J. Agrofor. Environ. 5 (2): 21-26, 2011 ISSN 1995-6983

Quality assessment of waters of Bogra city area, Bangladesh

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Abstract: A study was conducted at the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh-2202 to determine major ionic constituents including heavy metals in waters collected from fourteen different locations of Bogra city, and accordingly to assess their quality. The concentration of heavy metals in water samples were determined by using an atomic absorption spectrophotometer (AAS). The electrical conductivity (EC) values of water samples varied from 326 to 1265 µS cm^{-1} while the pH range was 6.26 to 7.25. In respect of total dissolved solids (TDS), all water samples were categorized as fresh water. Dissolved oxygen (DO) values of samples in the study area were within the range of 0.3 to 0.6 mg L^{-1}, indicating severe stress for aquatic biota. The mean concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, BO_3^{3-}, PO_4^{3-} and SO_4^{2-} in water samples were 51.67, 26.07, 32.77, 11.98, 0.25, 0.67 and 10.85 µg mL^{-1}, respectively. Considering Cl^{-} content, 50% water samples were found within the permissible limit of irrigation, but in respect of HCO_3^{-} content, all water samples were problematic for irrigation. According to drinking water quality guideline, all water samples of the study area were found unsuitable in respect of HCO_3^{-} and Cl^{-} contents. The mean concentrations of total Fe, Mn, Cr and Ni in water samples were 0.79, 0.25, 0.005 and 0.012 µg mL^{-1}, respectively while the amount of Zn, Cu and Pb were below the detectable limit. The quality assessment showed relatively high values of Fe and Mn in most of the water samples, which would make them unsafe for drinking and irrigation purpose, respectively.

Key words: Water quality, heavy metal, Bogra, Bangladesh.

Introduction

The overall global environment is being polluted fast and the causes are connected with various factors. Industrialization, waste disposal systems, lack of logistic support and monitoring, and unplanned urbanization have greatly transformed the natural environment. In recent times, the environment has become hostile, posing threat to health and welfare due to release of pollutants from industries and urban sewage (Ntengwe, 2006). In Bangladesh, there is a progressive increase in industrial wastes and due to the rapid industrialization such waste products have been causing severe contamination to the air, water and soils, thus polluting the environment. Heavy metals that have been identified in the polluted environment include As, Fe, Mn, Cu, Cd, Pb, Cr, Ni, Hg, Zn etc. These heavy metals enter into the environment through various industrial processes.

Water resource, the prominent component of the environment is getting polluted over the years. Wastewater is mainly used for irrigation purpose, because this contains nutrients that enhance the growth of crop plants but it is also known to have significant contribution to the heavy metal content of soils. About 80% of the diseases in developing countries are related to contaminated water and the resulting death toll is as much as 10 million per year (Anonymous, 2004). Heavy metal can cause surface and ground water contamination and are taken up by plants, released as gases into atmosphere or bound semi permanently by soil components such as organic matter and clay particles which later affect human health (Krishna and Govil, 2007). The presence of any metal may vary from site to site, depending upon the source of individual pollutant. Excessive uptake of metals by plants may produce toxicity in human nutrition, and cause acute and chronic diseases. For instance, Cd and Zn can lead to acute gastrointestinal and respiratory damages and acute heart, brain and kidney damages. Heavy metal pollution in the environment is quite relevant in the present scenario due to its deleterious effect on human health via food chain. Biosphere pollution by heavy metals has accelerated dramatically during the last few decades as a result of discharge of wastewaters from various industries and urban population. Therefore, the present research work was carried out to determine the concentration of major ionic constituents including heavy metals in waters collected from different areas of Bogra city, Bangladesh with a view to assess the level of contamination by using worldwide standards.

Materials and Methods

Bogra district has an area of 2919.9 sq. km. with annual average temperature maximum 34.6°C and minimum 11.9°C, and annual rainfall 1610 mm. Bogra is one among the newly industrial based areas of Bangladesh, which is highly susceptible to environmental pollution due to over population, rapid industrialization and urbanization in last 10 years. There are several types of industrial units including aluminium and ceramic factories, pharmaceutical and cosmetics industries, diesel plants, packaging industries, brick fields, garments and many others.

