ISSN 2250-3153

Assessment of Groundwater Quality for Drinking and Irrigation Purposes in Comilla District of Bangladesh

Prodip K. Roy*, **, B. Roy*, Bikash C. Roy****

* Department of Chemistry, Biology and Marine Sciences, University of the Ryukyus, Nishihara-cho, Okinawa 903-0213, Japan
**Department of Agricultural Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200, Bangladesh
***Department of Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200, Bangladesh

Abstract- Water in Comilla district of Bangladesh has been known to contaminate with heavy toxic metals especially arsenic and some ions, such as, Ca, Mg, Na, Cl, K, B, Cl, SO_4 and HCO_3. The presence of these toxic metal and ions in water are important parameters to evaluate water quality. For this study, 30 water samples were collected. The chemical analyses of these samples were done for quality assessment. The results showed that more than 50% samples were arsenic contaminated. But in case of ions contamination, all samples were in acceptable range. In addition, water suitability classification for drinking and irrigation purposes was performed based on some physicochemical parameters, such as electrical conductivity (EC), total dissolved solid (TDS), total hardness (HT), sodium adsorption ratio (SAR), and soluble sodium percentage (SSP). Based on the physiochemical properties of the analyzed samples were classified as "permissible" class and very few samples as "unsuitable" class. Although most samples are in "permissible" category, the presence of high level of arsenic makes waters unsafe for all living things, such as, humans, animals, and plants. This study was done thus to serve two purposes, one is to make awareness of the toxicity of heavy metal and irons and two is to seek quality water supply program either provided by public or private.

Index Terms- *Bangladesh, ground water, drinking water, water quality*

I. Introduction

The ground water is the main source for drinking and irrigation uses. Approximately, one-third of the world's population use groundwater for drinking purpose with or without treatment [2]. In Bangladesh, roughly 90% of drinking water[3] and 75% of irrigation water[3] are used directly from ground water sources without any treatment. These waters get polluted from various ways; such as industries discharge their effluent without proper treatment, and chemical drifting from excessive use of fertilizer for crop production. Additionally, naturally occurring heavy metals especially arsenic contamination in ground and underground waters cause medical issues even death. In Bangladesh, 40 million people are at risk of arsenic poisoning-related disease[4]. Most of the part of Comilla district in Bangladesh, both ground and surface waters are contaminated by arsenic and using this arsenic contaminated water, skin of hand and leg are affected, and its severe infection causes people death[5] So quality of ground water is an important factor in Bangladesh that deals an essential rule for several purposes of healthy living[6]. Water is essential for all living organisms on the earth for their survival, growth and development. The presence of the excess amount of some chemical constituents, like, Ca, Mg, Na, Cl, K, B, SO_4, HCO_3, and arsenic in water may deteriorate the water quality that sometime causes the death of life. So it is necessary to ensure quality water uses in daily life. In the study area, the water sample were collected from hand tube wells. The hand tube wells water source is generally considered as the poor type of groundwater sources in terms of physicochemical properties contamination due to the lack of concrete plinth and surrounding drainage system[7]. Over population pressure, unplanned urbanization, unrestricted exploration and dumping of the polluted water at the inappropriate place enhance the infiltration of harmful compounds to the groundwater[8]. Most of the industries discharge their effluent without proper treatment into nearby open pits or pass them through unlined channels, resulting in the contamination of groundwater[9]. The rapid industrialization and expansion of cities pose high pressure on water resources, including groundwater, results in their depletion and contamination. Several research groups have discussed identical on potential health impact due to poor-quality water[10]. The presence of heavy elements, metal ions and harmful microorganism in drinking water causes health problems too. Thus, water should be free from these toxic elements.
The present study investigated the chemical properties of groundwater to assess the ionic toxicity and suitability for drinking and irrigation purposes.

II. MATERIAL AND METHOD

For this study, 30 groundwater samples were collected from different locations at Homna Thana of Comilla district in April, 2007 (Figure 1). All water samples were collected from hand tube wells following the instructions outline[11]. After collection, the samples were immediately brought to the laboratory of Agricultural Chemistry, Hajee Mohammad Danesh Scie nce and Technology university, Dinajpur in Bangladesh for chemical analyses.

