



Toxicity analyses of ground water of some industrial areas of Bogra sadar upazila

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ABSTRACT

An investigation was carried out to assess the extent of ionic toxicity of ground water samples for agricultural usage in in the AEZ-04 viz., Karatoya-Bangali Floodplain (2,577 sq. km). Thirty water samples were collected from five industrial areas of Bogra sadar upazila to assess the dissolved chemical constituents and also to classify them on the basis of their comparative stability for agricultural usage. Water samples were collected from ground water sources namely shallow tube wells at Bogra sadar upazila. The chemical analyses included pH, electrical conductivity (EC), total dissolved solids (TDS), Ca, Mg, K, Na, Zn, Cu, Fe, Mn, Cd, Pb, B, As, CO₃, HCO₃, PO₄, SO₄ and Cl. The pH indicated that ground water samples were acidic to alkaline in nature (pH = 6.5-8.8 and pH = 7.2-8.7). Among them only 2 ground water samples were found 'unsuitable' for irrigation. The electrical conductivity (EC) and sodium absorption ratio (SAR) revealed that all the ground water samples were categorized as 'medium salinity' (C2) and 'low alkalinity' (S1) hazards with 'excellent' and 'good' in quality combining expressed as C2S1. Considering total dissolved solids (TDS) all the ground waters were as 'freshwater'. Soluble sodium percentage (SSP) indicated that all the ground water samples were 'excellent' and 'good' classes. Residual sodium carbonate (RSC) categorized the ground water samples as 'suitable' in quality for irrigation. All the ground waters were classified as 'moderately hard' and 'hard' classes. As the status of Ca, Mg, Na, K, Zn, Cu, As, B, Fe, CO₃, SO₄, PO₄, and Cl were not hazards in the investigated area because these detected ions were far below the recommended limits for irrigation. In all ground water samples, HCO₃ ion was considered as pollutant for irrigating crops, 15 samples for Cd, 11 samples for Pb and 3 samples for Mg and only 1 sample for PO₄ were found unsuitable for irrigation. Rest ionic constituents were suitable for irrigation purposes. As, B, SO₄, Cl and total dissolved solids (TDS) were not problematic for drinking, total dissolved solids (TDS), Cd, Cu and Zn were not hazardous for livestock usage and SO₄ and hardness (H_T) were not problematic for aquaculture. But rest ionic constituents for these respective usages were toxic.

INTRODUCTION

Groundwater contamination due to industrial activities is a matter of growing concern in many regions around the world. The quality of groundwater is essential for maintaining public health and ensuring the availability of safe drinking water.

In Bangladesh, industries are building up their positions at a high rate and with a costly result to the environment. Amongst the environmental components water and soil are mostly affected. The contamination of water with toxic effluents is

a major environmental problem. Some of these are carcinogenic at high concentrations and can cause serious health hazard if they enter into the food chain. Metallic effluents such as Cu, Zn, Mn, Fe, Cd, Pb, B, As etc. are usually present in water at low concentration, but enhanced concentration of these metals have found as a result of human activities. Investigations have been made in different countries by different researchers on the extent of heavy metals pollution in surface water, ground water, soil, sediments and vegetation (Zakir et al., 2006; Mohiuddin et al., 2010; Akbal et al., 2011; Zakir et al., 2011; Shikazono et al., 2012).

Industrial activities such as manufacturing, processing, and waste disposal can introduce various pollutants into the environment. These pollutants may include heavy metals, organic chemicals, and other toxic substances, which can infiltrate the groundwater through improper waste management practices, accidental spills, or leaching from industrial sites.

Bogra district is situated in the AEZ-04 viz., Karatoya-Bangali Floodplain (2,577 sq. km.) and AEZ-25 viz., Level Barind Tract (8 sq. km.). Bogra district has an area of 2919.9 sq. km. with an annual average temperature of maximum of 34.6°C and minimum of 11.9°C and annual rainfall of 1610 mm. Bogra is one of the newly industrial based areas of Bangladesh, which is highly susceptible to environmental pollution due to the over population, rapid industrialization and urbanization in last 10 years. There are several types of industrial units including aluminium factories, tanneries, pharmaceutical industries, cosmetics industries, diesel plants, ceramics factories, packaging industries, brickfields, garments and many more which are potentially posing a risk to the groundwater quality. The national profile shows that Bangladesh now has 30,000 industrial units of which 24,000 units are small and cottage. The remaining 6,000 are large and medium industries (DOE, 2011). From the different industrial zones of the country contamination of water by various metallic and non-metallic chemicals are very common. Inorganic pollutants are mostly metallic salts, basic and acidic compounds. These inorganic components undergo different chemical and biochemical interaction in the land and deteriorate water quality of the surrounding areas. Industries of Bogra regions are also experiencing the same consequences.

