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Appraisal of ionic contamination in water of the Bangshi river for irrigation usage towards food safety

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ABSTRACT

Ionic contamination has become a serious environmental problem due to long-term disposal of untreated industrial effluent containing metal ions in river water ecosystem when applied to soil system as irrigation water. Considering this issue, an attempt was made to explore ionic contamination in water samples collected from the adjacent crop fields irrigated with the contaminated river during dry season towards food safety. Fifteen water samples were collected randomly from the upstream to downstream of the Bangshi river to determine ions in order to categorize these samples on the basis of their applicability for irrigation usage. The chemical analyses included pH, electrical conductivity (EC), total dissolved solids (TDS), cations (Ca, Mg, K, Na, Cd, Cr & Mn) and anions (CO_3, HCO_3, Cl & PO_4). pH values of river water samples ranged from 6.5 to 7.6 indicating slightly acidic to slightly alkaline in nature. All the water samples were categorized as fresh water (TDS<1,000 mg L^{-1}) in quality. River water samples were medium salinity (C2, EC=250-750 µS cm^{-1}) hazard and were low alkalinity (S1, SAR<10) hazard expressing as C2S1. Regarding sodium adsorption ratio (SAR) values, samples were under excellent class (SAR<10) and as per soluble sodium percentage (SSP) values, all the samples were classified as permissible (SSP=40-60%) to doubtful (SSP=60-80%) classes. River water samples under consideration were free from residual sodium carbonate (RSC) and belonged to suitable (RSC<1.25 meq L^{-1}) class. On the basis of hardness (H_T), all the collected water samples were moderately hard (H_T=75-150 mg L^{-1}) in quality. Regarding the obtained permeability index (PI) values, water samples were under class-III implying 25% of maximum permeability when applied to soil system as irrigation water. The concentrations of Ca, Mg, K, Na, Cd, HCO_3, Cl and PO_4 in the studied water samples were within the acceptable limit and these ions were non-problematic for irrigation. Among the detected ions in river water samples, Cr and Mn ions were above the permissible limits for long-term irrigation usage and these ions were treated as chemical contaminants. The relationships between chemical quality parameters of river water such as EC, TDS, SAR, SSP, RSC, H_T and PI were established. Among the combination, significant correlation was existed between SAR vs SSP, TDS vs RSC, SSP vs PI, RSC vs H_T and RSC vs PI. Therefore, it is concluded from the present findings that among the detected ions, only two metals *viz.* Cr and Mn should be considered as chemical contaminants for long-term irrigation system towards food safety.

Introduction

Rivers are the important surface water sources and are being used for various agricultural purposes especially for irrigation. Ionic contamination of riverine ecosystems has become a serious environmental problem due to the rapid urbanization and industrialization. Due to uncontrolled rapid industrialization, river water pollution is posing an increasing threat to surface water irrigation in Bangladesh and degradation of water quality is likely to cause toxic effects on crops (Anny *et al*., 2017; Hafizur *et al*., 2017). The indiscriminate discharge of crudely treated and untreated industrial wastewater introduces toxic substances into aquatic environments degrading water quality to the extent that surface water is unsuitable for agricultural irrigation (Qadir *et al.,* 2010; Ouali *et al*., 2018). If the contaminated water is used for irrigation, some metal ions may accumulate in soil and create crop toxicity resulting contamination in food chain.

Savar area of Dhaka is one of the major industrial zones in Bangladesh, as the country's second largest Dhaka Export Processing Zone (DEPZ) is located there and the largest industrial belt of Bangladesh at present houses 92 industrial units which are categorically the leading pollution creators. These industrial units include textile/knitting plastic goods, footwear/leather goods, metal products, electronic goods, paper products, chemicals and fertilizers and miscellaneous products (Khanam *et al*., 2011). All these industrial activities severely deteriorate water quality of the Bangshi river, lakes, waterways, and wetlands that are either inside or adjacent to Savar industrial areas, thus posing dreadful risks to human health and environment of the area (Rahman *et al*., 2008; Ahmed *et al*., 2009a). Usually,

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water quality assessment is practiced by comparing measured physicochemical parameters with threshold values, recommended by national or international bodies (Bhuiyan *et al*., 2011).