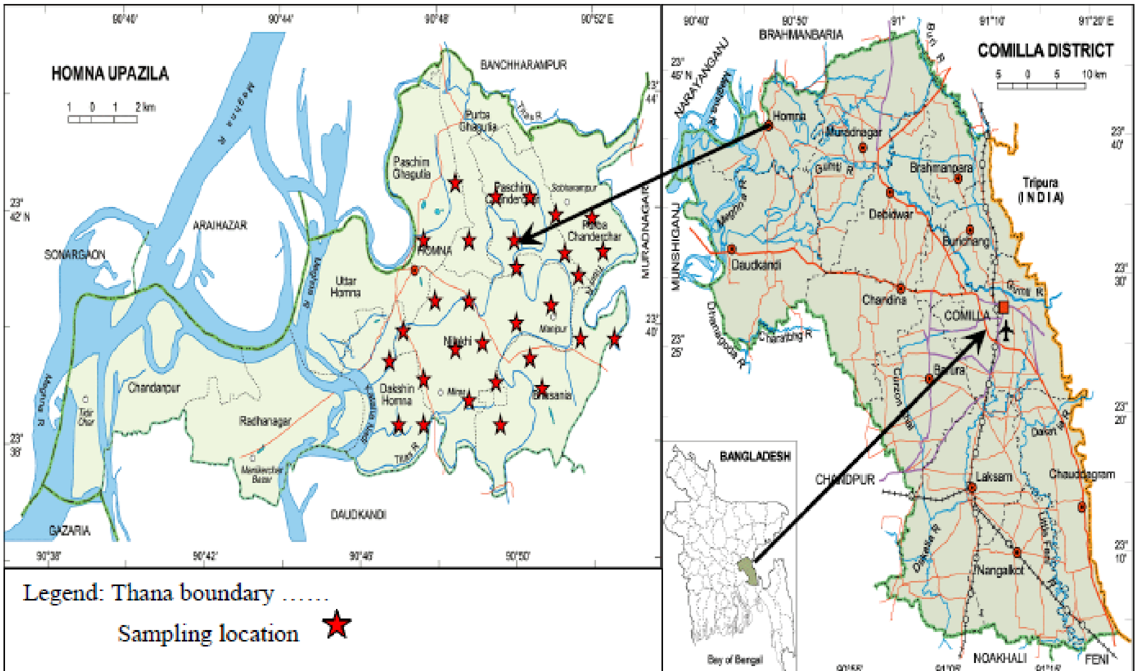

Figure 1. Sampling map of the study area.

The pH and EC of sampled waters was determined electrically by using a pH meter (Model: Hanna instrument-211) and Conductivity bridge (Moel; Hanna instrument-H18033), respectively [12]. The values of total dissolved solid (TDS) of waters were estimated by evaporating from a measured aliquot of filtered samples. Sodium (Na) and K were estimated by a frame-photometer. Calcium (Ca) and Mg were determined by a complex metric titration method using Na_2EDTA as titrant. The other ions like, Fe, Mn, Cu, Zn, and anions like, B, Cl, NO_3-N, SO_4-S, HCO_3, and CO_3 were determined as per standard procedure. Qualitative test using $AgNO_3$ was done to detect the presence or absence of arsenic. Water quality parameters viz. SAR, SSP, and H_T were used to classify t he suitability of waters, along with pH, EC, and TDS. The values of SAR, SSP, and H_T were calculated from the analyzed data using t he following formula:

$$SAR = [Na^+] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2}$$

$$SSP = \frac{\text{Soluble Na concentration (meqL}^{-1}\text{)}}{\text{Total cation concentration (meqL}^{-1}\text{)}} \times 100$$

$$H_T\,(mgL^{-1}) = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$$

Correlation coefficient analysis was done for all possible combinations within the quality parameter.

III. RESULTS

Tables 1 and 2 showed chemical constituents of groundwater samples. Drinking water qualities were mainly discussed based on these results. Irrigation purposes were also discussed because the study area was the agro-based region in Bangladesh.