Fourteen water samples were collected from some selected areas of Bogra city, Bangladesh (Table 1) following a standard procedure as outline by APHA (2005). Sampling was done during the month of October and November, 2010. About 500 mL water sample was collected from each location in plastic bottle and filtered through Whatman No.1 filter paper to remove unwanted solid and suspended materials. Then 3-4 drops of nitric acid were added to the samples to avoid any microbial growth. The pH, EC, TDS and DO values of water samples were measured by pH meter (Model-WTW pH 522), EC meter (Model-D.6072 Dreieich, West Germany), TDS meter (Model-HACH sensION™ + EC5, USA) and DO meter (Model-OXi 3150i, Germany), respectively. Carbonate, bicarbonate and chloride concentrations in water samples were determined by titrimetric method following the procedure as mentioned by Tandon (1995). Amount of phosphate and sulphate in water samples were measured spectrophotometrically following the procedure outlined by Tandon (1995) and Wolf (1982). Concentrations of calcium and magnesium were determined from water samples by titrimetric method using Na_2EDTA as a chelating agent (Page *et al*., 1982 and Singh *et al.*, 1999).

Flame emission spectrophotometer (Model: Jenway PEP7, UK) was used to determine potassium and sodium contents in water samples separately by using potassium and sodium filter, respectively. Determination of different heavy metal concentrations in water samples was done by using an atomic absorption spectrophotometer (AAS) (Varian Spectra AA55B, Australia). Mono element hollow cathode lamp was employed for the determination of each heavy metal of interest.

Table 1. Sources and sampling sites of waters collected from Bogra city, Bangladesh

Sample ID	Source of water	Sampling site
1.	Canal	Sabujbag
2.	Canal	Fuldighi
3.	Canal	Latifpur
4.	Canal	Chakfarid
5.	Tube well	Thonthonia
6.	Tube well	Jamil Madrasa
7.	Tube well	Khander
8.	Tube well	Sakpala
9.	Tube well	Bonani
10.	Tube well	Tinmatha
11.	Tube well	Charmatha
12.	Tube well	Sathmatha
13.	Tube well	Matidali
14.	Tube well	Coloni

Results and Discussion

Bogra district is highly susceptible to environmental pollution due to over population, rapid industrialization and urbanization in last 10 years. Due to these, water becomes polluted, which can affect its quality. In such a situation, the chemical analysis of water samples is necessary to determine the major ionic concentrations including heavy metals. To know the contamination level, sound information on physicochemical properties and effect of heavy metals on waters are must. Considering the above fact, the present study results are presented and accordingly discussed in the following section.

Physicochemical Properties of Water

The physicochemical properties of water samples are presented in Table 2. The pH value of water samples varied from 6.26 to 7.25. Out of 14 samples, 6 samples showed pH lower than 7.0 and the rest 8 samples represented above the neutral value. According to Ayers and Westcot (1985), the acceptable range of pH for irrigation water is 6.0 to 8.4. On the other hand, the guideline value of pH for drinking water is varied from 6.5-8.5 (USEPA, 2009). Considering these values as standard, all samples under the investigation area is not problematic for long-term irrigation as well as all the samples were found suitable for drinking except only one (ID 14) (Table 2). Electrical conductivity (EC) of the water samples ranged from 326 to 1265 $\mu S\ cm^{-1}$ with an average value of 842.07 $\mu S\ cm^{-1}$ (Table 2). Higher EC value reflected the higher amount of salt concentration which affected irrigation water quality related to salinity hazard (Agarwal *et al.*, 1982). TDS values of water samples in the study area were within the limit of 132 to 607 $mg\ L^{-1}$ and the average value was 388.71 $mg\ L^{-1}$ (Table 2). FAO standard range of TDS for long-term irrigation practices is 450 to 2000 $mg\ L^{-1}$ (Ayers & Wescot, 1985). According to USEPA (2009), the guideline value of TDS for drinking water is less than 500 $mg\ L^{-1}$. Considering this value as standard, 7 water samples were within the limit and could safely be used for drinking without any bad impact. But, the rest 7 samples exceeded the limit which may cause problems related to health hazard. Dissolved oxygen (DO) contents of waters in the study area were within the range of 0.3-0.6 $mg\ L^{-1}$ with an average value of 0.46 $mg\ L^{-1}$ (Table 2). As dissolved oxygen levels in waters dropped below 5.0 $mg\ L^{-1}$, aquatic life in the study area may put under stress, and the lower the concentration, the greater the stress (DEP, 2010).