Recently, special attention has been given to some problematic ions in water for management of these ions to reduce environmental problems related to soil properties and food quality. In the study areas, farmers are utilizing water of the Bangshi river for irrigation purpose due to scarcity of other sources of fresh water. For this purpose, water analyses are very important for evaluating its quality for irrigation and understanding of soil and water management. Keeping this fact in mind, a research work was undertaken to assess the ionic contamination of water in the selected sites of the Bangshi river for irrigation purpose towards food safety.

Materials and Methods

Water sampling area

Water sampling sites were concentrated at different locations of the Bangshi river at Savar upazila under Dhaka district of Bangladesh. The exact location of each sampling point was determined using GPS. Accordingly, the entire sampling sites were confined between 22°46'18.7" to 22°49'08.7"N latitude and 89°33'49.5" to 89°35'21.8"E longitude. The sampling locations have been identified using GPS. The detailed water sampling sites have been illustrated in Fig. 1. This sampling was carried out in the month of February, 2018.

Fig. 1. Study areas of the Bangshi river in location map

Water sampling technique

Considering the crop fields irrigated with this river water, fifteen water samples were collected randomly in 500 mL plastic bottles previously washed with diluted HCl (1:1) from the upstream to downstream of this river. All the bottles were rinsed 3 to 4 times before water sampling. For metal analysis, the collected water samples were acidified (pH<2) with HNO_3 to prevent the loss of metal ion following the sampling technique of APHA (2012). All the plastic bottles were sealed tightly and transferred to the Postgraduate Research Laboratory, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh for chemical analysis. All the samples were kept in a cool, clean, and dry place. River water samples were filtered through filter papers (Whatman No.: 1 and 42) to remove undesirable solids, sediments and suspended materials or chemicals before commencing the chemical analysis.

Table 1. Water sampling locations at the Bangshi river using GPS

Sample ID No.	Latitude (E)	Longitude (N)	Sample ID No.	Latitude (E)	Longitude (N)
1	22°49'08.7"	89°33'49.5"	9	22°48'23.3"	89°34'51.1"
2	22°49'00.9"	89°34'13.3"	10	22°47'51.1"	89°34'47.9"
3	22°48'49.0"	89°34'32.7"	11	22°47'57.8"	89°34'45.3"
4	22°48'46.1"	89°34'36.3"	12	22°47'26.2"	89°34'55.4"
5	22°49'00.9"	89°34'13.3"	13	22°47'12.4"	89°34'56.2"
6	22°48'23.3"	89°34'51.1"	14	22°47'06.3"	89°34'56.0"
7	22°48'21.6"	89°34'58.7"	15	22°46'18.7"	89°35'21.8"
8	22°48'04.5"	89°34'52.1"	-	-	-

Water analytical methods

pH, EC and TDS values of water samples were measured electrometrically as outlined by Gupta (2013). Ethylene diamine tetraacetic acid (EDTA) titrimetric method was used to determine the concentrations of Ca and Mg ions in water samples (Tandon, 2013). In river water samples, the contents of K and Na ions were determined by flame photometer (model: Jenway PEP7, UK) while the levels of Cd, Cr, and Mn ions were analyzed directly by atomic absorption spectrophotometer (model: Shimadzo AA7000, Japan) as described by APHA (2012). Titrimetric method was used to determine the concentrations of Cl and HCO_3 ions from water samples (Gupta *et al*., 2012; Tandon, 2013). The status of PO_4 ion in river water samples was determined by spectrophotometer (model: TG-60U, UK) following the method of APHA (2012).

Ionic contamination rating

The following chemical quality factors were considered for assessing major ionic contamination of water samples by the interpretation of analytical result:

i) Sodium adsorption ratio (SAR)

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

ii) Soluble sodium percentage (SSP)

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

iii) Residual sodium carbonate (RSC)

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

iv) Hardness (H_T)

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

v) Permeability index (PI)

$PI = [(Na^+ + \sqrt{HCO_3^-}) / (Ca^{2+} + Mg^{2+} + Na^+)] \times 100$

Whereas, all the ionic concentrations were expressed as meq L^{-1} but in case of hardness, cationic concentrations were expressed as mg L^{-1} (Raghunath, 1987).

Statistical analysis

Statistical analyses of analytical results obtained from river water samples were performed according to Gomez and Gomez (1984). MS Excel programs were used for correlation studies.

