



Heavy Metals and Major Ionic Pollution Assessment in Waters of Midstream of the River Karatoa in Bangladesh

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Abstract

In a quantitative assessment of water collected from the midstream of Karatoa river in Bangladesh, 31 water samples were analyzed to assess heavy metals, major ionic constituents and suitability parameters for irrigation usage. The electrical conductivity of all collected samples were within the range of 450 to 1653 $\mu\text{S cm}^{-1}$ indicating medium to high salinity. Total dissolved solids ranged from 247 to 789 mg L^{-1} and the samples were rated as fresh water ($<1000 \text{ mg L}^{-1}$). The anion chemistry in the Karatoa river water was dominated by HCO_3^- and Cl^- , which contributed 66 and 31%, respectively of the total anionic mass balance. On the other hand, the cation chemistry indicated that 8 samples showed dominance sequence as $\text{Ca} > \text{Mg} > \text{Na} > \text{K}$, 8 samples as $\text{Ca} > \text{K} > \text{Na} > \text{Mg}$, 7 samples as $\text{Ca} > \text{Mg} > \text{K} > \text{Na}$, 6 samples as $\text{Ca} > \text{Na} > \text{K} > \text{Mg}$ and only 2 samples as $\text{Ca} > \text{K} > \text{Mg} > \text{Na}$. Among the studied heavy metals (Fe, Mn, Cu, Zn, Pb, Cr and Ni), the most dominant metal was Fe and Mn. The concentration of Mn in 13 water samples exceeded the surface water quality standard (0.10 mg L^{-1}) indicating Mn toxicity. Considering hardness, 6 water samples were graded as moderately hard while the rest 25 samples were graded as hard. As regards to permeability index, 65% of the water samples collected from the midstream of Karatoa river belongs to the unsuitable category.

Keywords- *Water pollution, surface & irrigation water quality, Karatoa river*

Introduction

The contamination of water with heavy metals is a major environmental problem. Some of these metals are potentially toxic or carcinogenic at high concentrations and can cause serious health hazard if they enter into the food chain. Heavy metals like Cu, Zn, Mn, Fe, Ni, Cd, Cr, Co, Pb etc. are usually present in water at low concentration, but enhanced concentration of these metals have found as a result of human activities. Investigation 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).

It is reported that a large number of rivers and streams drain to the undulating landscape of the Jaintia Hills. Most of these rivers and streams flow towards south-east into the flood plains of Bangladesh and a few towards northern side into the Brahmaputra valley (Das *et al.*, 2002). The water is seriously affected by contamination of heavy metals originating from different industries and spoils, leaching of heavy metals, organic enrichment and silting by sand particles. Pollution of the water is evident by the colour of the water which in most of the rivers and streams in the industrial area varies from brownish to reddish orange. The experimental water samples were collected from the major polluting areas of midstream of the river Karatoa under sadar district of Bogra, Bangladesh. There are several types of industrial units including textile, dyeing, pharmaceuticals, leather and others present in Bogra. From the different industrial zones of the area,

contamination of river water by various metallic and non-metallic chemicals are very common. Ittefaq (2010) reported that the toxic waste, sewerages and effluents of more than hundred factories are being discharged to Karatoa river. Nowadays, offensive odour from this river are making nuisance to the people living surrounding areas. Huge amount of untreated municipal waste water, industrial effluents and others may associate with the heavy metal contamination in water of Karatoa river, which has been used by nearby villagers for irrigation, animal watering, bathing and washing etc. for the last several decades, and may have a significant contribution to increase heavy metal content of the surrounding water. As a result, environmental hazards are occurring including different health hazards.

This loading of toxic metals often leads to degradation of water health and contamination of food chain mainly through the crops produced using contaminated irrigation water. However, there is no systemic research report yet about the heavy metal pollution level and major ionic constituents in midstream waters of the Karatoa river in Bangladesh. Considering the above facts, the research work has carried out to determine the concentration of heavy metals and major ionic constituents of the Karatoa river in Bangladesh as well as to assess the suitability of waters for irrigation.

Materials and Methods

A total of 31 water samples were collected from the midstream of Karatoa river during March in 2011 following the sampling techniques as outlined by APHA (1995) and Sincero and Sincero (2004) (Table 1). Samples were collected in 500 ml narrow-mouth high density polyethylene bottles, which were cleaned in the laboratory with dilute HCl (1:1) and then rinsed twice with distilled water. Before sampling, bottles were also rinsed with the sampled water. For heavy metal analysis, 100 ml samples were acidified with HNO₃ and preserved separately in refrigerator. In the laboratory of the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensing-2202, the water samples were filtered through 0.45 µm Millipore membrane filters to separate undesirable solid and suspended materials. The samples were analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), major cations (Ca²⁺, Mg²⁺, Na⁺ and K⁺), major anions (Cl⁻, HCO₃⁻, CO₃²⁻, SO₄²⁻, BO₃³⁻ and PO₄³⁻) and heavy metals (Fe, Mn, Zn, Pb, Cr, Ni and Cu) following standard analytical methods. Calcium and magnesium were determined titrimetrically using standard EDTA. Chloride was measured by standard AgNO₃ titration, bicarbonate and carbonate by titration with standard H₂SO₄, sodium and potassium by flame photometry. Sulphate, borate and phosphate were determined by spectrophotometry. The concentrations of Fe, Mn, Zn, Pb, Cr, Ni and Cu in water samples were analyzed by atomic absorption spectrophotometer by using single hollow cathode lamp at the wavelengths of 248.3, 279.5, 213.9, 283.3, 357.9, 232.0 and 324.7 nm, respectively following the procedure as described by APHA (1995). The analytical precision for ions was determined by the ionic balances calculated as $100 \times (\text{cations} - \text{anions}) / (\text{cations} + \text{anions})$, which is generally within $\pm 5\%$ (Srinivasamoorthy *et al.*, 2011). The parameters such as sodium adsorption ratio (SAR), soluble sodium percent (SSP), residual sodium carbonate (RSC), permeability index (PI) and hardness (H_T) were calculated to evaluate the suitability of the water quality for agricultural purposes. Further the results of the analyses were interpreted using graphical representations like SAR vs salinity hazard as described by Richards (1968) and Doneen plot (Doneen 1964).

