Heavy Metal Contamination in Surface Water Used for Irrigation: Functional Assessment of the Turag River in Bangladesh

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Abstract The aim of the present study was to evaluate the degree of metal contamination of the Turag River water and its suitability for irrigation. Twenty water samples were analyzed for physicochemical parameters and metals viz., calcium, magnesium, potassium (K), sodium, copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni). All water samples were slightly alkaline to alkaline. Regarding electrical conductivity (EC), all samples were suitable for crop in soils with moderate permeability and leaching. Water samples were medium salinity and low alkalinity hazard classes. In terms of total dissolved solids (TDS), all samples were classified as freshwater. As per sodium adsorption ratio (SAR) and soluble sodium percentage (SSP), all samples were classified as excellent. No residual sodium carbonate (RSC) was detected in any of the samples, indicating suitability for irrigation; and all samples were considered very hard. Cr and Mn contents in all samples were above FAO guideline values and, therefore, these metals were considered toxic. Zn, Cu, Pb, Cd, and Ni concentrations were below acceptable limit for irrigation and do not pose a threat to soil environment. Significant relationships were found between EC and TDS, SAR and SSP, SAR and RSC, and SSP and RSC. The combinations of ions such as K–Zn, K–Fe, K–Cu, K–Mn, K–Pb, Zn–Fe, Zn–Cu, Zn–Mn, Fe–Mn, Cu–Mn, Cu–Pb and Mn–Pb exhibited significant correlation. This study revealed that Turag River water samples are contaminated with Cr and Mn. This fact should not be ignored because water contamination by metals may pose a threat to human health through food chain.

Keywords contamination · heavy metal · irrigation · surface water · Turag River

Introduction Metal contamination of riverine ecosystems has become a serious environmental problem due to the rapid urbanization and industrialization (Gaur et al., 2005; Suthar et al., 2009; Boran and Altinok, 2010). Metal contaminants enter into river water through anthropogenic sources such as long-term disposal of untreated and partially treated industrial effluents containing toxic metals, and indiscriminate use of metal-containing fertilizers and pesticides in agricultural fields (Martin, 2000; Macklin et al., 2006; Reza and Singh, 2010). Dike et al. (2004) observed that the rapid population increase coupled with factors such as urbanization, rapid industrial development, and agriculture result in huge accumulation of metal contaminants, which end up polluting water bodies such as rivers, streams, and lakes. Metal contaminants are a major cause of concern for the aquatic environment because of their toxicity, abundance, persistence, and subsequent accumulation in aquatic habitats (Deniseger et al., 1990; Sin et al., 2001). 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 (Roy et al., 2015). In addition, they may enter the human food chain and result in health problems. There is an increasing awareness of the hazards posed by environmental contamination with toxic metal ions. Heavy metals have toxic properties, leading to adverse effects on human health even in small doses. The effects of exposure to these environmental pollutants on human health are well known. Toxicity due to heavy metals can result in significant illness and reduced quality of life (Pendas and Pendas, 2000; Ferner, 2001). Some heavy metals like cadmium (Cd), chromium (Cr), manganese (Mn), and lead (Pb) are considered highly toxic for human life including liver and kidney problems and genotoxic carcinogens (Gambrell, 1994).

Bangladesh is a developing country dependent on rivers for cleaning as well as disposal purposes. It is, therefore, very important to regularly monitor the levels of metallic contamination of its rivers. In Bangladesh, about 0.4 millions m$^3$ of untreated industrial waste is being discharged into urban river water in a day (Rabbani and Sharif, 2005). The Turag River is one of the most important urban rivers in Bangladesh. Its vast catchment area receives untreated domestic wastewater from urban sewers and industrial effluents (Khan et al., 2007; Meghla et al., 2013). During the dry season, crop fields situated adjacent to the Turag River are irrigated continuously with contaminated water. The degree of metal contamination of the Turag River was evaluated by determining the concentration of metals in its waters. The final aim was to assess the suitability of Turag River water for irrigation of surrounding agricultural fields.

Materials and Methods

Study area. The study area was located in the Turag River (23° 53.20'–23° 53.31' N and 90° 25.07'–90° 27.66' E; Table 1). Sampling sites (20) were selected according to the location of fields irrigated with river water (Fig. 1). The exact location of each sampling point was determined using GPS.

Water sampling. River water samples were collected in January, 2014 from sampling sites, following the sampling techniques described by American Public Health Association (APHA, 2012). Water samples were acidified with HNO$_3$, (pH<2) to prevent the loss of metals by absorption and/or ion exchange with the walls of the glass containers. All the samples were filtered and tightly sealed immediately after collection to avoid air exposure and later analyzed.