Several studies have highlighted the issue of groundwater contamination in Bangladesh, particularly in industrial regions. A study by Chowdhury et al. (2019) conducted in the vicinity of Dhaka, the capital city, revealed high levels of heavy metals, including arsenic, lead, and chromium, in groundwater due to industrial activities and inadequate waste management. Another study by Ahmed et al. (2018) focused on industrial areas in Chittagong, Bangladesh, and

reported the presence of various pollutants, such as organic chemicals and heavy metals, in groundwater samples.

These findings emphasize the need for similar investigations in Bogra Sadar Upazila to evaluate the potential risks associated with industrial activities and groundwater contamination. A comprehensive toxicity analysis will provide critical information about the presence and concentrations of specific contaminants, enabling a better understanding of the overall water quality and potential health risks for the local population.

Considering the above facts, the present study was aimed to assess some contaminations, moreover some toxicity level in water of the investigated areas. The ionic toxicity and the level of toxic metallic contamination of ground water at some industrial areas of Bogra sadar upazila, Bangladesh were investigated.

MATERIALS AND METHOD

Degree of water toxicity or water quality was evaluated by detecting the concentrations of various constituents present therein. Essentially, all water samples contain substance derived from the natural environment or from the waste products of human activities. The major factor to assess water toxicity is the chemical properties. Determination of pH, electrical conductivity (EC), total dissolved solids (TDS), Ca, Mg, Na, K, Zn, Cu, Fe, Mn, Cd, Pb, B, As, CO₃, HCO₃, PO₄, SO₄ and Cl are included in chemical analyses.

Collection and preparation of water samples

The first consideration for assessment of water pollution is obtaining a sample or series of representative samples. 15 groundwater samples were randomly collected to cover most of the study areas during 6 September 2013 to 8 September 2013 following the instructions as outline by Hunt and Wilson (1986) and APHA (2005). All 15 groundwater samples were collected from shallow tube wells. The information regarding ground water sampling sites has been presented in Table 1. Groundwater samples were collected at running conditions of shallow tube well after pumping sufficient

quantity of ground water samples were taken from depth of 0.5 to 1.5 feet. The water samples were carried to the Soil Science Laboratory of Bangladesh Agricultural Research Institute, Joydebpur, Gazipur. The water samples were kept in a clean, cool and dry place. All the water

samples were filtered through filter paper (Whatman No. 1) to remove undesirable solids and suspended materials before chemical analysis. The chemical analyses were performed as quickly as possible on arrival at the laboratory.

Table 1: Detailed information of ground water sampling

Sample No.	Sampling sites		Water sources	Depth of well (m)	Duration of usages (years)
	Industries	Areas			
1.	Tajma Creamic	Koigari, Koloni, Bokshi	STW	9.14	10
2.	Industry	Bazar, Thonthonia	STW	7.92	15
3.			STW	27.43	7
4.	Bhandari Glass	Majhira, Sultanganj, Majhira	STW	21.33	8
5.	Works Industry	Cantonment area	STW	19.81	8
6.			STW	21.33	7
7.	North Bengal	Charmatha, Godarpara,	STW	27.43	5
8.	Tannery	Nishindara, Rajapur	STW	27.43	4
9.			STW	18.288	9
10.	Habib Match	Erulia, Noongola	STW	18.28	9
11.	Factory		STW	19.81	8
12.			STW	21.33	5
13.	Azad Pulp and Paper	Namuja, Shibgonj, Gokul	STW	13.71	9
14.	Mill		STW	33.52	4
15.			STW	30.48	4

Analytical techniques

The major chemical constituents of water and its quality factors were considered for analyses of pH (Singh et al. 1999), Electrical Conductivity (Ghosh et al. 1983), Total Dissolved Solids (Chopra and Kanwar, 1980), Ionic Constituents- Calcium (Ca) and Magnesium (Page et al. 1982 and Singh et al. 1999); Sodium and Potassium (Golterman (1971, Ghosh et al. 1983); Zinc (Zn), Copper (Cu), Iron (Fe) and Manganese (Mn) as described by APHA, 2005), Cadmium (Cd), Lead (Pb), Boron (B), Arsenic (As), Carbonate (CO₃), Bicarbonate (HCO₃), Phosphate (PO₄), Sulphate (SO₄) and Chloride (Cl). The chemical analyses of water samples were accomplished in the Laboratory of Soil Science Department of Bangladesh Agricultural Research Institute, Joydebpur, Gazipur.

Cadmium (Cd) and Lead (Pb) were analyzed by atomic absorption spectrophotometer (Model Hitachi 170-30) following the procedure as stated by APHA (1998). The concentration of boron (B), Carbonate (CO₃), Bicarbonate (HCO₃) and

Sulphate (SO₄) in water samples were determined by azomethine-H method as outlined by Tandon (1995).