Results and Discussion

The results of the geochemical analysis of water samples collected from midstream of the river Karatoa is given in Tables 2 & 3. Figure 1 shows the percent contribution of individual ions towards the total cationic and anionic mass balance.

a) Physicochemical properties of water

The pH of water samples collected from midstream of Karatoa river fluctuated between 6.98 to 7.70 with a mean value of 7.28 indicating neutral to little alkalinity of water (Table 2). These might be due to the presence of ions such as Ca, Mg and Na in water (Rao *et al.*, 1982). According to Ayers and Westcot (1985), the acceptable range of pH for irrigation water is from 6.5 to 8.4. So, on the basis of measured pH of all samples collected from the Karatoa river was not problematic for long-term irrigation. Conductivity is the measure of the capacity of a solution to conduct electric current. The electrical conductivity (EC) of all collected water samples were within the range of 450 to 1653 µS cm⁻¹ with an average of 763.81 µS cm⁻¹ (Table 2). Among the 31 samples, EC of 25 were less than their average value and the rest 06 samples were higher than the average. There were a wide spatial variations observed in the EC of waters of Karatoa river. A similar observation was reported by Singh *et al.* (2010) for waste water of Raniganj industrial area in India. According to Richards (1968), samples under test were rated in the category C2 (EC = 250-750 µS cm⁻¹) and C3 (EC = 751-2250 µS cm⁻¹) indicating medium to high salinity. Medium salinity class water might be applied with moderate leaching but high salinity class waters were treated as unsuitable for irrigation (Agarwal *et al.*, 1982). Dissolved oxygen (DO) of all collected water samples were within the range of 0.3 to 0.5 mg L⁻¹ with an average of 0.42 mg L⁻¹ (Table 2). Adequate dissolved oxygen is necessary for good water quality. As dissolved oxygen levels in water drop below 5.0 mg L⁻¹, aquatic life is put under stress. The lower the concentration, the greater the stress (DEP, 2010). Total dissolved solids (TDS) values of water samples collected from midstream of the river Karatoa were within the range of 247 to 789 mg L⁻¹ with an average value of 324.87 mg L⁻¹ (Table 2). All water samples containing TDS < 1000 mg L⁻¹ were rated as fresh water (Freeze and Cherry, 1979). High TDS values indicated the presence of an appreciable quantities of bicarbonates, sulphates and chlorides of Ca, Mg and Na (Karanth, 1994).

b) Major anionic constituents in water

Water samples collected from the study area contained Cl⁻ ranging from 2.61 to 5.36 me L⁻¹ with an average value of 3.12 me L⁻¹ (Table 2), which contributed 31% of the total anionic mass balance (Fig. 1a). Maximum permissible limit of Cl⁻ in irrigation water is 4.00 me L⁻¹ (141.80 mg L⁻¹) as reported by Ayers and Westcot (1985). On the basis of this limit, all water samples except 3 (Sample ID 16, 19 and 31) were within the permissible limit, and these water were suitable for irrigation. Excess chloride in the study area may result from anthropogenic sources including agricultural runoff, domestic and industrial wastes and leaching of saline

residues in the water (Appelo and Postma, 1993). According to DEP (2010), maximum recommended concentration of Cl⁻ in surface water is 250 mg L⁻¹. Considering this limit as standard, amount of Cl⁻ in all water samples of the study area were below the recommended value, which also indicates that all the water samples were suitable for different uses. The concentration of HCO₃⁻ in water samples was within the range of 2.0 to 8.0 me L⁻¹ with the mean value of 2.59 me L⁻¹ (Table 2) and it contributed 66% of the total anionic mass balance (Fig. 1a). Among the 31 samples, 67.74% samples were less than the mean value and the other 32.26% samples were higher than the mean value. In respect of HCO₃⁻ content, all of the studied water samples were found unsuitable for irrigation, which exceeded the recommended limit (1.50 me L⁻¹) as reported by Ayers and Westcott (1985). Bicarbonates are derived mainly from the soil zone CO₂ and dissolution of carbonates and reaction of silicates with carbonic acid. The soil zone in the subsurface environment contains elevated CO₂ pressure (produced as result of decay of organic matter and root respiration), which in turn combines with rainwater to form bicarbonate. Bicarbonate may also be derived from the dissolution of carbonates and/or silicate minerals by the carbonic acid (Singh *et al.*, 2009). The phosphate content of test samples collected from midstream of the Karatoa river varied from 1.13 to 2.56 mg L⁻¹ with a mean value of 1.58

mg L⁻¹. The maximum permissible limit of PO₄³⁻ in irrigation water is 2.00 mg L⁻¹ (Ayers and Westcott, 1985). Considering this limit as standard, out of the 31 samples, 26 samples were within the permissible value. The SO₄²⁻ content of all water samples collected from the study area ranged from 3.08 to 25.92 mg L⁻¹ with a mean value of 7.43 mg L⁻¹ (Table 2) and it contributed only 2% of the total anionic mass balance (Fig. 1a). The maximum permissible limit of SO₄²⁻ in irrigation water is 20.0 mg L⁻¹ (Ayers and Westcott, 1985). Out of the 31 samples, 29 samples were within the permissible value and suitable for irrigation. The BO₃³⁻ content of all water samples ranged from 0.30 to 1.35 mg L⁻¹ with a mean value of 0.59 mg L⁻¹ (Table 2). The maximum permissible limit of BO₃³⁻ in irrigation water is 1.00 mg L⁻¹ (Ayers and Westcott, 1985). Out of the 31 samples, 30 samples were within the permissible value and suitable for irrigation. Because boron is weakly absorbed in soil, marginal levels in irrigation water reportedly may not be immediately toxic; however, continued use exceeding specified levels cannot be tolerated by the plants (Gibeault and Cockerham, 1985). According to DEP (2010), the maximum permissible limit of BO₃³⁻ in surface water is 0.75 mg L⁻¹. Out of the 31 samples, 27 samples were within the permissible value and suitable for different uses.