Table 2. Physicochemical properties and major anionic constituents of water samples collected from different areas of Bogra city, Bangladesh

Sample ID	pH	EC ($\mu S\ cm^{-1}$)	TDS ($mg\ L^{-1}$)	DO ($mg\ L^{-1}$)	CO_3^{2-} ($me\ L^{-1}$)	HCO_3^- ($me\ L^{-1}$)	Cl^- ($me\ L^{-1}$)	BO_3^{3-} ($\mu g\ mL^{-1}$)	PO_4^{3-} ($\mu g\ mL^{-1}$)	SO_4^{2-} ($\mu g\ mL^{-1}$)
1	7.21	1215	572	0.40	0.40	15.60	6.20	0.56	1.87	16.95
2	7.14	1200	554	0.50	0.40	15.40	6.04	0.38	0.76	15.73
3	7.21	1265	588	0.30	0.80	15.60	6.37	0.04	0.69	14.83
4	7.09	1228	607	0.40	0.00	17.80	6.37	0.44	0.08	16.04
5	7.14	1255	601	0.50	0.80	15.40	6.26	0.10	0.74	13.31
6	6.91	326	132	0.40	0.80	13.80	1.30	0.10	0.01	0.20
7	6.85	333	138	0.50	0.40	13.80	0.85	0.33	BDL	BDL
8	6.97	649	282	0.50	0.80	11.40	3.33	0.21	BDL	BDL
9	6.76	542	227	0.50	0.80	13.60	2.93	0.04	BDL	0.13
10	6.75	492	202	0.50	0.80	11.60	1.58	0.16	BDL	2.40
11	7.09	1208	582	0.40	0.00	13.00	6.26	0.33	1.33	15.58
12	7.25	1171	565	0.60	0.40	16.00	5.58	0.38	0.54	17.78
13	7.03	530	223	0.40	0.80	15.20	1.75	0.10	BDL	6.87
14	6.26	375	169	0.50	1.20	15.80	0.34	0.38	0.02	10.36
Range	6.26-7.25	326-1265	132-607	0.30-0.60	0.00-1.20	11.40-17.80	0.34-6.37	0.04-0.56	BDL-1.87	BDL-17.78
Mean	6.98	842.07	388.71	0.46	0.60	14.57	3.94	0.25	0.67	10.85
DWGV *	6.5-8.5[b]	-	< 500[b]	-	-	-	< 0.141[a]	0.5[a]	-	-
IWGV **	6.0~8.4[c]	-	450~2000[c]	-	-	< 1.51[c]	< 4.0[c]	0.75[c]	2[c]	20[c]

BDL = Below Detectable limit; *DWGV = Drinking Water Guideline value; **IWGV = Irrigation Water Guideline value , [a] = WHO (2008); [b] = USEPA (2009); [c] = Ayers and Westcot (1985)

