples 6 samples exceeded the above guideline and may threaten 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.  $NO_3^-$ -N concentrations in the groundwater samples ranged from 0.1 to 1.22 mg/L. Production of N sensitive crops may be affected at N concentrations of above 5 mg/L. Sugar beets, for example, under excessive N fertilization, grow to a large size but with low purity and low sugar content and the amount of sugar produced per hectare may actually be reduced. For many grasses and grain crops, lodging may result from excessive vegetative growth (Clemson University, <http://www.clemson.edu/agrvlb/IRRWAT.htm>). Our results showed that the groundwater  $NO_3^-$ -N did not exceed the maximum concentration 30 mg/L as because most crops are relatively unaffected until N exceeds 30 mg/L (<http://www.fao.org/docrep/003/T0234E/T0234E06.htm>). Therefore, most crops can be irrigated in this region without any N hazard.

Trace metals including Cu<sup>2+</sup>, Zn<sup>2+</sup>, Fe<sup>3+</sup>, As<sup>3+</sup>, Mn<sup>2+</sup> were concentrations werelow and considered to be suitable for crop production and the soil environment (Ayers and Westcot, 1985). However, the average concentrations of Cu<sup>2+</sup>, Zn<sup>2+</sup>, Fe<sup>3+</sup>, As<sup>3+</sup> and Mn<sup>2+</sup> were 0.05 mg/L, 0.01 mg/L, 0.01 mg/L, 0.035 mg/L and 0.09 mg/L, respectively.

**5. Correlations among the parameters with depth**

There were few significant relationships among the measured concentrations with depth (Table 5). The high correlation between EC and TDS reflects the interdependency of these measurements as general measures of the amount of total dissolved solutes. The correlation between EC and TDS (r=0.99) is due to the fact that conductivity depends on total dissolved solids. The non-significant positive correlation (r=0.25) observed between SSP and SAR indicates that sodium adsorption by soil particles may or will increase with the amount of soluble sodium but might not create an alkali hazard in soil and will not

hinder successful crop production. 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. The positive relationship between EC and SAR (r=0.86) may indicate their common origin from geological sources the terrestrial watershed.

**6. Suitability for drinking and domestic uses**

In our survey, the pH (range 6.24 to 8.10) of all groundwater samples was within the safe limits prescribed for drinking water by WHO (1984). The recommended concentration of TDS is 500 mg/L (WHO, 1984) and 6 samples were above the recommended limit. Hard water leads to high incidence of urolithiosis (WHO, 1984), anencephaly, parental mortality, some types of cancer (Agarwal and Jagetia, 1997) and cardio-vascular disorders (Durvey *et al.*, 1991). 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,

Table 5. Correlation matrix of different chemical constituents of groundwater with depth, n=40, units of each parameter are in Table 2 and Table 3

	Depth	EC	TDS	Cl-	HCO <sub>3</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	SAR	SSP	HT
Depth	1												
EC	0.01	1											
TDS	0.02	0.99	1										
Cl-	0.05	0.98	0.97	1									
HCO <sub>3</sub> <sup>-</sup>	0.002	0.84	0.88	0.73	1								
NO <sub>3</sub> <sup>-</sup>	-0.26	-0.37	-0.40	-0.36	-0.50	1							
Ca <sup>2+</sup>	0.07	0.62	0.62	0.60	0.63	-0.50	1						
Mg <sup>2+</sup>	0.09	0.71	0.72	0.63	0.85	-0.55	0.85	1					
Na <sup>+</sup>	-0.05	0.90	0.89	0.91	0.64	-0.16	0.25	0.36	1				
K <sup>+</sup>	0.05	0.87	0.88	0.85	0.72	-0.24	0.39	0.48	0.85	1			
SAR	-0.05	0.86	0.85	0.88	0.59	-0.13	0.19	0.28	0.99	0.85	1		
SSP	-0.03	0.79	0.78	0.81	0.52	-0.07	0.12	0.18	0.94	0.87	0.25	1	
HT	0.08	0.70	0.70	0.64	0.77	-0.55	0.96	0.97	0.32	0.45	0.25	0.16	1

Italic values are significant at p=0.05 where r ≥ 0.32

excess concentration of some nutrients can cause health hazard. For example, the concentration of  $\text{Na}^+$  should not exceed 200 mg/L. A sodium-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). 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 ( $\text{Na}^+=200$  mg/L,  $\text{Cl}^-=250$  mg/L,  $\text{SO}_4^{2-}=150$  mg/L,  $\text{NO}_3^-=10$  mg/L) for drinking according to WHO (1984) and ISI (1983).