The presence of arsenic in water sample was tested according to APHA, 1995. Phosphate (PO₄) was determined as per Jackson (1973). Assessment of water quality or toxicity. The concentrations of major ions present in water samples affect water quality. The following water quality factors were considered in judging water pollution or toxicity by the interpretation of analytical results of waters:

Sodium absorption ratio (SAR)

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

Soluble sodium percentage (SSP)

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

Residual sodium carbonate (RSC)

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

Hardness (H_T)

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

Whereas, all the ionic concentrations were expressed as me L^{-1} but in case of hardness cationic concentrations were expressed as mg L^{-1} .

Statistical analyses

The statistical analyses of the analytical results obtained from water samples were performed (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Water quality rating or toxicity for irrigation usage

In the present study, major ions like Ca, Mg, K, Na, HCO_3 and Cl were found in significant quantities but the remaining detected ions were also recorded in minor amounts in all the collected water samples. The estimated amounts of these ions present in all the samples in relation to irrigation water quality have been discussed.

Cations

The amount of cations present in water samples have been illustrated in Table 2 and Table 3. The major cations were expressed as me L^{-1} and other cations in minor quantities were expressed as mg L^{-1} (Table 2 and Table 3).

Calcium

The concentration of Ca in ground water samples was found within the range of 0.90 me L^{-1} to 2.30 me L^{-1} with the average value of 1.66 me L^{-1} (Table 3). The standard deviation (SD) and coefficient of variation (CV) were 0.42 and 25.53%, respectively. The highest concentration (2.30 me L^{-1}) was found at sample no. 14. The lowest concentration (0.90 me L^{-1}) was found in the sample no. 12. The contribution of Ca content in water samples was largely dependent on the solubility of CaCO_3 , CaSO_4 and rarely on CaCl_2 (Karanth, 1994). Irrigation water containing less than the 20 me L^{-1} Ca was 'suitable' for irrigating crop plants (Ayers and Westcot, 1985). On the basis of Ca content, all the water samples can safely be used for irrigation and would not be affected the soils.

Table 2: pH, EC, TDS and anionic constituents of ground water samples

SL. No.	pH	EC $\mu\text{S cm L}^{-1}$	TDS mg L^{-1}	CO3 mg L^{-1}	HCO3 me L^{-1}	PO4 mg L^{-1}	SO4 mg L^{-1}	Cl me L^{-1}
1.	8.6	570.20	383.90	Trace	3.50	0.35	0.39	1.00
2.	7.8	489.60	356.80	Trace	3.10	0.35	0.26	1.20
3.	8.5	439.20	341.70	Trace	3.50	0.06	3.26	0.60
4.	8.0	457.90	377.70	Trace	3.50	0.11	0.26	0.60
5.	8.2	416.90	320.90	Trace	3.20	0.01	0.39	0.80
6.	8.0	374.80	311.80	Trace	2.50	0.09	Trace	0.80
7.	7.2	498.70	317.30	Trace	3.50	0.21	0.13	0.60
8.	7.4	435.50	276.80	Trace	2.50	2.20	0.26	1.20
9.	8.2	503.60	436.20	Trace	4.00	0.25	0.78	0.80
10.	8.3	398.70	314.30	Trace	3.00	0.27	10.30	0.80
11.	8.7	405.20	287.90	Trace	2.50	0.17	1.40	0.80
12.	8.4	400.80	273.00	Trace	3.00	0.29	Trace	0.80
13.	8.4	530.20	345.80	Trace	3.50	0.17	Trace	1.00
14.	7.2	524.20	440.70	Trace	4.50	0.24	0.91	0.80
15.	7.6	525.60	458.50	Trace	4.00	0.01	Trace	1.20
Range								
Min	7.2	374.80	273.00		2.50	0.01	Trace	0.60
Max	8.7	570.20	458.50		4.50	2.20	10.30	1.20
Mean		464.74	349.55		3.32	0.32	1.67	0.87
SD		59.67	59.32		0.58	0.53	3.00	0.21
CV%		12.84	16.97		17.57	166.99	179.99	24.15

Legend: Traces of CO_3 and SO_4 were considered as $<0.05 \text{ mg L}^{-1}$ and $<0.01 \text{ mg L}^{-1}$, respectively.