Major Anionic Constituents in Water

The anion chemistry of the analyzed water samples shows SO_4^{2-}, HCO_3^- and Cl^- to be the dominant anions towards the total mass balance in water samples of Bogra city (Fig. 1a). The concentration of CO_3^{2-} and HCO_3^- in water samples were within the range of 0-1.2 me L^{-1} and 11.4-17.8 me L^{-1} with the mean value of 0.60 me L^{-1} and 14.57 me L^{-1}, respectively (Table 2). HCO_3^- is contributing 38% to the total anionic balance in the study area (Fig. 1a). In respect of HCO_3^- content, all water samples were found unsuitable for irrigation, which exceeded the recommended limit (1.51 me L^{-1}) as reported by Ayers and Westcot (1985). Chloride constituted 15% of the total anionic balance in the study area (Fig. 1a), and its concentration in water samples collected from the study area ranged from 0.34 to 6.37 me L^{-1} with an average value of 3.94 me L^{-1}, while the maximum permissible limit of Cl^- in irrigation water is 4.00 me L^{-1} (Ayers and Westcot, 1985). Out of 14 samples, 7 samples were found within the permissible value, and these waters can be used safely for irrigation. On the other hand, according to WHO (2008), the guideline value of Cl^- for drinking water is 0.141 me L^{-1} or 5.0 mg L^{-1}, which indicates that all the waters collected from the study area were unsuitable for drinking purpose. The large variation in the chloride concentrations and the high observed concentrations in some water indicate local recharge, and attributed to contamination by untreated industrial and municipal waste effluents (Singh *et al*., 2010). The phosphate content of test samples collected from different sites of Bogra city varied from trace to 1.87 µg mL^{-1} with a mean value of 0.67 µg mL $^{-1}$. The PO_4^{3-} values were under the permissible limit (2.00 mg L^{-1}) of irrigation water as reported by Ayers and Westcot (1985), therefore, the waters might not be harmful for crop production. Sulphate content of all water samples ranged from trace to 17.78 µg mL^{-1} and the average value was 10.85 µg mL^{-1} (Table 2). Maximum permissible limit of SO_4^{2-} in irrigation water is 20.00 µg mL^{-1} (Ayers and Westcot, 1985), which indicates all water samples were within the safe limit for lorng-term irrigation. Sulphate constituted 42% of the total major anions in waters (Fig. 1a), which is usually derived from the oxidative weathering of sulphide bearing minerals like pyrite or dissolution of gypsum (Singh *et al.*, 2010). The amount of boron (BO_3^{3-}) present in the water samples varied from 0.04 to 0.56 µg mL^{-1} having a mean value of 0.25 µg mL^{-1} (Table 3). The recommended highest boron concentration in water for long-term irrigation in soil is less than 0.75 µg mL^{-1} (Ayers and Westcot, 1985). According to WHO (2008), the recommended limit of boron in water for drinking purpose is 0.5 µg mL^{-1}. As per the guideline values mentioned above, all water samples were suitable for drinking (except 1) and irrigation based on boron content (Table 3).