Results and Discussion

pH, EC and TDS values

pH value of the selected water samples from the Bangshi river ranged from 6.5 to 7.6 indicating slightly acidic to slightly alkaline in nature (Table 2). According to FAO (1992), the recommended pH range for irrigation water is from 6.5 to 8.4. Results revealed that all the samples were within the acceptable range and were not problematic for long-term irrigation. Arefin *et al.* (2016a) reported that pH value of the Turag river was from 7.40 to 7.79, which was higher than the present findings. Hossain *et al.* (2018) stated that pH value of the Rupsha river varied from 7.34 to 7.56, which was higher than the current study. An investigation was conducted on the Buriganga river by Fatema *et al.* (2018), who found that pH value ranged from 7.61 to 8.97. These values were also higher than the present study.

The results in Table 2 showed that electrical conductivity (EC) values of all the collected water samples fluctuated from 604.0 to 740.0 µS cm^{-1} with a mean value of 693.4 µS cm^{-1}. According to Wallender and Tanji (2011), all the samples under test were rated in C2 category (EC=250.0-750.0 µS cm^{-1}) indicating medium salinity (Fig. 2). Considering EC values, all the water samples could be safely used for moderate salt tolerance crops growing on soils with moderate level of permeability. EC values of the Buriganga river samples ranged from 180.0 to 598.0 µS cm^{-1} (Fatema *et al.*, 2018), which was lower than the present investigation. Another study was conducted by Hossain *et al.* (2018), who found that EC values of the Rupsha river fluctuated from 899.0 to 1,409.0 µS cm^{-1}, which was higher than the current study. EC values of surface water of the Shitalakhya river were found to range from 131.6 to 2,292.0 µS cm^{-1} (Mottalib *et al*., 2016).

Total dissolved solids (TDS) values of water samples were within the range of 442.0 to 556.0 mg L^{-1} having an average value of 518.13 mg L^{-1} (Table 2). According to Freeze and Cherry (1979), all the samples were classified as fresh water (TDS<1,000 mg L^{-1}) in quality. These water samples would not affect soil properties and plant growth as irrigation water. Another investigation was conducted by Rehnuma *et al.* (2016), who found that TDS values of the same river fluctuated from 408.0 to 561.0 mg L^{-1} during dry season. Hossain *et al*. (2018) reported that TDS values of water samples in the river Rupsha were within the range of 600.0 to 940.0 mg L^{-1}, which was higher than the present study. Tareq *et al.* (2013) observed that TDS values in water samples of the Brahmaputra river ranged from 62.0 to 245.0 mg L^{-1}, which was lower than the current investigation. TDS values in water samples of the Jamuna river varied from 106.0 to 131.0 mg L^{-1} (Uddin *et al*., 2014). All these values were lower than the present study.

Table 2. pH, EC, TDS and anionic constituents of the Bangshi river water samples

Sample ID No.	pH	EC (µS cm^{-1})	TDS (mg L^{-1})	Major anions (meq L^{-1})		Minor anion (µg mL^{-1})
				Cl	HCO_3	PO_4
1	7.4	695	445	1.70	1.60	0.66
2	7.6	724	550	1.86	2.00	0.50
3	6.5	652	442	0.90	1.00	0.92
4	6.8	690	484	1.00	1.20	0.54
5	7.5	680	550	1.70	1.90	0.38
6	7.6	736	544	1.50	2.10	0.72
7	7.3	680	484	1.24	1.40	0.58
8	7.4	673	538	1.26	1.70	0.44
9	7.5	674	540	1.82	1.80	0.92
10	7.3	685	556	1.32	1.60	0.64
11	7.6	740	552	1.38	2.40	0.50
12	7.3	604	506	1.24	2.10	0.46
13	7.2	712	505	1.18	1.40	0.78
14	7.5	728	525	1.16	1.80	0.36
15	7.6	728	551	1.60	2.20	0.50
Min.	6.5	604	442	0.90	1.00	0.36
Max.	7.6	740	556	1.86	2.40	0.92
Mean	-	693.4	518.13	1.39	1.74	0.59
SD	-	36.45	38.79	0.29	0.38	0.17
FAO value	6.5-8.4	-	-	4.00	1.50	2.00

[a]FAO (1992)

Cl, HCO_3 and PO_4 levels

Water samples collected from the Bangshi river contained Cl ion within the range of 0.90 to 1.86 meq L^{-1} with a mean value of 1.39 meq L^{-1} (Table 2). The recommended maximum concentration of Cl in irrigation water is 4.00 meq L^{-1} (FAO, 1992). On the basis of the acceptable range, all the water samples were within the acceptable range and this anion was not problematic for irrigation usage. Hossain *et al.* (2018) evaluated that water samples collected from the Rupsha river contained Cl ion within the limit of 16.00 to 24.99 meq L^{-1}, which was higher than the current study. Rout (2017) found that Cl content in water samples of the Yamuna river in Haryana, India fluctuated from 24.5 to 26.0 meq L^{-1} and these limits were also higher than the present investigation. The concentration of Cl ion in all the samples collected from the Kuroorthodu river in India ranged from 3.5 to 9.9 mg L^{-1} in monsoon and 7.0 to 37.5 mg L^{-1} in post-monsoon (Paul *et al*., 2018). All these values were higher than the present study.