Water analysis. pH and EC values of water samples were determined using pH and EC meter (sensION, Hach, Loveland, USA) (Gupta, 2013). The amount of total dissolved solids (TDS) in the samples was measured using a TDS meter (sensION, Hach, Loveland, USA). The contents of potassium (K) and sodium (Na) were determined by flame photometer (PPF7, Jenway, Stone, UK), whereas the concentrations of calcium (Ca), magnesium (Mg), Zn, Fe, Cu, Mn, Pb, Cd, Cr, and Ni were determined using an atomic absorption spectrophotometer (AA-7000, Shimadzu, Kyoto, Japan) with a specific lamp for each metal (APHA, 2012). For the determination of each metal in water samples, the standard solutions were prepared by pouring the required amount of solution from the stock solution (1,000 mg/L). The standards used were AR grade; the instrument was first calibrated with stock solutions of the prepared standards before analysis using atomic absorption spectrophotometer. The amount of carbonate (CO$_3$) and bicarbonate (HCO$_3$) in the water was estimated using the titrimetric method (Gupta, 2013). In the case of each ion, water samples were analyzed in triplicate.

| Sampling points | Sampling locations | Sampling points | Sampling locations |
|-----------------|--------------------|-----------------|--------------------|
| 1               | 23° 54.01' N 90° 26.24' E | 11              | 23° 53.73' N 90° 27.28' E |
| 2               | 23° 54.03' N 90° 26.36' E | 12              | 23° 53.73' N 90° 27.40' E |
| 3               | 23° 53.98' N 90° 26.53' E | 13              | 23° 53.68' N 90° 27.48' E |
| 4               | 23° 53.95' N 90° 26.62' E | 14              | 23° 53.60' N 90° 27.53' E |
| 5               | 23° 53.91' N 90° 26.76' E | 15              | 23° 53.50' N 90° 27.59' E |
| 6               | 23° 53.85' N 90° 26.81' E | 16              | 23° 53.39' N 90° 27.57' E |
| 7               | 23° 53.77' N 90° 26.93' E | 17              | 23° 53.31' N 90° 27.59' E |
| 8               | 23° 53.73' N 90° 27.03' E | 18              | 23° 53.23' N 90° 27.57' E |
| 9               | 23° 53.73' N 90° 27.12' E | 19              | 23° 53.06' N 90° 27.56' E |
| 10              | 23° 53.72' N 90° 27.18' E | 20              | 23° 53.05' N 90° 27.66' E |

Table 1 Sampling locations in the Turag River.
Water contamination rating. To evaluate the ionic contamination of the water, and assess the suitability of Turag River water for use in irrigation, the following chemical parameters were determined using the analytical results of river water samples:

Sodium adsorption ratio (SAR)

\[
SAR = \frac{Na}{\sqrt{Ca^{2+} + Mg^{2+}}} \quad (1)
\]

Soluble sodium percentage (SSP)

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

Residual sodium carbonate (RSC)

\[
RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad (3)
\]

Hardness (\(H_T\))

\[
H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+} \quad (4)
\]

All ionic concentrations are expressed as me/L except for hardness, which is expressed as mg/L.

Statistical analysis. Statistical analysis was performed according to the methods described by Gomez and Gomez (1984). The data were statistically analyzed using SigmaPlot 10. The correlation analysis was carried out to determine the relationship between metal ions and chemical parameters in water. Means and standard deviations (\(n=3\)) of the metal concentrations in water samples were calculated.

Results and Discussion

The ionic concentration and the degree of water contamination of different samples are presented in Tables 2-4. In the studied area, Ca, Mg, K, Na, and HCO_3 were dominant ions whereas CO_3 was not found in any of the samples. All studied heavy metals were detected in the samples.

pH, EC, and TDS values. The pH values of water samples varied between 7.40 and 7.79 indicating slightly alkaline to alkaline water (Table 2), which was not problematic for long-term irrigation of soils and crops (the acceptable pH limit varies between 6.50 and 8.40; FAO, 1992). This might be due to the presence of some metal ions like Ca, Mg, and Na in the water (Todd and Mays, 2005). More or less similar results of pH values in water samples of urban river namely Turag and Shitalakha were observed by Islam et al. (2014). EC was found to vary between 276.0 and 303.0 µS/cm with an average value of 288.60 µS/cm (Table 2). All water samples were considered to have medium salinity hazard (C2, EC=250–750 µS/cm) according to Wallender and Tanji (2011) as illustrated in Fig. 2 and could be used for crops growing on soils with a moderate level of permeability and leaching. In Bangladesh, EC values of water samples collected from Ganges River varied from 195.0 to 471.0 µS/cm (Tareq et al., 2013). Some EC values were similar to the current study. Uddin et al. (2014) reported that EC values of water samples in Jamuna River of Bangladesh ranged from 104.0 to 141.0 µS/cm, which were lower than the present study. The measured TDS ranged from 181.7 to 194.5 mg/L with a mean value of 186.63 mg/L (Table 2). All the tested samples were classified as freshwater (TDS <1000 mg/L).
mg/L) (Freeze and Cherry, 1979). Tareq et al. (2013) found that TDS values in water samples of Brahmaputra River in Bangladesh ranged from 62.0 to 245.0 mg/L, some of which were similar to findings of the present investigation. TDS values in water samples of Jamuna River in Bangladesh varied from 106.0 to 131.0 mg/L (Uddin et al., 2014). All these values were lower than the present study.