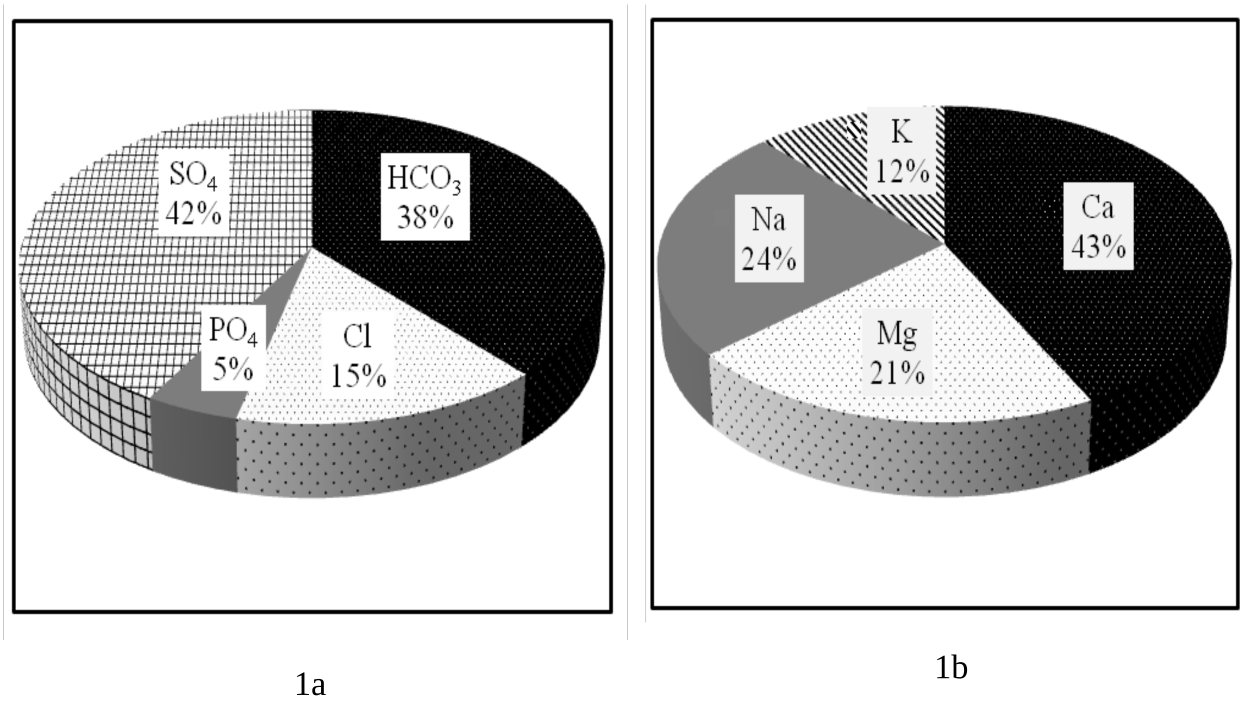

Fig. 1. Contribution of individual ions towards the total mass balance in the Bogra city water samples

Major Cationic Constituents in Water

Major nutrients and heavy metal concentrations in water samples are presented in Table 3. It is evident from Fig. 1b that the cationic chemistry of the water samples of Bogra city is dominated as the sequence of $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$. The content of Ca^{2+} in water samples collected from different areas of Bogra city varied from 18.04 to 86.17 µg mL^{-1} with an average value of 51.67 µg mL^{-1} (Table 3). On average, Ca^{2+} accounts for 43% of the total cations (Fig. 1b). The content of Ca^{2+} in waters is largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ (Karanth, 1994). Irrigation waters containing less than 20 me L^{-1} (800 µg mL^{-1}) Ca^{2+} is suitable for irrigating crops (Ayers and Westcot, 1985). On the basis of Ca^{2+} content, all water samples could safely be used for long-term irrigation and would not be affected soils quality. Magnesium is a common constituent of natural water. In the analyzed water samples, Mg^{2+} constitutes 21% of the total cationic balance and its concentration ranged from 6.01 to 42.08 µg mL^{-1} with an average value of 26.07 µg mL^{-1} (Fig. 1b & Table 3). According to Ayers and Westcot (1985), irrigation water containing below 5.0 me L^{-1} (121.5 µg mL^{-1}) Mg^{2+} is suitable for crops and soils. In the investigated areas, all water samples were within the limit and could safely be used for irrigation without any bad impact on soils.

Table 3. Major cationic constituents and heavy metal concentration in water samples collected from different areas of Bogra city, Bangladesh

Sample ID	Major nutrient concentrations (µg mL^{-1})				Heavy metal concentrations (µg mL^{-1})						
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	Mn	Cr	Ni	Zn	Cu	Pb
1	68.14	34.07	38.70	19.59	0.63	0.11	0.004	0.006	BDL	BDL	BDL
2	56.11	38.08	41.24	20.40	0.76	0.10	0.002	0.002	BDL	BDL	BDL
3	24.05	34.07	43.80	20.00	0.89	BDL	0.004	0.008	BDL	BDL	BDL
4	62.12	40.08	42.94	22.85	0.83	0.20	0.006	0.005	BDL	BDL	BDL
5	8.16	42.08	42.94	20.18	0.76	0.35	0.007	0.007	BDL	BDL	BDL
6	36.07	14.03	18.48	1.72	0.63	0.14	0.003	0.002	BDL	BDL	BDL
7	36.07	6.01	16.00	2.53	0.76	0.25	0.005	0.005	BDL	BDL	BDL
8	50.10	28.06	25.74	2.53	0.89	0.35	0.003	0.003	BDL	BDL	BDL
9	46.09	6.01	18.39	1.72	0.95	0.23	0.006	0.006	BDL	BDL	BDL
10	18.04	20.04	19.48	0.90	1.02	0.11	0.004	0.004	BDL	BDL	BDL
11	78.16	42.08	42.94	26.10	0.80	0.30	0.005	0.100	BDL	BDL	BDL
12	86.17	32.06	42.94	22.44	0.63	0.63	0.006	0.007	BDL	BDL	BDL
13	46.09	16.03	43.80	3.35	0.70	0.35	0.003	0.003	BDL	BDL	BDL
14	42.08	12.02	21.44	3.35	0.76	0.21	0.008	0.011	BDL	BDL	BDL
Range	18.0-86.17	6.01-42.08	16-43.80	0.90-26.1	0.63-1.02	BDL-0.63	0.002-0.006	0.002-0.10	-	-	-
Mean	51.67	26.07	32.77	11.98	0.79	0.25	0.005	0.012	-	-	-
DWGV*	-	-	20[a]	-	0.3[b]	0.4[a]	0.05[a]	0.07[a]	0.05[a]	2[a]	0.01[a]
IWGV**	800[c]	121.50[c]	920[c]	2[c]	5[c]	0.2[c]	0.011[d]	< .052[d]	-	-	-