The results in Table 2 revealed that the concentration of HCO_3 ion in the collected water samples fluctuated from 1.00 to 2.40 meq L^{-1} with an average value of 1.74 meq L^{-1}. According to FAO (1992), maximum permissible limits of HCO_3 ion for irrigation water used

continuously on soil is 1.5 meq L^{-1}. As per this acceptable range, HCO_3 status of 11 water samples was above the recommended limit and these samples were not suitable for irrigation purpose. The concentration of HCO_3 ion in the collected water samples of the Rupsha river fluctuated from 0.05 to 0.09 meq L^{-1} (Hossain *et al*., 2018) and these values were lower from the present investigation. In water samples of the Kosi river in India, HCO_3 concentration was found to vary between 0.38 and 2.12 meq L^{-1} (Semwal and Jangwan, 2009). These limits were more or less similar to the current study. Arefin *et al*. (2016a) reported that in the Turag river, the concentration of HCO_3 ranged from 0.80 to 2.40 meq L^{-1}. All these values of this anion were more or less similar to the current study.

The level of PO_4 ion in the selected water samples varied from 0.36 to 0.92 µg mL^{-1} having an average value of 0.59 µg mL^{-1} (Table 2). The permissible limit of PO_4 ion in irrigation water is 2.00 µg mL^{-1} (FAO, 1992). As per the acceptable range, all the water samples were suitable for irrigation having no hazard effects on soil properties and crop growth in the study area. The level of PO_4 ion in water samples varied from 0.25 to 1.47 µg mL^{-1} in the Rupsha river (Hossain *et al*., 2018), which was more or less similar to the present study. A research work was performed by Pia *et al.* (2018), who stated that the range of PO_4 ion fluctuated from 392.4 to 401.2 µg L^{-1} in the Shitalakshya river and these levels were higher than the current study. Dunca *et al.* (2018) conducted a research work on water samples of the Timis river in Romania and reported that PO_4 level of 10 sampling sites was from 0.042 to 0.437 µg mL^{-1}, which was lower from the current findings.

Ca, Mg, K and Na levels

The concentrations of Ca and Mg ions in all the samples fluctuated from 1.14 to 1.94 and 0.88 to 1.50 meq L^{-1} with mean values of 1.48 and 1.10 meq L^{-1}, respectively (Table 3). Water containing less than 20.0 meq L^{-1} of Ca and 5.0 meq L^{-1} of Mg ions is suitable for irrigating agricultural crops (FAO, 1992). Considering the limits of these ions, water samples of the study area could safely be applied for long-term irrigation without any harmful effect on soil properties and crop growth. Hossain *et al.* (2018) stated that the concentrations of Ca and Mg ions in all the samples of the Rupsha river were found to vary from 2.96 to 3.60 and 3.28 to 4.80 meq L^{-1} respectively, which was higher than the present findings. Semwal and Jangwan (2009) studied that Ca concentration in water samples of the Kosi river in India varied from 0.25 to 1.70 meq L^{-1}, which was more or less similar to the present study. They also stated that Mg concentration in water samples of the Bhagirathi river in India varied from 0.25 to 0.99 meq L^{-1}, which was lower than the present study. The results in Table 3 reported that the contents of K and Na ions in all the samples ranged from 0.68 to 0.98 and 2.18 to 5.40 meq L^{-1} with average values of 0.87 and 3.54 meq L^{-1}, respectively. On the basis of FAO (1992), water containing less than 0.50 meq L^{-1} of K and 40.0 meq L^{-1} of Na ions is suitable for irrigating agricultural crops. As per the limits of these alkali metals, water samples could safely be applied for long-term irrigation but in case of K ion, all the collected river water samples might be problematic for irrigation. In the Rupsha river sample, the concentration of K ion was found to vary from 0.10 to 0.16 meq L^{-1} (Hossain *et al*., 2018) and these levels were lower than the current study. Semwal and Jangwan (2009) investigated that K level in water samples of the Kosi river in India varied from trace to 0.10 meq L^{-1}, which was lower than the present finding. Hossain *et al.* (2018) stated that the concentration of Na ion in the Rupsha river varied from 2.33 to 3.23 meq L^{-1}, which was more or less similar to the present findings. Semwal and Jangwan (2009) stated that the contents of Na ions in water samples of the Bhagirathi river in India varied from 0.04 to 0.22 meq L^{-1}, which was lower than the present study.