Table 3: Cationic constituents of ground water samples

SL. No.	Ca	Mg	Na	K	Zn	Cu	Fe	Mn	Cd	Pb	B	As
	me L ⁻¹	me L ⁻¹	me L ⁻¹	me L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹
1.	1.3	2.6	1.14	0.09	0.011	0.013	0.50	0.08	0.005	Trace	0.15	Trace
2.	2.2	1.6	1.05	0.04	0.021	0.012	0.65	0.07	0.013	Trace	0.12	Trace
3.	1.3	2.3	1.02	0.02	0.024	0.010	0.35	0.05	0.006	0.02	0.38	Trace
4.	1.5	2.2	0.90	0.05	0.035	0.017	0.80	0.06	0.014	Trace	0.34	Trace
5.	2.0	1.5	0.84	0.07	0.038	0.013	0.90	0.21	0.020	Trace	0.18	Trace
6.	1.8	1.2	0.71	Trace	0.043	0.011	0.92	0.81	0.003	Trace	0.23	Trace
7.	2.2	1.9	0.66	0.02	0.059	0.011	0.62	0.09	0.014	0.36	0.24	Trace
8.	1.4	1.4	0.99	0.15	0.064	0.010	0.59	0.10	0.021	0.20	0.32	Trace
9.	1.9	2.8	0.73	0.05	0.067	0.011	1.25	0.05	Trace	0.17	0.33	Trace
10.	1.2	2.4	0.54	0.02	0.019	0.011	0.72	0.09	0.009	0.29	0.36	Trace
11.	1.3	1.7	0.56	0.10	0.026	0.011	0.52	0.02	0.010	0.63	0.52	Trace
12.	0.9	1.8	0.62	0.02	0.025	0.016	0.45	0.03	0.018	0.68	0.40	Trace
13.	1.9	2.3	0.92	0.05	0.044	0.015	0.28	0.08	0.008	0.24	0.24	Trace
14.	2.3	2.5	0.83	0.06	0.047	0.014	0.48	0.05	0.019	0.37	0.18	Trace
15.	1.7	2.9	1.02	0.04	0.021	0.014	0.74	0.07	Trace	0.18	0.36	Trace
Range												
Min	0.90	1.20	0.54	Trace	0.011	0.010	0.28	0.02	Trace	Trace	0.12	
Max	2.30	2.90	1.14	0.15	0.067	0.017	1.25	0.81	0.021	0.68	0.52	
Mean	1.66	2.07	0.84	0.06	0.036	0.013	0.65	0.12	0.012	0.31	0.29	
SD	0.42	0.53	0.19	0.04	0.017	0.002	0.25	0.19	0.006	0.21	0.11	
CV%	25.53	25.49	22.83	66.68	47.99	17.44	38.29	157.0	48.79	65.72	37.91	

Legend: T=Trace, Traces of K, Cd, Pb and As were <0.01 me L⁻¹, <0.005 mg L⁻¹, <0.01 mgL⁻¹, and <0.05 mg L⁻¹, respectively.

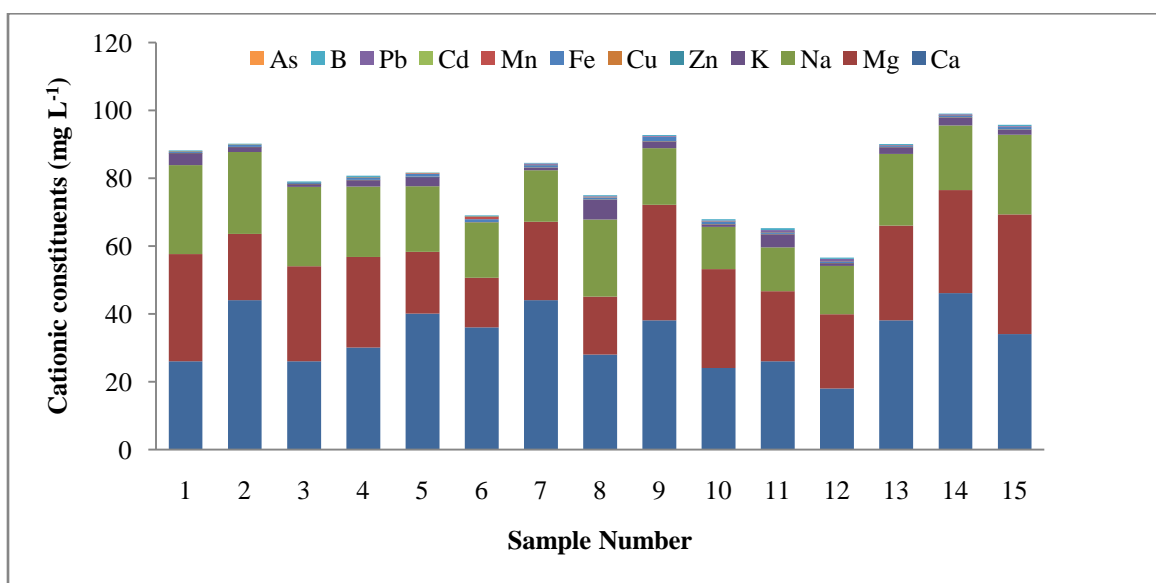


Figure 1: Bar diagram for representing major cationic constituents of ground water samples