3.1. Chemical properties of waters

In the study area, the pH values of sampled waters were ranged from 6.98 to 7.39 with an average value of 7.20. Most of the samples were alkaline in nature. As major ions, Ca, Mg, Na, K, Cl, and HCO_3 distributed at varying concentrations of the water samples. The concentrations of major ions varied from 0.40 to 6.01, 0.70 to 7.18, 3.2 to 7.8, 0.0010 to 0.0133, 4.2 to 10.2 and 2.0 to 6.4 $meqL^{-1}$ with the average values of 2.79, 4.01, 5.0, 0.0026, 6.4 and 3.6 $meqL^{-1}$, respectively. Some other ions like, NO_3, CO_3, SO_4, and B were carefully analyzed and were found nil to be very low in amount. The concentrations of SO_4 and B were found within the range of 0.02 to 0.19 $meqL^{-1}$ and 0.05 to 0.28 mgL^{-1}, respectively. Heavy metals like, Fe, Mn, Zn, and Cu were analyzed. The concentrations of Mn, Zn, and Cu were nil and was very low in case of Fe. So, the waters were free from the toxic effect of heavy metals. Arsenic was tested by qualitatively using $AgNO_3$. In the study area, groundwater contains arsenic at the different level. Out of 30 samples, 17samples (56.66%) were arsenic contaminated with different levels.

Table1. Chemical composition and computed parameters for suitability classification of water.

S/N	Source	pH	Ca $meqL^{-1}$	Mg $meqL^{-1}$	Na $meqL^{-1}$	K $meqL^{-1}$	B mgL^{-1}	Cl $meqL^{-1}$	SO_4 $meqL^{-1}$	HCO_3 $meqL^{-1}$	Arsenic
1	HTW	7.13	2.60	3.13	7.8	0.0017	0.11	8.4	0.07	3.0	ND
2	HTW	7.20	2.00	3.54	4.8	0.0019	0.12	6.4	0.02	2.6	ND
3	HTW	7.21	1.90	2.93	5.2	0.0018	0.10	5.8	0.14	2.8	L
4	HTW	7.13	1.80	2.83	4.6	0.0019	0.12	5.2	0.18	2.4	L
5	HTW	7.07	2.30	2.42	4.2	0.0023	0.12	5.4	0.14	2.4	ND
6	HTW	7.14	4.10	4.14	5.1	0.0024	0.06	6.8	0.07	4.8	ND
7	HTW	7.30	2.40	5.26	4.8	0.0018	0.05	6.0	0.10	4.4	L
8	HTW	7.29	4.40	2.93	4.2	0.0022	0.08	5.4	0.02	4.6	ND
9	HTW	7.09	2.90	4.35	5.1	0.0015	0.11	6.4	0.02	4.2	ND
10	HTW	7.34	1.20	1.21	5.2	0.0010	0.28	4.2	0.07	2.4	H
11	HTW	7.35	2.20	3.44	4.7	0.0019	0.05	5.8	0.02	3.2	ND
12	HTW	7.31	2.60	3.64	6.2	0.0021	0.12	6.4	0.19	4.0	ND
13	HTW	7.25	5.01	3.64	3.3	0.0026	0.09	5.8	0.06	4.2	H
14	HTW	7.26	3.80	6.67	4.2	0.0036	0.13	6.8	0.18	5.8	L
15	HTW	7.39	1.50	5.26	3.8	0.0031	0.11	6.4	0.19	2.8	M
16	HTW	7.10	1.30	0.70	5.2	0.0022	0.09	4.2	0.02	2.2	M
17	HTW	7.27	2.20	5.06	4.2	0.0025	0.12	6.8	0.06	3.0	ND
18	HTW	7.28	2.30	2.73	6.1	0.0024	0.06	5.6	0.02	4.2	ND
19	HTW	7.35	4.10	5.06	5.8	0.0023	0.05	7.6	0.02	5.4	H
20	HTW	7.24	3.50	5.16	5.6	0.0018	0.06	7.2	0.03	5.2	L
21	HTW	7.05	3.10	6.57	6.8	0.0024	0.11	9.2	0.19	4.4	L
22	HTW	7.08	3.00	3.13	6.2	0.0021	0.06	7.6	0.06	3.2	M