BDL = Below Detectable limit; *DWGV = Drinking Water Guideline value ; **IWGV = Irrigation Water Guideline value, [a] = WHO (2008); [b] = USEPA (2009); [c] = Ayers and Westcot (1985); [d] = USEPA (1999)

The concentration of Na^{+} in water samples varied from 16.00 to 43.80 µg mL^{-1} with the mean value of 32.77 µg mL^{-1} (Table 3). Sodium accounted for 24% of the total cations in the waters collected from Bogra city (Fig. 1b). High Na^{+} content in irrigation water causes exchange of Na^{+} in water for Ca^{2+} and Mg^{2+} in soil, reduces permeability, and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Saleh *et al.*, 1999; Collins and Jenkins, 1996). According to Ayers and Westcot (1985), irrigation water generally containing less than 40 me L^{-1} Na^{+} is suitable for crops and soils. In respect of Na^{+} content, all water samples under investigation could safely be applied for long-term irrigation without any harmful influence on soils and crops. On the other hand, according to WHO (2008), the guideline value of Na^{+} for drinking water is 20 µg mL^{-1}, and considering this value as standard, only 4 water samples were found within the limit and could safely be used for drinking without any harmful affect on human body. According to Berner and Berner (1987), Na^{+} in the aquatic system is mainly derived from atmospheric deposition, evaporate dissolution and silicate weathering. The concentration of K^{+} present in water samples of investigated area varied from 0.90 to 26.10 µg mL^{-1} with the mean value of 11.98 µg mL^{-1} (Table 3). On average, K^{+} is contributing 12% of the total cationic balance in waters of Bogra city (Fig. 1b). According to Ayers and Westcot (1985), the recommended concentration of K^{+} in irrigation water is 2.0 µg mL^{-1}. In the investigated areas, out of 14 water samples, only 3 samples did not exceed the recommended limit and the rest of the samples exceeded the limit.