### 7. Industrial rating of groundwater samples based on $\text{Cl}^-$ , $\text{Fe}^{3+}$ , $\text{SO}_4^{2-}$ , $\text{NO}_3^-$ , $\text{Mn}^{2+}$ , pH, TDS and hardness

Based on pH (6.24 to 8.10), these waters might not be suitable for brewing and laundering but could safely be used for tanning. For brewing, laundering and tanning, the recommended limits

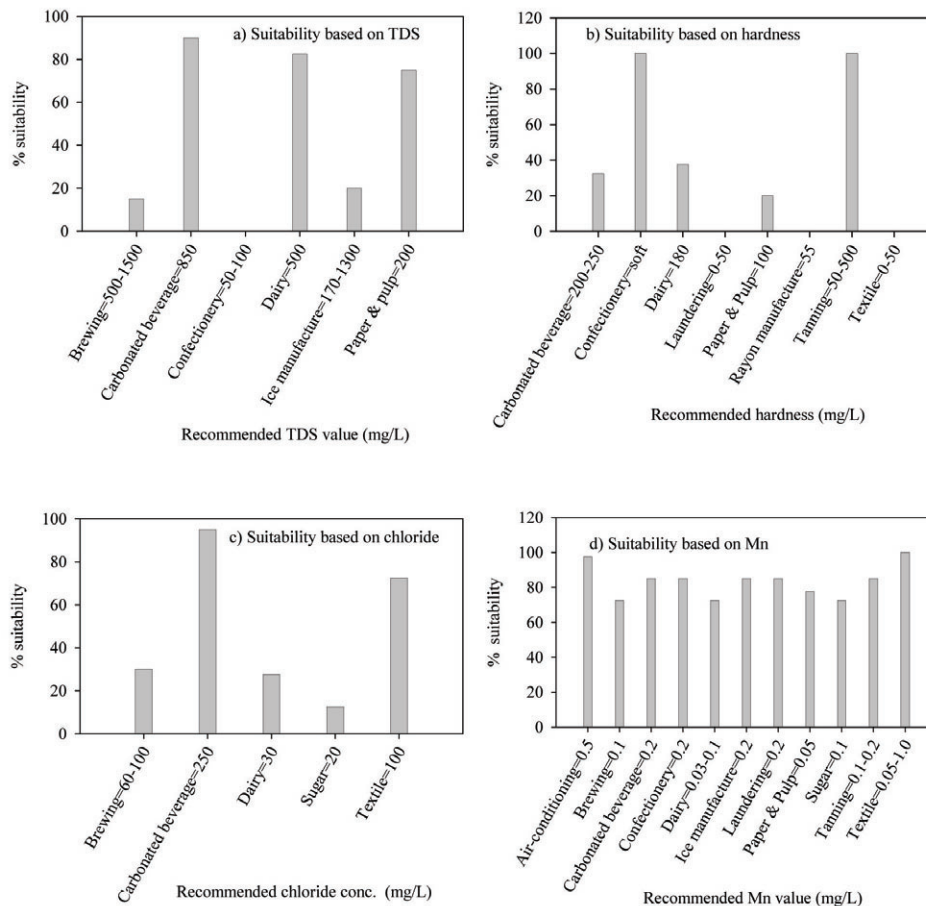


Figure 3. Relative suitability of studied water samples for various industries based on a) TDS, b) hardness, c) chloride, and d) manganese concentrations. In X axis, the recommended concentrations for different industries are shown according to USEPA (1975)

of pH are 6.5-7.0, 6.0-6.8 and 6.0-8.0, respectively (Todd, 1980). The TDS concentrations ranged from 107 to 1044 mg/L. These concentrations were not found suitable for confectionery as the recommended limits of TDS for the above industry is 50-100 mg/L (USEPA, 1975). However, for brewing, carbonated beverage, dairy, ice manufacture, and paper and pulp industries, the percent suitability were 15, 90, 82, 20 and 75, respectively (Fig. 3). 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 textile and laundering while the suitability were for tanning (100 %), paper and pulp industries (20 %), carbonated beverage (32 %), dairy (37 %) and confectionery industries (100 %) in the studied samples. Based on chloride concentration, the percent suitability for brewing, carbonated beverage, dairy, sugar and textile industries were 30, 95, 27, 12 and 12. The allowable limits of Mn for various industries range from 0.05 to 1.0 mg/L except for sugar manufacture (Todd, 1980). For sugar manufacture water should be free from Mn. The concentration of Fe in the present study ranged from trace to 0.125 mg/L and the groundwater sampled in this study may be suitable for nearly all industrial uses.

#### IV. Conclusion

Because irrigation is a primary use of groundwater in this region, irrigation return-flow could become a cause of groundwater pollution in this region. If salts accumulate on the surface in irrigated fields, they can leach through the soil zone by recharge water and reach the water table. Further, recycling of groundwater for irrigation can result in a progressive increase in soil and

groundwater salinity. Based on the patterns we observed, it can be concluded that all the shallow tube well and deep tube well water samples of the Phulbari 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. Our results illustrate the necessity of improving our knowledge of groundwater quality in the study area. Especially for drinking and industrial water use, continued monitoring of chemical and bacteriological indicators of water quality is needed.

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