Table 1. Detailed information regarding water sampling sites at midstream of Karatoa river in Bangladesh

Sample ID.	Sampling area	Possible source of contamination
01	SP ghat	Sewage sludge
02	SP ghat	Sewage sludge
03	SP ghat	Sewage sludge
04	SP ghat	Sewage sludge
05	SP ghat	Sewage sludge
06	SP ghat	Sewage sludge
07	Bogra Mohila Mohabiddaloy	Pharmaceutical waste
08	Bogra Mohila Mohabiddaloy	Pharmaceutical waste
09	Bogra Mohila Mohabiddaloy	Pharmaceutical waste
10	Bogra Mohila Mohabiddaloy	Pharmaceutical waste
11	Bogra Mohila Mohabiddaloy	Pharmaceutical waste
12	Bogra Mohila Mohabiddaloy	Pharmaceutical waste
13	Backside of DC Office	Hide processing waste
14	Backside of DC Office	Hide processing waste
15	Backside of DC Office	Hide processing waste
16	Backside of DC Office	Hide processing waste
17	Backside of DC Office	Hide processing waste
18	Backside of DC Office	Hide processing waste
19	Fatah Ali Bridge	Industrial effluent
20	Fatah Ali Bridge	Industrial effluent
21	Fatah Ali Bridge	Industrial effluent
22	Fatah Ali Bridge	Industrial effluent

Sample ID.	Sampling area	Possible source of contamination
23	Fatah Ali Bridge	Industrial effluent
24	Fatah Ali Bridge	Industrial effluent
25	Chasi Bazar	Municipal waste
26	Chasi Bazar	Municipal waste
27	Chasi Bazar	Municipal waste
28	Chasi Bazar	Municipal waste
29	Chasi Bazar	Municipal waste
30	Chasi Bazar	Municipal waste
31	Chasi Bazar	Municipal waste

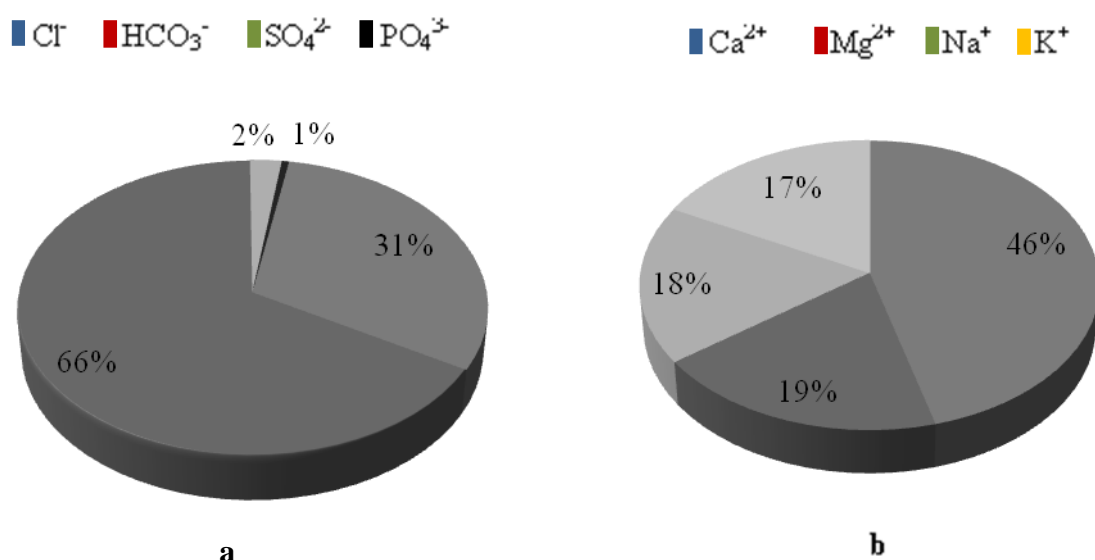


Fig. 1. Contribution of individual major ions towards the total anionic (a) and cationic (b) mass balance in water of midstream of Karatoa river in Bangladesh

c) Major cationic constituents in water

The major cations measured from collected water samples of midstream of the river Karatoa were expressed as mg L⁻¹ (Table 3). The cation chemistry was dominated by calcium, sodium, potassium and magnesium in the water of the major polluting areas of Karatoa river. Among the 31 water samples, 8 samples showed dominance sequence as Ca > Mg > Na > K, 8 samples as Ca > K > Na > Mg, 7 samples as Ca > Mg > K > Na, 6 samples as Ca > Na > K > Mg and only 2 samples as Ca > K > Mg > Na. Weathering of rock forming minerals and cation exchange processes normally control the levels of these cations. High concentrations of Ca and Mg in the water are attributed to the weathering of crystalline dolomitic limestones and Ca-Mg silicates (amphiboles, pyroxenes, olivine, biotite and others) (Ghosh *et al.*, 1983). The sodium and potassium in the aquatic system were derived from the atmospheric deposition, evaporate dissolution and silicate weathering. The weathering of Na and K silicate minerals like albite, anorthite, orthoclase and

microcline may be the possible source of Na and K in water of the study area (Singh *et al.*, 2009).