Heavy Metal Concentration in Water

The concentration of 7 heavy metals analyzed in the 14 water samples collected from different areas of Bogra city are presented in Table 3. Among the heavy metals, the concentration of Zn, Cu and Pb were below detectable limit. On the other hand, the concentration of Cr and Ni in water samples ranged from 0.002 to 0.006 and 0.002 to 0.10 µg mL^{-1} with a mean value of 0.005 and 0.012 µg mL^{-1}, respectively. It can be inferred from Table 3 that Ni concentration in sample ID 11 (0.10 µg mL^{-1}) exceeded both the guideline values for drinking and irrigation water quality as reported by WHO (2008) and USEPA (1999), respectively. All water samples contained comparatively less amount of iron (Fe) and the range was varied from 0.63 to 1.02 µg mL^{-1} with the mean value of 0.79 µg mL^{-1} (Table 3). The recorded Fe concentrations of all water samples were far below the acceptable limit (5.00 µg mL^{-1}) for irrigation quality as reported by Ayers and Westcot 1985, and due to this reason, all samples under test may use for long term irrigation without any detrimental affect on soil and crops. On the other hand, in all sites, concentration of Fe were above the desirable limit for drinking water (0.30 µg mL^{-1}) of USEPA (2009), and as per this result, all water samples are unsuitable for drinking based on Fe content. The concentration of Mn in water samples collected from Boga city area ranged from trace to 0.63 µg mL^{-1} with a mean value of 0.25 µg mL^{-1} (Table 3). Mn exceeded the drinking water standard value (0.40 µg mL^{-1}) as stated by WHO (2008) in only one sample. On the other hand, out of 14 water samples, 9 exceeded the irrigation water quality guideline value of Mn (0.20 µg mL^{-1}) as reported by Ayers and Westcot (1985). Thus, the concentrations of most heavy metals in the water samples collected from the study area were well below the desirable/ permissible levels recommended for the drinking water by World Health Organization (WHO, 2008). The water that contained higher concentration of some metals (i.e. Fe, Mn and Ni) would require treatment before domestic and irrigation usage.

Relationship between Analyzed Parameters

The Pearson's correlation matrix for the analyzed parameters of the water data collected from Bogra city are presented in Table 4. Among the relationship between water quality parameters pH showed highly significant positive correlation with EC (r = 0.764**), TDS (r = 0.749**), Cl^- (r = 0.798**), Mg^{2+} (r =0.701**), Na^+ (r = 0.745**), K^+ (r = 0.702**) and SO_4^{2-} (r = 0.558*). Similarly, EC showed highly positive significant relationship with TDS (r =0.998**), Cl^- (r = 0.986**), Mg^{2+} (r = 0.926**), Na^+ (r = 0.863**), K^+ (r = 0.960**), PO_4^{3-} (r = 0.589*) and SO_4^{2-} (r = 0.876**). TDS showed significant positive correlation with Cl^- (r = 0.982**), Mg^{2+} (r = 0.927**), Na^+ (r = 0.862**), K^+ (r = 0.960**), PO_4^{3-} (r = 0.568*) and SO_4^{2-} (r = 0.888**). It is also evident from Table 4 that the relationship between the combinations HCO_3^- vs Na^+; HCO_3^- vs K^+; HCO_3^- vs SO_4^{2}; Cl^- vs Mg^{2+}; Cl^- vs Na^+; Cl^- vs K^+; Cl^- vs PO_4^{3-}; Cl^- vs SO_4^{2-}; Ca^{2+} vs BO_3^{3-}; Mg^{2+} vs K^+; Mg^{2+} vs PO_4^{3-}; Mg^{2+} vs SO_4^{2-}; Na^+ vs K^+; Na^+ vs SO_4^{2-}; K^+ vs PO_4^{3-}; K^+ vs SO_4^{2-}; BO_3^{3-} vs SO_4^{2-} and PO_4^{3-} vs SO_4^{2-} showed positive significant correlation, which indicates the parameters were interrelated with each other and may be originated from the same source to the study area. On the contrary, CO_3^{2-} showed negative significant correlation with pH, EC, TDS, Cl^-, Ca^{2+}, Mg^{2+}, K^+, BO_3^{3-} and SO_4^{2-}. Other relationships among the heavy metals and other properties of waters were not significant (Table 4).

Table 4. Pearson correlation coefficient matrix for major ionic constituents and other properties of water samples of different areas of Bogra city, Bangladesh