Ca, Mg, K, and Na contents. In the analyzed samples, the concentrations of Ca, Mg, K, and Na ions ranged from 4.49 to 6.41, 1.96 to 2.98, 0.70 to 0.81, and 0.54 to 0.61 me/L, with average values of 5.44, 2.53, 0.74, and 0.58 me/L, respectively (Table 2). The concentration of Ca and Mg was higher than that of K and Na. According to FAO (1992), the accepted limits of Ca, Mg, and Na ions are, respectively, 20.0, 5.0, and 4.0 me/L, whereas the K concentration usually used for irrigation is 2.0 me/L. Considering these limits, using this water for irrigation would have no impact on soil properties and crop growth. Semwal and Jangwan (2009) studied that Ca, Mg, K and Na concentrations in water samples of Bhagirathi and Kosi Rivers, India varied from 0.25 to 1.70, 0.70 to 0.81, 0.45 to 0.54, and 0.29 to 0.30 me/L, which were lower than the present study.

CO$_3$ and HCO$_3$ contents. The amount of HCO$_3$ in the collected samples was within acceptable limits (0.80–2.40 me/L), with a mean value of 1.34 me/L (Table 2). According to Evangelou (1998), the recommended limit for HCO$_3$ in irrigation water is 1.50 me/L (long-term use). Considering this limit, HCO$_3$ concentration detected in the samples is not considered toxic for irrigation purpose. In water samples of Kosi River in India, HCO$_3$ concentration was found to vary between 0.38 and 2.12 me/L (Semwal and Jangwan, 2009). These values were similar to the current study. CO$_3$ was not found in any of the samples.

Zn, Fe, Cu, and Mn contents. Analyzed samples contained Zn ranging from 0.06 to 0.30 mg/L, with a mean value of 0.10 mg/L (Table 3). The recorded concentrations of Zn in the samples were far below the acceptable limit for long-term irrigation purpose (2.00 mg/L; FAO, 1992). The concentration of Zn in water samples of Buriganga River in Bangladesh varied from 0.22 to 0.26 mg/L (Mohiuddin et al., 2011). These values were higher than the current study. Islam et al. (2012) investigated that Zn content in water samples of Balu River in Bangladesh ranged from 8.39 to 76.86 µg/L, some of which were lower and some were higher than the present study. The concentration of Fe in

| Sample ID | pH     | EC µS/cm | TDS mg/L | Ca    | Mg     | K     | Na     | HCO$_3$ |
|-----------|--------|----------|----------|-------|--------|-------|--------|---------|
| 1         | 7.72   | 295.0    | 189.3    | 5.37  | 2.83   | 0.70  | 0.61   | 0.80    |
| 2         | 7.79   | 286.0    | 184.7    | 5.13  | 1.96   | 0.71  | 0.61   | 1.20    |
| 3         | 7.69   | 283.0    | 183.0    | 5.05  | 2.61   | 0.70  | 0.59   | 1.20    |
| 4         | 7.50   | 297.0    | 191.1    | 5.69  | 2.24   | 0.76  | 0.59   | 2.40    |
| 5         | 7.59   | 303.0    | 194.5    | 5.85  | 2.97   | 0.78  | 0.60   | 2.40    |
| 6         | 7.52   | 290.0    | 193.0    | 5.85  | 2.62   | 0.74  | 0.56   | 1.20    |
| 7         | 7.54   | 287.0    | 184.9    | 5.61  | 2.89   | 0.71  | 0.57   | 1.60    |
| 8         | 7.55   | 282.0    | 181.7    | 4.49  | 2.28   | 0.71  | 0.55   | 1.20    |
| 9         | 7.57   | 276.0    | 182.1    | 5.05  | 2.53   | 0.72  | 0.54   | 0.80    |
| 10        | 7.45   | 278.0    | 182.9    | 5.69  | 2.64   | 0.73  | 0.58   | 0.80    |
| 11        | 7.57   | 285.0    | 183.2    | 5.53  | 2.46   | 0.74  | 0.57   | 0.80    |
| 12        | 7.53   | 290.0    | 185.9    | 5.13  | 2.19   | 0.75  | 0.58   | 1.60    |
| 13        | 7.52   | 288.0    | 184.9    | 5.37  | 2.31   | 0.73  | 0.57   | 1.60    |
| 14        | 7.58   | 286.0    | 185.5    | 5.61  | 2.44   | 0.74  | 0.58   | 0.80    |
| 15        | 7.52   | 295.0    | 190.3    | 5.37  | 2.13   | 0.81  | 0.58   | 0.80    |
| 16        | 7.49   | 291.0    | 187.9    | 5.69  | 2.58   | 0.75  | 0.57   | 1.20    |
| 17        | 7.55   | 294.0    | 187.3    | 5.53  | 2.46   | 0.79  | 0.58   | 1.60    |
| 18        | 7.53   | 289.0    | 188.8    | 5.77  | 2.53   | 0.74  | 0.59   | 2.40    |
| 19        | 7.52   | 287.0    | 186.4    | 4.57  | 2.98   | 0.77  | 0.56   | 1.20    |
| 20        | 7.40   | 290.0    | 183.2    | 6.41  | 2.94   | 0.74  | 0.59   | 1.20    |
| Min.      | 7.40   | 276.0    | 181.7    | 4.49  | 1.96   | 0.70  | 0.54   | 0.80    |
| Max.      | 7.79   | 303.0    | 194.5    | 6.41  | 2.98   | 0.81  | 0.61   | 2.40    |
| Mean      |       | 288.60   | 186.63   | 5.44  | 2.53   | 0.74  | 0.58   | 1.34    |
| SD        | -      | 6.40     | 3.83     | 0.45  | 0.29   | 0.03  | 0.02   | 0.54    |
| CV (%)    | -      | 2.22     | 2.05     | 8.24  | 11.57  | 4.03  | 3.14   | 40.25   |
| FAO Guideline Value | 6.5-8.4 | -         | -         | 20.0² | 5.00²  | 0.05² | 40.00² | 1.50² |