The content of Ca in water samples collected from the midstream of the river Karatoa varied from 24.05 to 70.54 mg L⁻¹ with an average value of 44.32 mg L⁻¹ (Table 3) and it contributed 46% of the total cationic mass balance (Fig. 1b). The contribution of Ca in water was largely dependent on the solubility of CaCO₃, CaSO₄ and rarely on CaCl₂ (Karanth, 1994). Irrigation water containing less than 20 me L⁻¹ (800 mg L⁻¹) Ca is suitable for irrigating crops (Ayers and Westcot, 1985). On the basis of Ca content, all water samples could safely be used for irrigation. The concentration of Mg was detected within the range of 3.89 to 30.13 mg L⁻¹ with a mean value of 15.84 mg L⁻¹ (Table 3), which contributed 19% of the total cationic mass balance (Fig. 1b). According to Ayers and Westcot (1985), irrigation water containing below 5.0 me L⁻¹ (121.5 mg L⁻¹) Mg is suitable for crops and soils. In the investigated areas, all water samples were within this recommended limit, and could safely be used for irrigation and would not affect soils of the

study area. The concentration of Na in water of the study area varied from 12.48 to 24.88 mg L⁻¹ with the mean value of 15.94 mg L⁻¹ (Table 3), which contributed 18% of the total cationic mass balance (Fig. 1b). Sodium in the aquatic system is mainly derived from atmospheric deposition; evaporate dissolution and silicate weathering (Berner and Berner, 1987). According to Ayers and Westcot (1985), irrigation water generally containing less than 40 me L⁻¹ Na is suitable for crops and soils. The detected Na content in all the water samples under test were far below this specified limit. Water for irrigation should satisfy the needs of soil and plants of the area for normal growth and crop production. The concentration of K present in the water samples collected from midstream of the river Karatoa varied from 8.55 to 21.53 mg L⁻¹ with the mean value of 15.03 mg L⁻¹ (Table 3) and it contributed 17% of the total cationic mass balance (Fig. 1b). According to Ayers and Westcot (1985), the recommended limit of K in irrigation water is 2.0 mg L⁻¹. In the investigated area, all of the water samples exceeded the limit.

d) Heavy metals concentration in water

In the water samples collected from midstream of the river Karatoa, the most dominant metal was Fe followed by Mn, Ni and Cr. The presence of higher concentration of heavy metals in water may cause health hazards to the population of the area (Singh *et al.*, 2009). The concentration of Fe in waters ranging from trace to 0.89 mg L⁻¹ with an average value of 0.495 mg L⁻¹ (Table 3). According to Ayers and Westcot (1985), the maximum recommended concentration of Fe in water used for irrigation is 5.0 mg L⁻¹ and according to DEP (2010), the maximum recommended concentration of Fe in surface water is 1.0 mg L⁻¹. Considering these limits as standard, amount of Fe in all water samples of the study area were below the recommended limits, which indicates that all water samples were suitable for different uses.

The concentration of Mn in water samples collected from midstream of the river Karatoa varied from trace to 0.32 mg L⁻¹ with a mean value of 0.10 mg L⁻¹ (Table 3). According to Ayers and Westcot (1985), the maximum recommended limit of Mn in water used for irrigation is 0.20 mg L⁻¹. Considering this limit as standard, amount of Mn in all water samples except one (Sample ID 19) of the study area were below the recommended value. According to surface water quality guideline, the maximum permissible limit of Mn is 0.1 mg L⁻¹ (DEP, 2010). Considering this value, out of the 31 samples, 18 samples were within the permissible limit and the rest 13 samples exceeded the limit, which may problematic for different uses in respect of Mn concentration. The concentration of Cr in water samples varied from 0.002 to 0.009 mg L⁻¹ with an average value of 0.005 mg L⁻¹. The concentration of Ni in water samples collected from the Karatoa river ranged from 0.001 to

0.012 mg L⁻¹ with a mean value of 0.005 mg L⁻¹ (Table 3). According to USEPA (1999), the maximum recommended limit of Cr and Ni in water used for irrigation are 0.011 and 0.052 mg L⁻¹, respectively. Considering these limits as standard, amount of Cr and Ni in all water samples of the study area were below the recommended value. Similarly, the water samples collected from midstream of the river Karatoa contained trace amount of Cu, Zn and Pb (Table 3), which indicates that all of these water can safely be used for irrigation as well as other purposes in respect of these heavy metals.

e) Suitability of water for irrigation usage

The important characteristics or properties of water to be considered for irrigation use are electrical conductivity, salinity, percent sodium, sodium adsorption ratio, residual sodium carbonate and permeability index.

(i) Sodium adsorption ratio (SAR)

A high Na concentration changes soil properties and reduces soil permeability, which leads to development of an alkaline soil (Singh *et al.*, 2010). The Na or alkali hazard is determined by the absolute and relative concentration of cations and is expressed in terms of the SAR, which is determined by the following formula:

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

[all concentrations in meq L⁻¹]

The computed sodium adsorption ratio (SAR) of water samples ranged from 0.60 to 1.00 with a mean value of 0.75 (Table 4). Among the 31 samples, 22 samples were found below the average value and the rest 9 samples had more than the average value. Considering SAR value, Todd (1980) categorized irrigation waters into 4 groups, and considering this classification, all water samples were graded as excellent category for irrigation purpose. The present investigation revealed that a good proportion of Ca and Mg existed in all waters. These were suitable for good structure and tilth condition of soil and also the improvement of soil permeability. The irrigation water with SAR less than 10 might not be harmful for agricultural crops (Todd, 1980). The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that water samples fall in the categories of C2S1 and C3S1 indicating medium to high salinity and low alkali water (Fig. 2). High salinity water cannot be used on soils with restricted drainage and it requires special management for salinity control (such as good drainage, high leaching and organic matter addition) and plants with good salt tolerance should be selected for such area. Low sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.