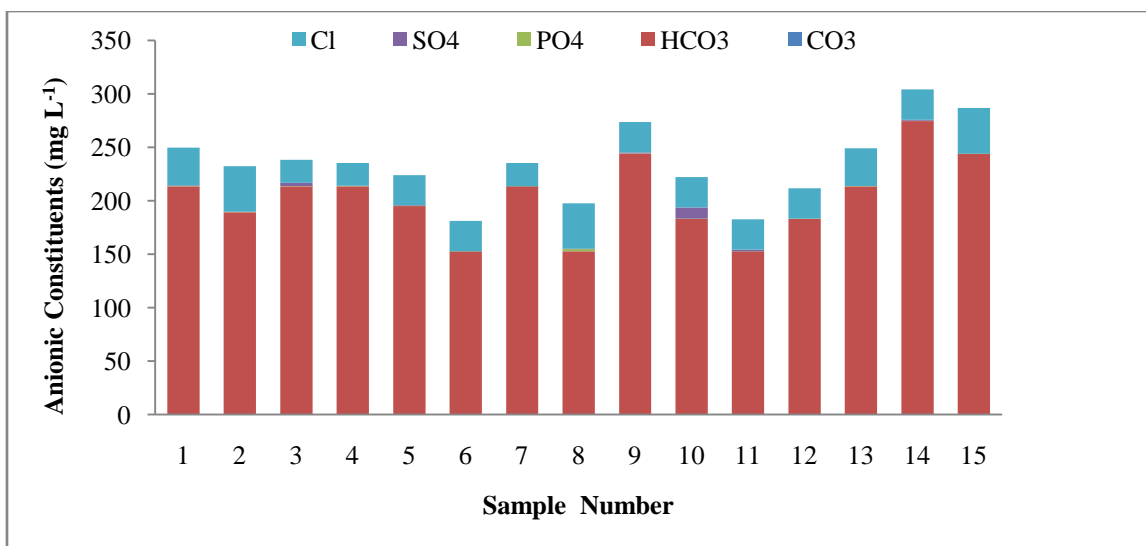


Figure 2: Bar diagram for representing major anionic constituents of ground water sample4.2 Ionic constituents

Magnesium

In ground water samples, Mg content was found within the range of 1.20 me L⁻¹ to 2.90 me L⁻¹ with the average value of 2.07 me L⁻¹ (Table 3). The standard deviation (SD) and co-efficient of variation (CV) were 0.53 and 25.49%, respectively (Table 3).

According to Ayers and Westcot (1985), all the irrigation waters contain below 5.0 me L⁻¹ Mg. In the study area, not a single sample did exceed this limit (Table 1). Therefore, all the water samples were 'suitable' for irrigation with respect to Mg content.

Sodium

The concentration of Na in all the ground water samples was within the range of 0.54 me L⁻¹ to 1.14 me L⁻¹ with the mean value of 0.84 me L⁻¹ (Table 3). The respective standard deviation (SD) and co-efficient of variation (CV) were 0.19 and 22.83%. Waters generally contain less than 40 me L⁻¹ Na (Ayers and Westcot, 1985). The recorded Na content in all water samples under test was far below this specific limit. In respect of Na content, all the waters of the study area can be safely applied for long-term irrigation without the harmful effects on soils and crops.

Potassium

Potassium status of the ground water samples within the range of trace to 0.15 me L⁻¹ with the mean value of 0.06 me L⁻¹ (Table 3). The standard deviation (SD) and co-efficient of variation (CV) were 0.04 and 66.68%, respectively (Table 3). The presence of higher quantity of K in some water samples might be due to some potash bearing minerals like sylvite (KCl) and nitre (KNO₃) in the aquifer (Karanth, 1994). The detected quantity of K in all the collected water samples had no significant influence on the water quality for irrigation.

Zinc

The status of zinc present in 15 ground water samples was reported to vary from 0.011 mg L⁻¹ to 0.067 mg L⁻¹ with the mean value of 0.036 mg L⁻¹ (Table 3). The highest amount of Zn (0.067 mg L⁻¹) was detected from sample no. 9 and the lowest amount of Zn (0.011 mg L⁻¹) was detected from sample no. 1. The calculated standard deviation was 0.017 and co-efficient of variation was 47.99%. Therefore the waters of the study area were detected below the recommended limits and might be safely used for the irrigation purpose.

Copper

In the collected ground water samples Cu ranging from 0.010 mg L⁻¹ to 0.017 mg L⁻¹ with the mean value of 0.013 mg L⁻¹ (Table 3). The SD and CV were 0.002 and 17.44%, respectively. The concentration of Cu in the investigated area was observed within the safe limit. Because the recommended maximum concentration of Cu for irrigation water used continuously on all soils 0.20 mg L⁻¹ (Ayers and Westcot, 1985). So, the concentration of Cu in the study area might not be harmful for irrigation usage.

Iron

The concentration of iron in the collected ground water samples ranged from 0.28 mg L⁻¹ to 1.25 mg L⁻¹ with the mean value of 0.65 mg L⁻¹ (Table 3). The highest concentration (1.25 mg L⁻¹) was obtained from sample no. 9 and the lowest concentration (0.28 mg L⁻¹) was obtained from sample no. 13. The calculated standard deviation was 0.25 and CV was 38.29% (Table 3).

The data indicated that the concentration of Fe was below the recommended limits for irrigation. Irrigation water containing 5.0 mg L⁻¹ was suitable for crop productions as stated by Ayers and Westcot (1985). In present study, Fe concentration was low (0.25 to 1.25 mg L⁻¹) perhaps due to relatively high pH of the water samples. Therefore, iron content in waters of the study area would not create a problem for irrigation usage.