23	HTW	7.03	3.00	4.55	5.2	0.0023	0.05	8.8	0.18	2.0	M
24	HTW	6.98	3.00	7.18	4.4	0.0020	0.12	10.2	0.02	2.2	ND
25	HTW	7.17	1.50	5.16	5.8	0.0023	0.10	8.0	0.19	2.6	L
26	HTW	7.23	0.40	3.23	5.4	0.0018	0.11	4.6	0.04	3.1	L
27	HTW	7.17	1.70	1.72	6.2	0.0017	0.11	4.6	0.06	3.8	ND
28	HTW	7.26	2.80	6.17	3.2	0.0133	0.10	7.6	0.09	2.8	ND
29	HTW	7.30	6.01	4.35	3.2	0.0041	0.08	5.2	0.04	6.2	L
30	HTW	7.25	5.01	4.14	5.6	0.0035	0.09	6.4	0.19	6.4	L
Min.		6.98	0.40	0.70	3.2	0.0010	0.05	4.2	0.02	2.0	
Max.		7.39	6.01	7.18	7.8	0.0133	0.28	10.2	0.19	6.4	
Mean		7.20	2.79	4.01	5.0	0.0026	0.09	6.4	0.09	3.6	

Key: HTW indicates hand tube well. H, M, L, and ND indicate high level, medium level, low level, and not detected, respectively.

3.2. EC, TDS, SAR, SSP, and H_T

Electrical conductivity of waters fluctuated between 620 and 1540 µcm^{-1}. TDS of waters varied from 435 to 904 mgL^{-1} with an average value of 676.9 mgL^{-1}. The important quality parameter viz. SAR, SSP, and H_T computed from the analyzed data are depicted in Table 2. The computed SAR of water samples was within the range from 1.11 to 4.04 with the mean value of 2.47. The calculated SSP values of all water samples were varied from 23.58 to 72.09 with the average of 44.17. The calculated H_T values of all water samples varied from 99.98 to 518.99 mgL^{-1} with the average of 337.11 mgL^{-1}. The higher values of hardness indicated that the presence of higher amount of Mg and vice-versa[13].

Table 2: Chemical composition and computed parameters for suitability classification of groundwater

S/N	EC µScm^{-1}	TDS mgL^{-1}	SAR	SSP	H_T mgL^{-1}
1	1240	748	3.81	57.59	284.61
2	910	577	2.47	46.38	274.46
3	940	573	2.83	51.79	239.58
4	880	513	2.56	49.78	229.59
5	780	515	2.23	47.00	234.72
6	1210	785	2.05	38.17	409.55
7	1120	705	2.13	38.49	379.15
8	1080	692	1.73	36.37	364.83
9	1140	709	2.26	41.26	359.38
10	680	455	3.86	68.26	119.86
11	920	593	2.37	45.42	279.50
12	1140	715	2.94	49.79	309.50
13	1060	683	1.26	27.60	429.74
14	1240	855	1.57	28.59	518.99
15	820	586	1.86	35.95	334.06
16	620	435	4.04	72.09	99.98
17	1080	626	1.93	36.62	359.17
18	1060	671	3.18	54.76	249.66
19	1360	873	2.25	38.74	454.36
20	1320	831	2.27	39.24	429.28
21	1540	897	2.68	41.24	478.94
22	1140	704	2.89	50.22	304.65

23	1160	675	2.26	40.74	374.35
24	1280	744	1.71	30.15	503.81
25	1160	674	2.87	46.52	329.08
26	840	522	3.79	59.72	179.36
27	840	590	3.87	64.41	169.81
28	1160	648	1.31	26.24	444.00
29	1280	809	1.11	23.58	514.69
30	1360	904	2.13	38.30	454.64
Minimum	620	435	1.11	23.58	99.98
Maximum	1540	904	4.04	72.09	518.99
Mean	1078.66	676.9	2.47	44.17	337.11

3.3. Proposed suitability classification

In irrigated agriculture, EC, SAR, and SSP are considered to be the major criteria for assessing suitability classification. All water samples were classified ‘permissible’ to ‘good’ for EC. So, these sources of water might not cause any harm for agriculture purpose. With respect to SAR, all samples were graded as ‘excellent’ in class[14-19, 23].

Table 3: Quality classification and suitability of groundwater for irrigation purpose.

S/N	Overall suitability classification						
	EC	TDS	SAR	SSP	Boron	Alkalinity and salinity hazard	Proposed suitability classification
1	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
2	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
3	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
4	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
5	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
6	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
7	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
8	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
9	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
10	Good	Fre	Ex.	Dou.	Excellent	C3S1	Unsuitable
11	Permi.	Fre	Ex.	Permi.	Excellent	C2S1	Permissible
12	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
13	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
14	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
15	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
16	Good	Fre	Ex.	Dou.	Excellent	C3S1	Unsuitable
17	Permi.	Fre	Ex.	Good	Excellent	C2S1	Moderate suitable
18	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
19	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
20	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
21	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
22	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Moderate suitable
23	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
24	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible

25	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
26	Permi.	Fre	Ex.	Permi.	Excellent	C3S1	Permissible
27	Permi.	Fre	Ex.	Dou.	Excellent	C3S1	Unsuitable
28	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
29	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible
30	Permi.	Fre	Ex.	Good	Excellent	C3S1	Permissible

Key: C2 and C3 represent medium and high salinity hazard and S1 represent a low sodium hazard.