Table 2. pH, EC, TDS, DO and major anionic constituents of water collected from midstream of Karatoa river in Bangladesh

Sample ID	pH	EC $\mu\text{S cm}^{-1}$	DO mg L^{-1}	TDS mg L^{-1}	Cl me L^{-1}	CO_3^{2-} me L^{-1}	HCO_3^- me L^{-1}	BO_3^{3-} $\mu\text{g mL}^{-1}$	PO_4^{3-} $\mu\text{g mL}^{-1}$	SO_4^{2-} $\mu\text{g mL}^{-1}$
1	7.22	450	0.40	293	3.17	Trace	4.00	0.61	2.02	8.83
2	7.30	736	0.40	291	2.96	Trace	2.00	0.66	1.88	7.92
3	7.15	706	0.50	286	3.03	Trace	2.20	0.55	2.13	8.92
4	7.32	728	0.50	309	3.03	Trace	2.40	0.58	1.64	6.25
5	7.01	736	0.30	306	2.96	Trace	2.40	0.52	2.12	5.92
6	7.10	724	0.50	303	2.96	Trace	2.80	0.55	1.72	5.83
7	7.22	748	0.40	308	3.03	Trace	2.00	0.58	1.36	6.08
8	7.36	765	0.40	328	3.10	Trace	2.20	0.52	1.41	5.83
9	7.36	800	0.40	330	3.24	Trace	2.20	0.63	1.16	7.25
10	7.27	740	0.40	301	3.10	Trace	2.20	0.41	1.34	5.50
11	7.35	706	0.40	282	2.96	Trace	2.60	0.55	1.31	5.58
12	7.29	564	0.40	247	2.96	Trace	2.00	0.63	1.33	6.33
13	7.32	730	0.50	298	3.03	Trace	2.40	0.52	1.31	6.33
14	7.32	719	0.40	291	2.96	Trace	2.60	0.47	1.99	7.17
15	7.25	732	0.50	312	2.89	Trace	3.00	0.61	1.84	6.75
16	7.70	1224	0.40	562	5.36	Trace	2.60	0.69	1.36	25.92
17	7.14	736	0.50	312	3.03	Trace	2.60	0.77	1.47	5.92
18	7.29	737	0.40	308	2.96	Trace	2.20	0.79	2.16	5.42
19	7.23	1653	0.40	789	5.36	Trace	8.00	1.35	1.95	23.33
20	7.19	743	0.40	306	2.96	Trace	2.40	0.91	2.56	4.75
21	7.24	678	0.40	276	2.75	Trace	2.00	0.55	1.60	4.25
22	7.34	679	0.40	270	2.89	Trace	2.00	0.47	1.23	3.58
23	7.28	674	0.40	256	2.75	Trace	2.00	0.30	1.33	3.08
24	7.01	688	0.40	272	2.82	Trace	2.40	0.58	1.13	4.08
25	7.30	678	0.40	279	2.75	Trace	2.00	0.61	1.21	5.50
26	7.38	660	0.40	277	2.61	Trace	2.00	0.44	1.18	4.92
27	7.51	656	0.40	269	2.61	Trace	2.20	0.49	1.28	5.25
28	6.98	705	0.40	288	2.89	Trace	2.20	0.52	1.34	3.92
29	7.18	780	0.50	326	2.68	Trace	2.80	0.36	1.46	6.33
30	7.34	672	0.40	283	2.75	Trace	2.00	0.47	1.49	6.67
31	7.62	1131	0.40	513	4.23	Trace	4.00	0.47	1.60	17.00
Max.	7.70	1653	0.50	789	5.36	Trace	8.00	1.35	2.56	25.92
Min.	6.98	450	0.30	247	2.61	Trace	2.00	0.30	1.13	3.08
Mean	7.28	763.81	0.42	324.87	3.12	-	2.59	0.59	1.58	7.43
SD	0.16	213.33	0.05	107.55	0.66	-	1.12	0.19	0.37	5.19

Table 3. Heavy metals and major cationic concentrations ($\mu\text{g mL}^{-1}$) of water collected from midstream of Karatoa river in Bangladesh