Table 3. Cationic constituents of the Bangshi river water samples

Sample ID No.	Major ions (meq L^{-1})				Metal ions (µg mL^{-1})		
	Ca	Mg	K	Na	Cd	Cr	Mn
1	1.64	1.36	0.70	5.20	BDL	0.53	0.46
2	1.59	1.10	0.92	3.90	BDL	0.56	0.40
3	1.69	1.26	0.86	2.60	BDL	0.52	0.38
4	1.44	1.10	0.68	2.18	BDL	0.48	0.44
5	1.24	1.50	0.96	3.04	BDL	0.52	0.42
6	1.49	1.10	0.84	2.30	BDL	0.45	0.30
7	1.29	1.16	0.87	3.13	BDL	0.48	0.34
8	1.94	0.96	0.88	3.90	BDL	0.42	0.32
9	1.20	1.00	0.89	3.47	BDL	0.50	0.35
10	1.34	1.14	0.90	4.24	BDL	0.47	0.32
11	1.39	1.20	0.94	3.47	BDL	0.44	0.34
12	1.64	0.88	0.96	2.60	BDL	0.40	0.30
13	1.79	0.92	0.90	5.40	BDL	0.33	0.29
14	1.44	0.96	0.89	4.34	BDL	0.36	0.30
15	1.14	1.00	0.98	3.69	BDL	0.28	0.22
Min.	1.14	0.88	0.68	2.18	-	0.28	0.22
Max.	1.94	1.50	0.98	5.40	-	0.56	0.46
Mean	1.48	1.10	0.87	3.54	-	0.44	0.34
SD	0.22	0.17	0.085	0.97	-	0.079	0.064
[a]FAO value	20.00	5.00	0.50	40.00	0.01	0.10	0.20

[a]FAO (1992); BDL=Below Detection Limit

Cd, Cr and Mn levels

The concentration of Cd ion in water samples of the Bangshi river was found below detection level (Table 3). According to FAO (1992), the permissible limit of Cd ion in water used for irrigation is 0.01 µg mL^{-1}. Similar findings were observed in water samples of the Bangshi, Buriganga, Turag and Shitalakha rivers (Hossain *et al.,* 2012; Islam *et al*., 2014). Das *et al.* (2011) reported that the level of Cd ion in the Buriganga river varied from 0.11 and 2.37 µg mL^{-1} and these values were higher than the current study. The concentration of Cd ion in water samples of the Rupsha river varied from 0.016 to 0.035 µg mL^{-1} (Hossain *et al.,* 2018), which was higher than the present study. The recorded level of Cr ion in river water samples ranged from 0.28 to 0.56 µg mL^{-1} having a mean value of 0.44 µg mL^{-1}.

According to FAO (1992), the permissible limit of Cr in irrigation water is 0.10 µg mL^{-1}. On the basis of this limit, the detected level of this metal ion exceeded the permissible limit and all the water samples under investigation were problematic for soils and crops grown in the irrigated areas. So, this metal ion was considered as chemical contaminants for long-term irrigation towards food safety. The anthropogenic supply of this heavy metal was possibly due to the uncontrolled discharge of untreated industrial effluents from the textile and leather tanning industries into this river water. Similar findings were observed by Rahman and Mondal (2013) and Arefin *et al.* (2016b). Another observation was reported by Arefin *et al.* (2016a), who found that the concentration of Cr in the Turag river varied from 0.23 to 0.47 µg mL^{-1}. The status of Cr ion in water samples of the Buriganga river was between 2.75 and 7.00 µg mL^{-1} and these values were higher than the current study (Das *et al.*, 2011). Ahmed *et al*. (2009b) reported that the concentration of Cr ion in the Dhaleshwari river ranged from 378.87 to 501.11 µg L^{-1} and these values were more or less similar to the current study. The status of Mn in all the water samples under investigation ranged from 0.22 to 0.46 µg mL^{-1} with an average value of 0.34 µg mL^{-1}. The permissible limit of Mn in water used for irrigation is 0.20 µg mL^{-1} (FAO, 1992). As per this limit, the recorded limit of this metal ion in water samples exceeded the acceptable range and this ion was treated as chemical contaminants. So, water samples could not be safely applied for long-term irrigation. Industrial activities were mainly responsible for the high level of Mn in this river water probably originating from dyeing and textile industries. Similar observations were reported by Rahman and Mondal (2013) and Arefin *et al.* (2016b). The concentration of Mn ion ranged from 0.35 to 0.92 µg mL^{-1} in Turag river (Arefin *et al*., 2016a), which was higher than the current finding. Zakir *et al.* (2012) reported that the concentration of Mn in water samples collected from the Karatoa river in Bangladesh varied from trace to 0.32 µg mL^{-1}. These values were more or less similar to the present study. The concentration of Mn ion in water samples collected from the Halda river varied between 0.05 and 0.28 µg mL^{-1} (Bhuyan and Bakar, 2017).