3.4. Correlation coefficient analysis

Correlation coefficient analyses were performed among the parameters viz. pH, EC, SAR, and SSP in all possible combinations (Table 4). It was evident that pH value was no significantly correlated with EC, TDS, SAR, and SSP. EC value was significantly correlated with TDS, SAR, and SSP at the 1% level of significance. It indicated that EC had an influence on TDS, SAR, and SSP. TDS value had significantly correlated with SAR and SSP at the 1% level of significance. SAR value showed a close relationship with SSP at the 1% level of significance.

Table 4: Correlation matrix among the standard parameters of suitability classification.

	pH	EC	TDS	SAR	SSP
EC	-0.11598^{NS}				
TDS	-0.12005^{NS}	0.97991**			
SAR	-0.02148^{NS}	-0.35176**	-0.39264**		
SSP	-0.01392^{NS}	-0.54803**	-0.59479**	0.96686**	

Legend: NS, *, and ** indicate not significant, significant at 5% and 1% level, respectively.

IV. DISCUSSION

4.1. Chemical properties of waters

All the water samples were alkaline in nature irrespective of their sources as mentioned earlier. The pH value above 7.0 due to change of temperature, release of CO_3, and other changes[20]. The 'highest desirable' and 'maximum permissible' limits for drinking purpose are 7.0 to 8.5 and 6.5 to 8.5, respectively[21]. So, these waters were found within the safe limit of WHO standard for drinking purpose. The pH range 6.0 to 8.5 is 'suitable' for irrigation water and not harmful for soils and crops[22]. The range of Ca content in groundwater largely depends on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$. As major ions, Ca, Mg, Na, K, Cl, and HCO_3 distributed at varying concentrations in the water samples. In the study area, water sources were within acceptable limits and were suitable for drinking and irrigation purpose with respect to major ions in the concentrations with the average values of 2.79, 4.01, 5.0, 0.0026, 6.4, and 3.6 $meqL^{-1}$, respectively. Some other ions like, NO_3, CO_3, SO_4 and also B was found nil to be very low in amount. The concentrations of SO_4 and B were far lower than the standard values (20 mgL^{-1} for SO_4 and 0.75 mgL^{-1} for B) and were not creating any problem for irrigation[22]. The concentrations of Mn, Zn, and Cu were nil. So, the waters were free from the toxic effect of these heavy metals and suitable for drinking and also for crop production. In the study area, groundwater was contaminated with different levels of arsenic. Among 30 samples, 17 (56.66%) were arsenics contaminated. Based on arsenic contamination, groundwater of the study area is harmful for using as drinking and irrigation water.

4.2. EC, TDS, SAR, SSP, and H_T

Electrical conductivity is a parameter that measures the total amount of soluble salts. In the study area, electrical conductivity of waters with an average value of 1078.66 μScm^{-1}, which showed high levels of a salt present in the waters. High salt containing water produces salinity while using for irrigation purpose, but it is 'permissible' water class[14]. The concentration of TDS presents in water samples is very important to assess the suitability for drinking, domestic, industrial, irrigation and livestock consumption quality. High TDS values indicate the presence of appreciable quantities of bicarbonate, sulphate and chlorides of Ca, Mg, Na, and Si[13]. The average value of TDS is 676.9 mgL^{-1}. All waters samples contained less than 1000 mgL^{-1} TDS and were suitable for irrigation purpose that is 'Fresh water' in class[15]. TDS less than 500 mgL^{-1} desirable for drinking purposes[16]. So, the water samples are unsuitable for drinking purpose. The computed SAR of water samples was with the mean value of 2.47. The SAR values of the sampled waters were far less from 10.00 SAR. So, the waters of all sources were safe for irrigation purpose[16]. The calculated SSP values of all water samples were had an average of 44.17. Which were less than 80 SSP and not harmfully affect irrigated crops and soil[14]. The calculated H_T values of all water samples were with the average of 337.11 mgL^{-1}. Among 30 water samples, 27 water samples were 'maximum permissible' for drinking purposes[21] and 19 samples were 'very hard', 2 were 'moderately hard' and the rest of 'hard' in class for irrigation purposes[19].