Sample ID	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	Pb	Cr	Ni
1	41.68	17.49	16.08	15.85	0.51	0.18	Trace	Trace	Trace	0.005	0.004
2	40.08	18.47	15.28	16.25	0.52	0.19	Trace	Trace	Trace	0.006	0.008
3	41.08	15.56	14.48	15.44	0.51	0.18	Trace	Trace	Trace	0.007	0.009
4	44.89	16.53	14.88	16.25	0.39	0.15	Trace	Trace	Trace	0.004	0.004
5	46.49	15.56	15.28	16.25	0.25	0.11	Trace	Trace	Trace	0.004	0.007
6	48.09	03.89	12.48	14.23	0.51	0.07	Trace	Trace	Trace	0.002	0.003
7	40.08	16.53	15.28	15.44	Trace	Trace	Trace	Trace	Trace	0.003	0.004
8	40.08	18.47	17.28	15.85	Trace	0.06	Trace	Trace	Trace	0.008	0.011
9	40.08	14.58	17.68	16.66	0.13	0.07	Trace	Trace	Trace	0.004	0.002
10	51.30	12.63	16.08	15.44	0.25	Trace	Trace	Trace	Trace	0.002	0.002
11	54.51	12.63	15.28	16.25	Trace	0.04	Trace	Trace	Trace	0.003	0.004
12	48.09	13.61	15.28	15.04	0.63	Trace	Trace	Trace	Trace	0.003	0.007
13	42.29	12.64	16.48	14.63	0.57	0.11	Trace	Trace	Trace	0.005	0.009
14	51.30	11.67	15.68	15.85	0.51	0.07	Trace	Trace	Trace	0.006	0.007
15	48.09	13.61	14.88	16.25	0.13	0.14	Trace	Trace	Trace	0.005	0.005
16	70.54	30.13	24.48	8.95	Trace	0.07	Trace	Trace	Trace	0.004	0.007
17	43.28	16.53	16.08	16.25	Trace	0.06	Trace	Trace	Trace	0.008	0.012
18	48.09	13.61	14.48	17.07	0.13	0.04	Trace	Trace	Trace	0.009	0.010
19	70.54	27.22	24.88	12.60	0.38	0.32	Trace	Trace	Trace	0.005	0.004
20	40.08	19.44	15.68	17.47	0.29	0.18	Trace	Trace	Trace	0.003	0.002
21	35.27	09.72	14.88	15.04	0.25	0.04	Trace	Trace	Trace	0.004	0.005
22	24.05	06.81	15.28	13.41	0.24	0.05	Trace	Trace	Trace	0.002	0.001
23	38.47	12.64	14.48	14.23	0.25	0.04	Trace	Trace	Trace	0.004	0.003
24	40.08	18.47	14.88	14.63	0.43	0.06	Trace	Trace	Trace	0.004	0.003
25	43.28	22.36	15.68	13.82	0.63	0.07	Trace	Trace	Trace	0.002	0.001
26	43.28	24.31	14.08	13.41	0.89	0.11	Trace	Trace	Trace	0.007	0.009
27	38.47	10.69	13.28	13.41	0.78	0.09	Trace	Trace	Trace	0.005	0.006
28	35.27	12.63	15.28	15.89	0.76	0.07	Trace	Trace	Trace	0.006	0.004
29	40.08	14.58	13.28	13.82	0.63	0.11	Trace	Trace	Trace	0.002	0.002
30	40.08	14.58	12.88	21.53	0.51	0.14	Trace	Trace	Trace	0.003	0.005
31	44.89	23.33	22.08	8.55	0.76	0.14	Trace	Trace	Trace	0.003	0.005
Max.	70.54	30.13	24.88	21.53	0.89	0.32	Trace	Trace	Trace	0.009	0.012
Min.	24.05	3.89	12.48	8.55	Trace	Trace	Trace	Trace	Trace	0.002	0.001
Mean	44.32	15.84	15.94	15.03	0.495	0.101	-	-	-	0.005	0.005
SD	9.04	5.53	2.88	2.34	0.247	0.067	-	-	-	0.002	0.003

Table 4. Quality rating and suitability of water for irrigation collected from the midstream of Karatoa river in Bangladesh

Sample ID	SAR	SSP %	RSC meL ⁻¹	Hardness mg L ⁻¹	Water class based on			
					SAR ¹	SSP ²	RSC ³	Hardness ⁴
1	0.74	38.35	2.24	175.91	Ex.	Good	Mar.	Hard
2	0.71	37.82	0.24	175.93	Ex.	Good	Suit.	Hard
3	0.69	37.87	0.54	166.49	Ex.	Good	Suit.	Hard
4	0.66	36.91	0.60	179.99	Ex.	Good	Suit.	Hard
5	0.70	37.28	0.60	180.02	Ex.	Good	Suit.	Hard
6	0.66	39.79	1.44	136.17	Ex.	Good	Mar.	MH
7	0.72	38.46	0.32	167.97	Ex.	Good	Suit.	Hard
8	0.85	39.47	0.44	175.93	Ex.	Good	Suit.	Hard
9	0.86	42.55	0.60	159.98	Ex.	Perm.	Suit.	Hard
10	0.74	37.62	0.40	180.03	Ex.	Good	Suit.	Hard
11	0.69	36.28	0.72	188.06	Ex.	Good	Suit.	Hard
12	0.71	37.16	0.24	176.03	Ex.	Good	Suit.	Hard
13	0.81	40.72	0.83	157.55	Ex.	Perm.	Suit.	Hard
14	0.73	37.96	0.84	176.09	Ex.	Good	Suit.	Hard
15	0.69	37.45	1.24	176.03	Ex.	Good	Suit.	Hard
16	0.87	30.04	0.40	299.88	Ex.	Good	Suit.	Hard
17	0.74	38.55	0.84	175.97	Ex.	Good	Suit.	Hard
18	0.67	37.51	0.44	176.03	Ex.	Good	Suit.	Hard
19	0.90	32.65	5.12	287.95	Ex.	Good	Unsuit.	Hard
20	0.72	38.33	0.60	179.90	Ex.	Good	Suit.	Hard
21	0.81	44.44	0.72	128.03	Ex.	Perm.	Suit.	MH
22	1.00	53.17	1.12	88.05	Ex.	Perm.	Suit.	MH
23	0.73	39.96	0.52	147.99	Ex.	Good	Suit.	MH
24	0.69	36.54	0.64	175.93	Ex.	Good	Suit.	Hard
25	0.68	33.94	0.01	199.88	Ex.	Good	Suit.	Hard
26	0.60	31.29	-0.08	207.87	Ex.	Good	Suit.	Hard
27	0.69	39.47	0.79	140.00	Ex.	Good	Suit.	MH
28	0.79	43.13	0.80	139.96	Ex.	Perm.	Suit.	MH
29	0.72	36.62	1.20	159.98	Ex.	Good	Suit.	Hard
30	0.63	43.12	0.39	159.98	Ex.	Perm.	Suit.	Hard
31	0.94	36.09	1.92	207.88	Ex.	Good	Mar.	Hard
Max.	1.00	53.17	5.12	299.88	-	-	-	-
Min.	0.60	30.04	-0.08	88.05	-	-	-	-
Mean	0.75	38.40	0.86	174.25				
SD	0.09	4.19	0.93	41.09				