Manganese

The content of Mn in ground water samples varied from 0.02 mg L⁻¹ to 0.81 mg L⁻¹ with the average value of 0.12 mg L⁻¹ (Table 3). The calculated standard deviation and CV were 0.19 and 157.00%, respectively. According to Ayers and Westcot (1985) the maximum recommended content of Mn for water used for irrigation is 0.20 mg L⁻¹. On the basis of Mn content, only 2 samples (5 & 6) were toxic for continuous irrigation.

Cadmium

The concentration of Cd in the water ground samples was within the range of trace to 0.021 mg

L⁻¹ with the mean value of 0.012 mg L⁻¹ (Table 4.4). The respective SD and CV were 0.006 and 48.79%. The highest value of Cd was recorded in sample no. 8 and the trace values were recorded in samples no. 9 and 15. Considering Cd ions, 15 water samples were hazardous for long-term irrigation because the recorded content of Cd exceeded the acceptable limit (0.01 mg L⁻¹).

Lead

All the ground water samples collected from Bogra sadar upazila contained a Pb ranging from traces to 0.68 mg L⁻¹ with the mean value of 0.31 mg L⁻¹ (Table 3). The respective SD and CV were 0.21 and 65.72%. The highest value of Pb was found in the sample no. 12 and the trace amounts of Pb were detected in 5 water samples. The present study indicated that the content of Pb in water samples collected from Bogra sadar upazila might not be harmful for crop production and irrigation usage.

Boron

Boron status of the 15 ground water samples ranged from 0.12 mg L⁻¹ to 0.52 mg L⁻¹ with the mean value of 0.29 mg L⁻¹ (Table 3). The computed standard deviation and co-efficient of variation were 0.11 and 37.91%, respectively. The recommended maximum concentration of B for irrigation water used continuously on soil is less than 0.75 mg L⁻¹ (Ayers and Westcot, 1985). In the study area, all the water samples were suitable for irrigation based on B content (0.75 mg L⁻¹). According to Wilcox (1955) 20 samples were excellent for sensitive crops and rest 10 samples were good for sensitive crops.

Arsenic

All the collected water samples contained trace amount of As (<0.05 mg L⁻¹) (Table 3). In respect of As ions, all the water under study were not problematic when applied to soil as irrigation water as the obtained concentration of As in waters did not exceed the maximum recommended limit (0.10 mg L⁻¹).

Anions

The collected water samples were analyzed for determining the amount of anions like CO_3 , HCO_3 , PO_4 , SO_4 and Cl. From the analyses, it was evident that HCO_3 showed dominance among the anions and then comes Cl, after that PO_4 . SO_4 was detected in trace partially while CO_3 totally detected in trace amounts.

Carbonate

The amount of carbonate was not detected higher than trace amount ($<0.10 \text{ mg L}^{-1}$) in all the water samples (Table 1). The limit was recommended by Ayers and Westcot, 1985. For this reason, this anion was not considered as pollutant for irrigating crops.

Bicarbonate

The concentration of HCO_3 in ground water samples was within the range of 2.50 me L^{-1} to 4.50 me L^{-1} with the average value of 3.32 me L^{-1} (Table 1). The calculated SD and CV were 0.58 and 17.57%, respectively. Bicarbonate content was recorded comparatively higher among the ionic constituents. In respect of HCO_3 content, all the water samples were toxic for irrigation because HCO_3 content exceeded the recommended limit (1.50 me L^{-1}).

Phosphate

The phosphate content of all the collected ground water samples varied from 0.01 mg L^{-1} to 2.20 mg L^{-1} with the mean value of 0.32 mg L^{-1} (Table 1). The SD and CV were 0.53 and 166.99%, respectively. The status of PO_4 in all samples was found within the recommended limit as per Ayers and Westcot (1985) except one sample (no. 8) was 'doubtful' for long-term irrigation because its content (2.20 mg L^{-1}) exceeded the acceptable limit (2.00 mg L^{-1}). The present investigation showed that PO_4 concentration in water samples of the investigated area would not be harmful for crop productions except one.

Sulphate

In all the ground water samples sulphate content varied from trace to 10.30 mg L^{-1} with the mean

value of 1.67 mg L^{-1} (Table 1). Out of 15 samples, 4 samples contained trace amounts and the highest concentration (10.30 mg L^{-1}) was found in the sample no. 10. The SD and CV were 3.00 and 179.99%, respectively. According to Ayers and Westcot (1985), the acceptable limit of SO_4 in irrigation water is less than 20 mg L^{-1} . On the basis of limit, all the waters under investigation were not problematic for irrigation without any toxic effect on soils and crops grown in the study area.