4.3. Proposed suitability classification

The irrigation water with SAR less than 10 might not be toxic for agriculture crop[16]. According to this classification, all the samples were rated as a low alkalinity hazard (S1) class for irrigation as per SAR value (Table 3). So, in the study area, alkalinity problem might not occur using this water. From the calculated value of SSP, 14 samples were 'permissible' and 13 were 'good' in class. Based on suitability class of B, all waters were graded as 'excellent' for irrigation, and could safely be used for successful crop production. For the irrigation water, EC, SAR, and SSP are considered to be the major criteria for assessing suitability classification, whereas TDA and B are minor. The waters were classified as 'suitable', 'moderately suitable', 'permissible' and 'unsuitable'[23]. Accordingly, the 'suitable' classed waters where those in which having EC, SAR, and SSP belonged to the 'excellent' to 'good category' (Table 3). When all the major criteria of water samples were 'doubtful' or 'unsuitable', then the category was referred to as 'unsuitable'. Based on these criteria, out of 30 samples, 3 were in this category.

I.4. Correlation coefficient analysis

The significant coefficient analyses were performed among EC-TDS,-SAR,-SSP; TDS-SAR,-SSP; SAR-SSP. These results reported that the quality of free soil solution may indicate the distribution of Na ion in the absorbed phase. The presence of Na in irrigation water influences the physical properties of the soil, particularly the permeability by affecting the swelling and dispersion of the clay[24]. Besides, when the excess carbonate (residual) concentration becomes too high, then combines with Ca and Mg to form a solid material (scale) which settles out of the water. The result is an increase in both the Na percentage and SAR[25]. At the same time, as per result, it may create alkali hazardous in soil and may encumber successful crop production. On the other hand, insignificant correlation of a coefficient among pH-EC,-TDS,-SAR,-SSP indicates that the increase of one parameter will result in the decreasing of the aforementioned parameters.

V. CONCLUSION

In the study area, water quality parameters of the groundwater samples were beyond the 'permissible' limit for drinking purpose as per WHO standard, but some of these were 'unsuitable' for irrigation purpose under normal condition for undesirable levels of EC, TDS, SSP, and H_T. Among the thirty water samples, 56.66% water samples were contained arsenic that requires some degree of treatment and protection from contamination before drinking and irrigation. These findings highlight the need for a quality water supply program for Comilla district, Bangladesh, with special emphasis on the arsenic-affected area.

ACKNOWLEDGMENT

We are grateful to Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh for the support of research. Thankful to the Department of Food Processing and Engineering, Department of Soil Science, Hajee Mohammad Danesh Science and Technology University, Dinajpur, the Director, SRDI, Dinajpur for their laboratory services and TNO, Homna Thana, Comilla District, Bangladesh for their kind cooperation in this research work.