Legend: Ex. = Excellent, Perm. = Permissible, MH = Moderately hard, Suit. = Suitable, Unsuit.= Unsuitable, Mar. = Marginal, ^{1, 2, 3 & 4} = Todd (1980), Wilcox (1955), Ghosh *et al.* (1983) and Sawyer and McCarty (1967)

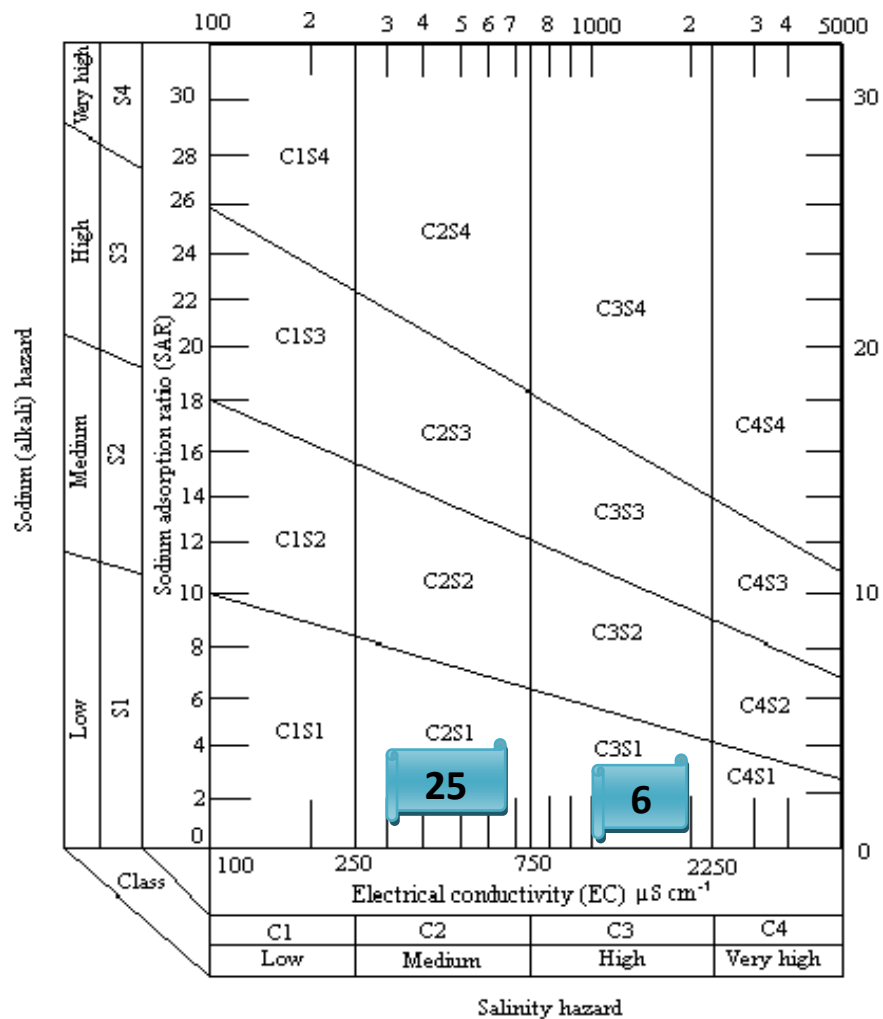


Fig. 2. Diagram for classifying irrigation water on the basis of SAR and EC as described by Richards (1968)

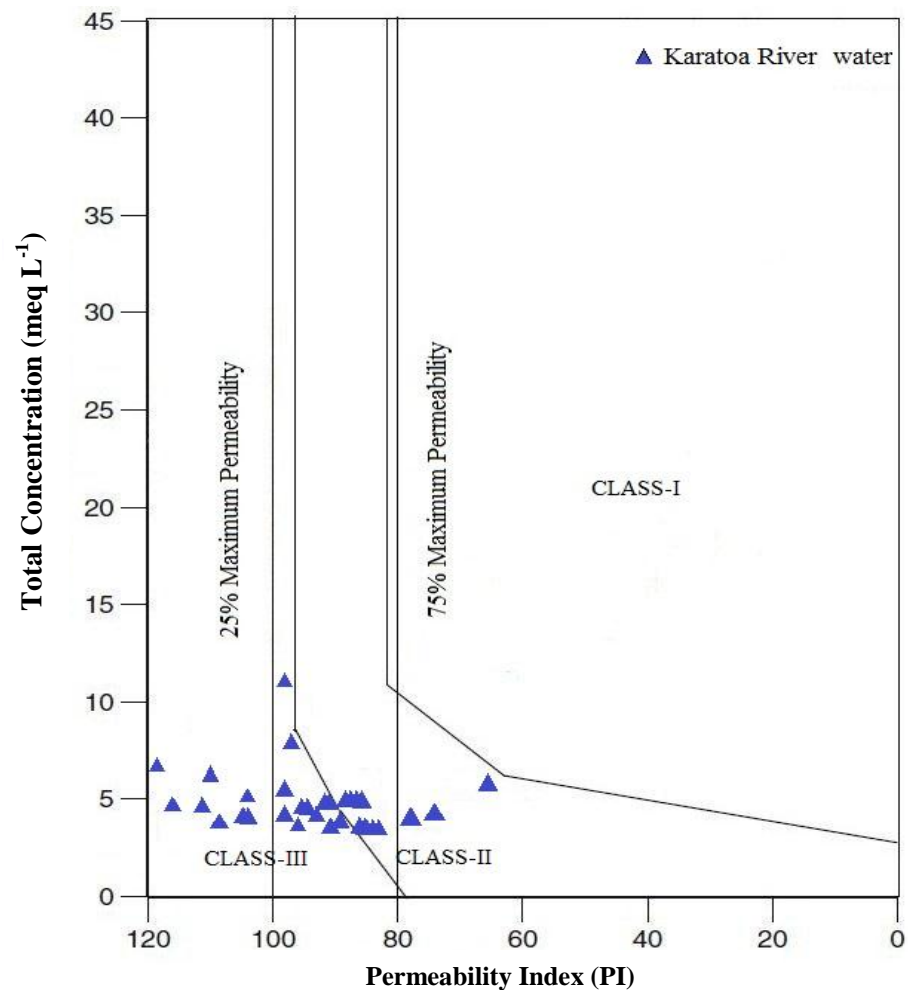


Fig. 3. Diagram for classifying irrigation waters on the basis of permeability index as described by Doneen (1964)