Chloride

Ground water samples collected from the study area contained Cl ranging from 0.60 me L^{-1} to 1.20 me L^{-1} with the average of 0.87 me L^{-1} (Table 1). The SD and CV were 0.21 and 24.15%, respectively. Chlorine content of all the waters collected from the study area was not problematic for irrigation as the obtained anionic concentration was below the recommended limit (4.00 me L^{-1}). Most of the chloride in water samples was present as sodium chloride (NaCl) but chloride content may exceed sodium due to the base phenomena (Karanth, 1994).

Water quality determining indices

Sodium absorption ratio (SAR)

The computed sodium absorption ratio (SAR) of ground water samples was within the range of 0.40 to 0.84 with the average of 0.62 (Table 4). The SD and CV were 0.14 and 22.40%, respectively.

On the basis of SAR, Todd (1980) categorized irrigation water into 4 groups (Excellent <10 , Good 10-18, Fair 18-26, Poor >26 SAR). Considering this classification, all the waters were 'excellent' for irrigation. The present investigation expressed that a good proportion of Ca and Mg existed in waters which was 'suitable' for good structure and tilth condition of soil and also the improvement of soil permeability. The irrigation water with SAR less than 10.00 might not be harmful for agricultural crops (Todd, 1980). All the water samples used for irrigation were also classified on the basis of alkalinity (Richards, 1968). According to this classification, all the samples were rated as low hazard (S1) class for irrigation as per SAR value (Table 4).

Soluble sodium percentage (SSP)

The calculated soluble sodium percentage (SSP) value of all the collected ground water samples varied from 13.46% to 28.93% with the mean value of 19.34% (Table 4). The SD and CV were 4.12 and 21.30%, respectively. According to the water classification proposed by Wilcox (1955), 9 samples were classified as 'excellent' (SSP<20%) and the rest 6 samples were rated as 'good' class (SSP=20%-40%). In the study area, the ground waters might be applied for irrigating agricultural crops.

Residual sodium carbonate (RSC)

The computed residual sodium carbonate (RSC) values from the data generated out of chemical analyses of ground water samples ranged from -0.70 me L⁻¹ to 0.30 me L⁻¹ with the mean value of -0.41 me L⁻¹ (Table 4). The standard deviation (SD) and co-efficient of variation (CV) were 0.27 and -66.49%, respectively. Among the 15 ground water

samples under test, 14 samples contained negative value and only one sample was positive in value.

According to Eaton (1950) and Ghosh et al. (1983), all the water samples were found to be 'suitable' class (RSC<1.25 me L⁻¹). For this reason, all the water samples might not be problematic for irrigation purposes.

Hardness (H_T)

The calculated hardness of all the ground water samples varied from 134.83 mg L⁻¹ to 239.87 mg L⁻¹ with the mean value of 186.53 mg L⁻¹ (Table 4). The standard deviation (SD) and the coefficient of variation (CV) were 33.54 and 17.98%, respectively.

According to the classification proposed by Sawyer and McCarty (1967) only 4 ground water samples (no. 6, 8, 11 and 12) were graded as 'moderately hard' and rest 11 samples were graded as 'hard'. Hardness of water samples resulted due to the abundant presence of divalent cations like Ca²⁺ and Mg²⁺ (Todd, 1980).

Table 4: Quality rating and suitability of ground water used for irrigation

Sl. No.	SAR	SSP %	RSC me L ⁻¹	H _T mg L ⁻¹	Water class based on				Alkalinity and salinity hazard
					SAR	SSP	RSC	H _T	
1.	0.82	23.98	-0.40	194.76	Ex.	Good	Suit.	Hard	C2S1
2.	0.76	22.29	-0.70	189.99	Ex.	Good	Suit.	Hard	C2S1
3.	0.76	22.41	-0.10	179.80	Ex.	Good	Suit.	Hard	C2S1
4.	0.66	20.43	-0.20	184.83	Ex.	Good	Suit.	Hard	C2S1
5.	0.63	20.63	-0.30	174.98	Ex.	Good	Suit.	Hard	C2S1
6.	0.58	19.14	-0.50	150.01	Ex.	Ex.	Suit.	MH	C2S1
7.	0.46	14.23	-0.60	204.95	Ex.	Ex.	Suit.	Hard	C2S1
8.	0.84	28.93	-0.30	139.94	Ex.	Good	Suit.	MH	C2S1
9.	0.48	14.23	-0.70	234.79	Ex.	Ex.	Suit.	Hard	C2S1
10.	0.40	13.46	-0.60	179.77	Ex.	Ex.	Suit.	Hard	C2S1
11.	0.46	18.03	-0.50	149.89	Ex.	Ex.	Suit.	MH	C2S1
12.	0.53	19.16	0.30	134.83	Ex.	Ex.	Suit.	MH	C2S1
13.	0.63	18.76	-0.70	209.86	Ex.	Ex.	Suit.	Hard	C2S1
14.	0.54	15.64	-0.30	239.87	Ex.	Ex.	Suit.	Hard	C2S1
15.	0.67	18.73	-0.60	229.75	Ex.	Ex.	Suit.	Hard	C2S1
Range									
Min	0.40	13.46	-0.70	134.83					
Max	0.84	28.93	0.30	239.87					
Mean	0.62	19.34	-0.41	186.53					
SD	0.14	4.12	0.27	33.54					
CV%	22.40	21.30	-66.49	17.98					