	pH	EC	TDS	DO	CO_3^{2-}	HCO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	BO_3^{3-}	PO_4^{3-}	SO_4^{2-}	Fe	Mn	Cr
EC (µS cm^{-1})	0.76**																
TDS (mg L^{-1})	0.75**	0.99**															
DO (mg L^{-1})	-0.25	-0.21	-0.20														
CO_3^{2-} (me L^{-1})	-0.59*	-0.57*	-0.58*	0.12													
HCO_3^- (me L^{-1})	0.25	0.49	0.51	-0.18	-0.23												
Cl^- (me L^{-1})	0.80**	0.99**	0.98**	-0.23	-0.60*	0.42											
Ca^{2+} (µg mL^{-1})	0.30	0.34	0.35	0.13	-0.63*	0.23	0.35										
Mg^{2+} (µg mL^{-1})	0.70**	0.93**	0.93**	-0.20	-0.54*	0.33	0.91**	0.27									
Na^+ (µg mL^{-1})	0.75**	0.86**	0.86**	-0.30	-0.46	0.57*	0.82**	0.35	0.82NS								
K^+ (µg mL^{-1})	0.70**	0.96**	0.97**	-0.19	-0.67**	0.55*	0.93**	0.45	0.89**	0.84**							
BO_3^{3-} (µg mL^{-1})	0.09	0.32	0.35	0.18	-0.56*	0.38	0.27	0.66**	0..32	0.21	0.43						
PO_4^{3-} (µg mL^{-1})	0.52	0.59*	0.57*	-0.18	-0.39	-0.31	0.60*	0.31	0.53*	0.50	0.57*	0.34					
SO_4^{2-} (µg mL^{-1})	0.56*	0.88**	0.89**	-0.04	-0.57*	0.63*	0.80**	0.49	0.84**	0.83**	0.91**	0.66**	0.54*				
Fe (µg mL^{-1})	-0.29	-0.13	-0.15	-0.02	0.16	-0.48	-0.09	-0.41	-0.10	-0.30	-0.26	-0.42	-0.14	-0.37			
Mn (µg mL^{-1})	0.31	0.20	0.22	0.50	-0.06	0.11	0.18	0.34	0.14	0.36	0.23	-0.10	-0.08	0.32	-0.25		
Cr (µg mL^{-1})	-0.40	0.04	0.08	0.31	0.10	0.35	-0.02	-0.04	-0.05	-0.06	0.12	0.13	-0.28	0.13	0.04	0.31	
Ni (µg mL^{-1})	0.09	0.28	0.29	-0.21	-0.48	-0.21	0.28	0.40	0.35	0.25	0.42	0.15	0.39	0.25	0.03	0.11	0.13

** = Significant at 1% level of probability; * = Significant at 5% level of probability

The pH values of the water samples of Bogra city area were within the range of 6.26 to 7.25 indicating almost neutral condition of samples. The obtained EC values of samples varied from 326 to 1265 µS cm^{-1}. In respect of TDS (132 to 607 mg L^{-1}), all water samples were categorized as fresh water. The order of abundance of ionic constituents in water sample was $Ca^{2+} > Na^+ > Mg^{2+} > K^+ = SO_4^{2-} > HCO_3^- > Cl^- > PO_4^{3-}$. The mean concentrations of Ca^{2+}, Mg^{2+}, Na^+, K^+, BO_3^{3-}, PO_4^{3-} and SO_4^{2-} in water samples were 51.67, 26.07, 32.77, 11.98, 0.25, 0.67 and 10.85 µg mL^{-1}, respectively. Considering Cl^- content, 7 samples were found within the permissible value, and these waters can be used safely for irrigation. But in respect of HCO_3^- content, all water samples were found problematic for irrigation because the concentration exceeded the recommended limit that may create harmful effect on soils and crops. On the other hand, all the waters collected from the study area were found unsuitable for drinking purpose according to WHO (2008) guideline values of HCO_3^- and Cl^- (1.51 and 0.141 me L^{-1}, respectively). The mean concentrations of total Fe, Mn, Cr and Ni in water samples were 0.79, 0.25, 0.005 and 0.012 µg mL^{-1}, respectively while the amount of Zn, Cu and Pb were below the detectable limit. The quality assessment shows relatively high values of HCO_3^-, Cl^- and Fe in major water samples, which would make them unsafe for drinking purpose. Similarly, the concentrations of HCO_3^-, Cl^- and Mn in most of the water samples exceeded the irrigation water quality guideline value, which would create bad impact on soils and crops. Among the correlations between metallic concentrations in water samples were not significant, which indicates the metals present in water samples were not interrelated with each other and might be originated from different sources to the study area.

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