SAR, SSP, RSC, Hardness and PI values

The calculated SAR values of river water samples varied from 1.93 to 4.64 having a mean value of 3.13. (Table 4). Water used for irrigation having SAR less than 10 might not be harmful for agricultural crops (Todd and Mays, 2005). Considering this classification, all the samples were rated as low alkalinity hazard (S1, SAR<10) class reflecting excellent for irrigation as illustrated in Fig. 2. Hossain *et al.* (2018) found that in the Rupsha river water samples, SAR values ranged from 1.23 to 1.63, which was lower than the present study. SAR values of water samples collected from the Turag river varied between 0.27 and 0.33 (Arefin *et al.*, 2016a), which were lower than the current investigation. As regards to SAR value, water samples collected from the Buriganga river were excellent in quality (Zaman *et al*., 2002).

The results in Table 4 reflected that the computed SSP values of water samples in the investigated river fluctuated from 52.96 to 69.92% with an average value of 62.55% (Table 4). According to water classification proposed by Todd and Mays (2005), 5 samples were classified as permissible (SSP=40-60%) and 10 samples were classified as doubtful (SSP=60-80%). Arefin *et al.* (2016a) observed that in the Turag river water samples, the computed SSP values fluctuated from 12.45 to 15.70%, which was lower than the current study. The computed SSP values in the Rupsha water samples ranged from 25.26 to 30.63% (Hossain *et al.*, 2018). All these values were lower than the present study. RSC values of the collected water sample from the study area fluctuated from -1.95 to 0.06 meq L^{-1} with an average value of -0.84 meq L^{-1} (Table 4). As per classification suggested by Schwartz and Zhang (2012), all the water samples were rated as suitable class (RSC<1.25 meq L^{-1}). For this reason, all the river water samples might not be problematic for irrigation usage. RSC values of water sample collected from the Rupsha river ranged from -7.78 to -6.51 meq L^{-1} (Hossain *et al*., 2018), which was lower than the present study. RSC values of water samples in the Turag river varied from -8.15 and -5.53 meq L^{-1} (Arefin *et al*., 2016a), which was lower than the current study.

The obtained results in Table 4 revealed that hardness (H_T) values of the collected water samples ranged from 106.20 to 148.91 mg L^{-1} having a mean value of 128.77 mg L^{-1}. Sawyer and McCarty (1967) suggested a classification for irrigation water based on hardness and according to this classification, all the samples were moderately hard (H_T=75-150 mg L^{-1}) in quality. Arefin *et al.* (2016a) reported that in the Turag river water samples, hardness (H_T) values varied between 336.68 and 465.15 mg L^{-1}, which were higher than the current study. The hardness (H_T) values of the Rupsha river water samples ranged from 327.67 to 391.51 mg L^{-1} (Hossain *et al*., 2018), which were also higher than the present investigation. The computed permeability index (PI) values were found to vary from 64.86 to 88.73% having an average value of 78.90% (Table 4). Accordingly, PI values indicated the suitability of water for irrigation purpose (Vasanthavigar *et al.,* 2010).

Regarding the obtained PI values, all the water samples were under class-III implying 25% of maximum permeability when applied to soil system as irrigation water as presented in Fig. 3. Hossain *et al.* (2018) stated that the computed PI values of the Rupsha river water samples were found to vary from 27.55 to 32.42%, which was lower than the current study. In the monsoon season, PI values of the Shailmari river water varied from 62.70 to 80.34% (Islam *et al*., 2016) and these values were more or less similar to the present study.