Legend: Ex=Excellent, MH=Moderately hard, Suit=Suitable, C2=Medium salinity and S2=Low alkalinity

Water quality rating for drinking

According to USEPA (1975), the relative suitability of water used for drinking standards was performed on the basis of TDS, As, Fe, Mn, B, Cl, NO₃ and SO₄ contents. The recorded concentration of As in all ground water samples of the experimental area was less than 0.05 mg L⁻¹ indicating these waters would not be hazardous for drinking. Among the 15 ground waters 10 samples (no. 1, 2, 4, 5, 6, 7, 8, 10, 13 and 15) were 'unsuitable' and rest 5 samples were found 'suitable' for drinking due to lower amount of Mn (>0.05 mg L⁻¹) and this ion was considered as pollutant in the study area (USEPA, 1975).

The water samples were problematic because Fe content of those waters exceeded the acceptable limit (Fe = 0.30 mg L⁻¹). The measured TDS of all water samples was below the recommended limit (500 mg L⁻¹) and all the waters were not problematic as per TDS. All the collected water samples were not hazardous for drinking on the basis of B, Cl and SO₄ concentrations, as the detected quantities of these ions were far below the recommended limits (B =1.00, Cl=250.00, SO₄=250.00 mg L⁻¹). NO₃ was not found in the water samples of the study areas.

Water quality rating for livestock use

The concentration of some toxic ions like Cd, Cu, Fe, Pb, Mn, Zn, Cl and TDS were considered for classifying water samples on the basis of ESB (1972). Regarding to contents of TDS, only 10 ground water samples (no. no. 1, 2, 4, 5, 6, 7, 8, 10, 13 and 15) were 'unsuitable' but the rest 5 samples were 'suitable' for livestock usage due to lower quantities of Mn (>0.05 mg L⁻¹). Out of 15 ground water samples, only 1 sample (no. 13) was fit but the rest water samples were hazardous for livestock consumption because these samples contained higher amount of Fe (>0.30 mg L⁻¹) showing this ions as pollutant. In respect of Cl ion, 5 ground water samples (no. 1, 2, 8, 13 and 15) were toxic to livestock consumption because Cl content exceeded the recommended limit as per ESB (1972). In case of Pb content 9 ground water samples (no. 7, 8, 9, 10, 11, 12, 13, 14 and 15) were unsafe for livestock consumption but rest were safe as per limit of ESB (1972)

recommendation. Rest all ions like Cd, Cu and Zn were not hazardous because these ions were detected in quantities that was far below the recommended limits.

Water quality rating for aquaculture usage

The concentration of Cd in 12 ground water samples (no. 1, 2, 3, 4, 5, 7, 8, 10, 11, 12, 13 and 14) were toxic for aquaculture usages. Because, Cd ion exceeded the acceptable limit (0.05 mg L⁻¹). But 3 ground water samples (no. 6, 9 and 15) were suitable for aquaculture usages. The concentration of Cu in all water samples were within the acceptable limit (0.50 mg L⁻¹). The recorded contents of Cl, Fe, Pb, Mn and Zn in all water samples were hazardous for this usage because these ions exceeded the recommended limits as stated by Meade (1989). The concentration of SO₄ in all water samples were within the acceptable limit (<50.00 mg L⁻¹). The measured TDS in 12 ground water samples (no. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12 and 13) and Hardness (H_T) in all water samples, was within the specified limit (<400.00 mg L⁻¹ & 10-400 mg L⁻¹, respectively) and was not problematic for the aquaculture usages. But according to measured TDS 3 ground water samples (no. 9, 14, 15) were not within the specified limit (<400.00 mg L⁻¹). So they were problematic for aquaculture.

CONCLUSION

The ionic concentrations of water samples analyzed were in the following order of magnitude HCO₃>Mg>Ca>Cl>Na>K>SO₄>Fe>Pb>B>PO₄>Mn>Zn>Cd>Cu>As>CO₃. From the present investigation, it can be concluded that all the collected ground water samples would create problem for irrigating crops grown in the study areas and in most cases, HCO₃ ion would exhibit as pollutant for irrigation. Considering drinking purpose for human and livestock, Fe, Mn, Pb and Cl ions were treated as pollutants in most of the collected water samples. And in case of aquaculture, Fe, Mn, Pb, Cl, Cd and TDS measured were treated as pollutants in maximum collected water samples. It may be suggested that water samples should be treated to remove the pollutants before the use of water for specific purpose. Regarding this aspect, appropriate

sustainable technology should be established for the chemical quality of water, the biological and radiological qualities of waters should be assessed in future for the appropriate management of water use.

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