(ii) Soluble sodium percentage (SSP)

Percent Na is widely used for evaluating the suitability of water for irrigation (Wilcox, 1955). High Na irrigation water causes exchange of Na in water for Ca and Mg 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 (Collins and Jenkins, 1996; Saleh *et al.*, 1999). The Indian Standard (BIS, 1991) recommends a maximum SSP of 60% for irrigation water, where SSP is calculated by:

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

[all concentrations in meq L⁻¹]

The calculated SSP value of all collected water samples varied from 30.04 to 53.17% with the mean value of 38.40% (Table 4). According to water classification proposed by Wilcox (1955), out of 31 water samples, 25 samples were classified as good (SSP = 0 - 40%) and the rest 6 samples were classified as permissible (SSP = 40 - 60%). In the study area, the water having good to permissible classes might safely be applied for irrigating agricultural crops.

(iii) Residual sodium carbonate (RSC)

The quantity of bicarbonate and carbonate in excess of alkaline earths (Ca²⁺ + Mg²⁺) also influence the suitability of water for irrigation purposes. When the sum of carbonates and bicarbonates is in excess of calcium and magnesium, precipitation Ca and Mg may occur (Raghunath, 1987). The effects of carbonate and bicarbonate, and suitability of water for irrigation can be assessed by computing residual sodium carbonate (RSC) values as follows:

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

[all concentrations in meq L⁻¹]

A high RSC value in water leads to an increase in the adsorption of Na on soil. Irrigation waters having RSC values greater than 5 meq L⁻¹ are considered harmful to the growth of plants, while waters with RSC value above 2.5 meq L⁻¹ are not considered suitable for irrigation. Hence, continued usage of high RSC waters will affect the yields of crop. The computed RSC varied from -0.08 to 5.12 meq L⁻¹ with mean value of 0.86 meq L⁻¹ (Table 4). Among the water samples under test, 1 sample exhibited negative value. According to Ghosh *et al.* (1983), out of 31 water samples, 27 samples were found in suitable class (RSC < 1.25 meq L⁻¹), 3 samples were in marginal class (RSC = 1.25-2.50 meq L⁻¹), and the rest 1 sample was in unsuitable class (RSC > 2.50 meq L⁻¹).

(iv) Hardness (H_T)

Water hardness has no known adverse effects on human; however, some evidence indicates its role in heart disease (WHO, 2008). Hardness of water resulted due to the abundant presence of divalent cations like Ca²⁺ and Mg²⁺ (Todd, 1980). Hard water is unsuitable for domestic usage, as well as hardness of water limits its use for industrial purposes; causing scaling of pots, boilers and irrigation pipes may cause health problems to humans, such as kidney failure (WHO, 2008). Hardness of water was computed by the following formula:

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

The calculated hardness of all water samples varied from 88.05 to 299.88 mg L⁻¹ with the mean value of 174.25 mg L⁻¹ (Table 4). On the basis of total hardness, water can be classified as soft (< 75 mg L⁻¹), moderately hard (75-150 mg L⁻¹), hard (150-300 mg L⁻¹) and very hard (> 300 mg L⁻¹) (Sawyer and McCarty 1967). According to the criteria described above, out of 31 water samples, 6 samples were graded as moderately hard and the rest 25 samples were graded as hard.

(v) Permeability index (PI)

Soil permeability is affected by long term use of water rich in Na⁺, Ca²⁺, Mg²⁺, and HCO₃⁻. The PI is also used to assess suitability of water for irrigation and is defined as follows:

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

[all concentrations in meq L⁻¹]

Doneen (1964) classified irrigation waters in three PI classes. Class-I and Class-II water types are suitable for irrigation with 75% or more of maximum permeability, while Class-III types of water, with 25% of maximum permeability, are unsuitable for irrigation. Plotting our data on Doneen's chart indicates that 35.5% of the water samples fall in Class-II, implying that the water is good for irrigation usage (Domenico and Schwartz 1990). However, 64.5% of the water samples collected from midstream of Karatoa river belongs to Class- III, the unsuitable category (Fig. 3).

Conclusion

The collected water samples of midstream of Karatoa river is neutral to slight alkaline. The EC of all collected water samples show medium to high salinity and DO indicating that the aquatic life in the study area is in under stress. On the basis of K⁺ content, all of the water samples exceeded the limit (2.0 mg L⁻¹) for irrigation usage but in context of Ca²⁺, Mg²⁺ and Na⁺, all water samples under the

study area could safely be applied for long-term irrigation without any harmful effect on both soils and crops. Similarly, in respect of Cl^- , BO_3^{3-} , PO_4^{3-} and SO_4^{2-} content, only 3, 1, 5 and 2 water samples, respectively were problematic for irrigation purpose. Among the studied heavy metals (Fe, Zn, Cu, Pb, Cr, Ni and Mn), the most dominant metal was Fe and Mn. In respect of Mn content, out of 31 samples, 1 and 13 water samples were exceeded the maximum permissible limit for irrigation and surface water quality guideline, respectively. High values of RSC, H_T and PI at some sites in midstream of Karatoa river restrict their use for irrigation. However, suitable water treatment and a soil management plan are needed for their use for this purpose in such areas.

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