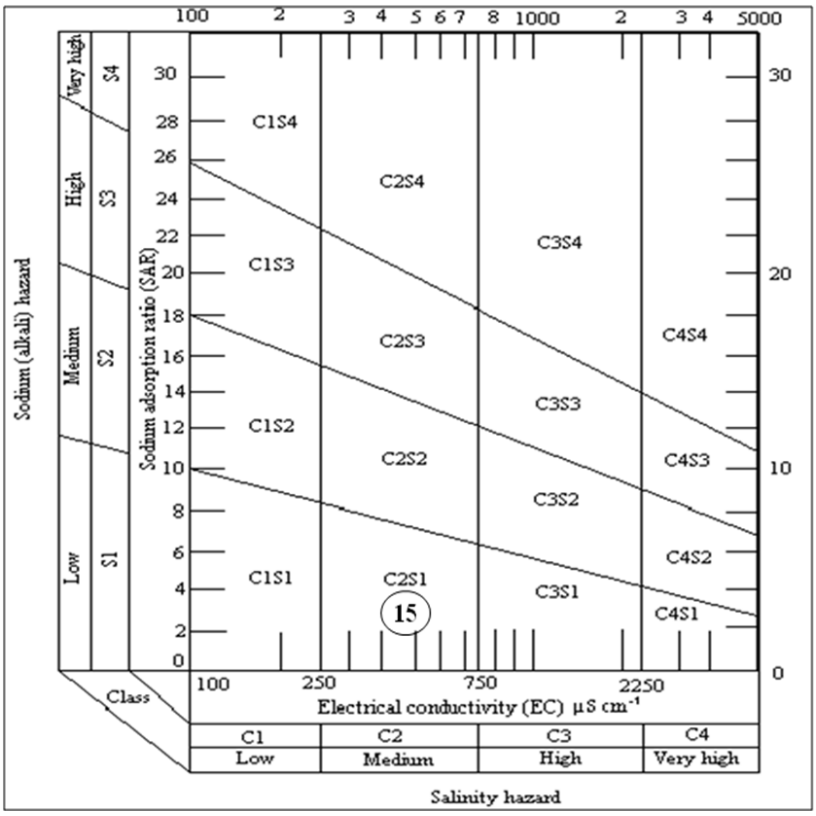

Fig. 2. Diagram for classifying river water used for irrigation (Wallender and Tanji, 2011)

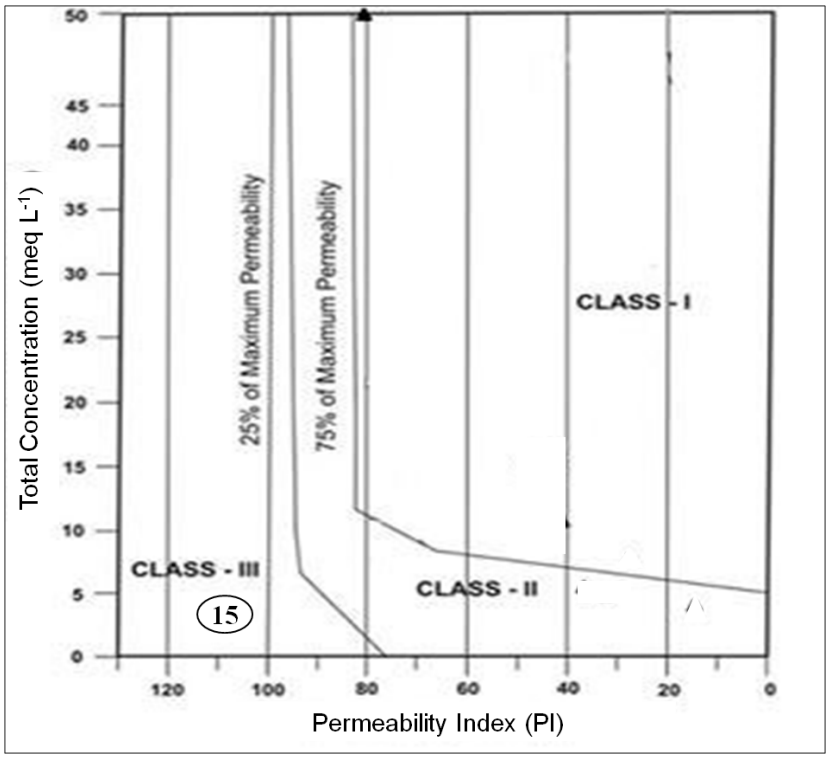

Fig. 3. Diagram for classifying river water based on permeability index (Vasanthavigar *et al.*, 2010)