REFERENCES

[1] Mirza, M.M.Q. (1996). Diversion of the Ganges water at Farakka and its effects on salinity in Bangladesh. Journal of Environmental Management, 22:711–722.
[2] Nickson, R. T., McArthur, J. M., Shrestha, B., Kyaw-Myint, T.O. and Lowry, D. (2005). Arsenic and other drinking waterquality issues, Muzaffargarh District, Pakistan. Applied Geochemistry, 20:55–68.
[3] Shahid, S., Chen, X. and Hazarika, M.K. (2006). Evaluation of groundwater quality for irrigation in Bangladesh using geographic information system. Journal of Hydrology and Hydromechanics, 54:3–14
[4] Islam, M.J., Uddin, S.M.H., Zaman, M.W., Mahmood, R.I. and Rahman, M.S. (2003). Toxicity assessment of groundwater in different aquifers of Khagrachari in Bangladesh. Asian Journal of Plant Science, 2:257–260.
[5] Roy, P.K., Roy, B., Sarker, B.C., Uddin, M.N. and Roy, S.R. (2010). Arsenic contamination and ionic toxicity for suitability assessment of groundwater and surface water for irrigated in Comilla region. Journal of Agroforestry and Environment, 4:57–62.
[6] Mandal, P., Upadhyay, R. and Hasan, A. (2010). Seasonal and spatial variation of Yamuna river water quality in Delhi, India. Environ Monit Assess, 170: 661–670.
[7] World Health Organization-WHO. (1997). Guidelines for drinking water quality. 2nd Edition Surveillance and Control of community supplies. Geneva, Switzerland.
[8] Pandey, S.K. and Tiwari, S. (2009). Physico-chemical analyses of groundwater of selected area of Ghazipur city-A case study. Nature and Science, 7:17–20.
[9] Jinwal, A. and Dixit, S. (2008). Pre and post monsoon variation in physio-chemical characteristic in groundwater quality in Bhopal, India. Asian Journal of Experimental Sciences, 22:311–316.
[10] Frengstad, B., Skrede, A.K.M., Banks, D., Krog, J.R. and Siewere, U. (2000). The Chemistry of Norwegian ground water:III. The distribution of trace elements in 476 crystalline bedrock ground waters, as analyzed by ICP-MS techniques. The Science of the Total Environment, 246:21–40.
[11] Eaton, A.D., Clescri, L.S. and Greenberg, A.E. (1995). Standard methods for the examination of water and wastewater. (19th Ed.). American public health association. American water works association. Water Environment Federation. Washington DC.
[12] Ghosh, A.B., Bajaj, J.C., Hasan, R. and Singh, D. (1983). Soil and water testing method. A laboratory manual, division of soil science and agricultural chemistry. IARI, New Delhi. pp.1–48.
[13] Karanth, K.R. (1994). Groundwater assessment development and management. TATA McGraw-Hill Publishing Company Limited. New Delhi, pp. 217–273.
[14] Wilcox, L.V. (1955). Classification and use of irrigation water. United States Department of Agriculture. Circular No. 969. Washington DC. p. 19.
[15] Freeze, A.R. and Cherry, J.A. (1979). Groundwater. Prentice Hall, Inc. Englewood Cliffs, New Jersey.07632. pp. 84–387.
[16] Todd, D.K. (1980). Groundwater hydrology (2nd Ed). John-Wiley and Sons. Inc., New York 10016. pp. 267–315.
[17] Eaton, F.M. (1950). Significance of carbonation irrigation waters. Soil Science, 67:12–133.
[18] Richards, L.A. (1954). Diagnosis and improvement of saline and alkali soils. (Ed.) U.S. Agricultural Hand Book 60, and IBM. Publishing Co. Ltd. New Delhi, India. pp. 98–99.
[19] Sawyer, C.N. and McCarty, P.L. (1967). Chemistry for sanitary engineers. 2nd ed. McGraw-Hill, New York. p. 518.
[20] UNDP (United Nations Development Program). (1987). The groundwater resources and its available for development. Master plan organization, Ministry of irrigation, Water development and flood control, Government of the people's republic of Bangladesh. Technical reports No. 5. pp. 4–46.
[21] World Health Organization. (2011). Guidelines for Drinking Water Quality. 4th Edn., World Health Organization, Geneva, Switzerland.
[22] Ayers, R.S. and Westcot, D.W. (1985). Water quality for agriculture. FAO irrigation and drainage Paper 29 (Rev. 1): pp. 40–96.
[23] Sarker, B.C., Hara, M. and Zaman, M.W. (2000). Suitability assessment of natural water in relation to irrigation and soil properties. Soil Science and Plant Nutrition, 46:773–786.
[24] Finkel, H.J. (1993). CRC Handbook of irrigation technology. CRC Press, Inc. Boca Raton, Florida. Vol. I. p. 88.
[25] Johnson, G. and Hhang, H. (2003). Classification of irrigation water quality. Oklahoma cooperative extension. Fact sheet 2401 (www.osuextra.com).

AUTHORS

First Author – Prodip K. Roy, Ph.D. student, Department of Chemistry, Biology and Marine Sciences, University of the Ryukyus, Nishihara-cho, Okinawa 903-0213, Japan. Email: prodipkroy@gmail.com

Second Author – B. Roy, Professor, Department of Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200, Bangladesh
Email: balaram_roy@yahoo.com

Third Author – Bikash C. Roy, Professor, Department of Agricultural Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200, Bangladesh
Email: bikashsarker@hotmail.com

Correspondence Author – Prodip K. Roy, prodipkroy@gmail.com, Tel.: +81-(0)80-3945-4180