Table 4. Ionic contamination rating of the Bangshi river water samples with their suitability for irrigation

Sample	SAR		SSP		RSC		H□		PI	
ID No.	Ratio	Class	%	Class	meqL^{-1}	Class	mg L^{-1}	Class	%	Class
1	4.25	Ex.	66.29	Doubt.	-1.40	Suit.	148.91	MH	78.84	Class-III
2	3.36	Ex.	64.18	Doubt.	-0.69	Suit.	133.62	MH	80.64	Class-III
3	2.14	Ex.	53.98	Perm.	-1.95	Suit.	146.49	MH	64.86	Class-III
4	1.93	Ex.	52.96	Perm.	-1.34	Suit.	126.12	MH	69.40	Class-III
5	2.60	Ex.	59.35	Perm.	-0.84	Suit.	135.80	MH	76.44	Class-III
6	2.02	Ex.	54.80	Perm.	-0.49	Suit.	128.62	MH	76.67	Class-III
7	2.83	Ex.	62.02	Doubt.	-1.05	Suit.	121.57	MH	77.30	Class-III
8	3.24	Ex.	62.24	Doubt.	-1.20	Suit.	144.23	MH	76.53	Class-III
9	3.31	Ex.	66.46	Doubt.	-0.40	Suit.	109.20	MH	84.86	Class-III
10	3.81	Ex.	67.45	Doubt.	-0.88	Suit.	123.09	MH	81.92	Class-III
11	3.05	Ex.	63.00	Doubt.	-0.19	Suit.	128.54	MH	82.82	Class-III
12	2.32	Ex.	58.55	Perm.	-0.42	Suit.	125.30	MH	79.08	Class-III
13	4.64	Ex.	69.92	Doubt.	-1.31	Suit.	134.76	MH	81.17	Class-III
14	3.96	Ex.	68.55	Doubt.	-0.60	Suit.	119.23	MH	84.30	Class-III
15	3.57	Ex.	68.58	Doubt.	0.06	Suit.	106.20	MH	88.73	Class-III
Min.	1.93		52.96		-1.95		106.20		64.86	
Max.	4.64		69.92		0.06		148.91		88.73	
Mean	3.13		62.55		-0.84		128.77		78.90	
SD	0.83		5.57		0.53		12.40		5.97	

Legend: Ex.=Excellent; Doubt.= Doubtful; Perm.= Permissible; Suit.= Suitable & MH= Moderately Hard

Table 5. Correlation matrix among chemical quality parameters of the Bangshi river water samples

Parameters	TDS	SAR	SSP	RSC	H_T	PI
EC	0.399^{NS}	0.347^{NS}	0.346^{NS}	0.336^{NS}	-0.179^{NS}	0.416^{NS}
TDS		0.101^{NS}	0.312^{NS}	0.754**	-0.490*	0.625*
SAR			0.941**	0.046^{NS}	-0.026^{NS}	0.640*
SSP				0.324^{NS}	-0.315^{NS}	0.832**
RSC					-0.737**	0.788**
H_T						-0.629*

Legend: ^{NS}Not significant; *Significant at 5% level & **Significant at 1% level.
Tabulated values of r with 13 df were 0.441 at 5% and 0.641 at 1% levels of significance, respectively.

Relationships between chemical quality parameters

The relationships between chemical quality parameters *viz*., EC, TDS, SAR, SSP, RSC, H_T and PI were studied (Table 5). Significant positive correlation was existed between TDS vs RSC, TDS vs PI, SAR vs SSP, SAR vs PI, RSC vs PI and SSP vs PI, whereas negative significant correlation was existed among the combinations of TDS vs H_T, RSC vs H_T and H_T vs PI. In rest of the combinations, the relationship between quality criteria was insignificant as their respective calculated correlation coefficient (r) values were below the tabulated values of r at both 1% and 5% levels of significance.

Conclusion

Among the detected ions under investigation, Cr and Mn ions were above the permissible limits for long-term irrigation and these ions were treated as chemical contaminants in water samples of the Bangshi river for irrigating soils and crops. The detected ions as chemical contaminants should carefully be considered for long-term irrigation purpose towards food safety.

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