Table 2 pH, EC, TDS, and ionic constituents of Turag River water samples

FAO (1992).
water samples varied from 0.77 to 14.79 mg/L, with an average value of 4.55 mg/L (Table 3). Fe was considered as contaminant for long-term irrigation purpose in only 6 samples (samples 4, 5, 12, 15, 17, and 19). In these samples, Fe concentration was above the acceptable limit (5.00 mg/L; FAO, 1992). In the contaminated river water, Fe possibly originated from the pharmaceutical, tannery and textile industries. Afrin et al. (2014) found that the concentration of Fe ranged from 0.78 to 6.33 mg/L in water samples of Turag River in Bangladesh, some of which were lower and some were higher than the current study. The concentration of Fe in water samples of Karatoa River, Bangladesh ranged from 0.78 to 6.33 mg/L in water samples of Turag River in Bangladesh, some of which were lower and some were higher than the current study. The concentration of Fe in water samples of Karatoa River, Bangladesh ranged from 0.78 to 6.33 mg/L in water samples of Turag River in Bangladesh, some of which were lower and some were higher than the current study. The concentration of Fe in water samples of Karatoa River, Bangladesh ranged from 0.78 to 6.33 mg/L in water samples of Turag River in Bangladesh, some of which were lower and some were higher than the current study. The concentration of Cu in water samples varied from 0.001 (trace concentration) and 0.09 mg/L, with an average value of 0.046 mg/L (Table 3). In all samples, the concentration of this metal was below the recommended limit for irrigation purpose (0.20 mg/L; FAO, 1992). The concentration of Cu in surface water samples varied between 0.01 and 0.07 mg/L in Turag River, Bangladesh. These values were almost similar to the present study. The concentration of Mn ion, however, ranged from 0.35 to 0.92 mg/L (mean value of 0.53 mg/L; FAO, 1992) (Table 3). Probably, Mn in the contaminated river water originated from the dyeing and textile industries. Therefore, Mn concentration was considered toxic for long-term irrigation purpose. The detected concentrations of Mn (28.28–730.79 µg/L) in most of the water samples of Balu River, Bangladesh were similar to the current study (Islam et al., 2012). Zakir et al. (2012) reported that the concentration of Mn in water samples collected from Karatoa River in Bangladesh varied from trace to 0.32 mg/L. All these values were lower than the present study.

**Cr, Pb, Cd, and Ni contents.** The concentration of Cr in the samples was between 0.23 and 0.47 mg/L, with an average value of 0.32 mg/L (Table 3). These levels of Cr were considered toxic for long-term irrigation purpose (maximum acceptable value is 0.10 mg/L; FAO, 1992). Chromium in the contaminated river water probably originated from the leather tanning and textile industries. Due to the high Cr concentration, it is strongly recommended not to use river water from this area for irrigation purpose. Similar findings were observed by Alam et al. (2003); Ahmed et al. (2010) and Islam et al. (2014), who reported that Cr was the most abundant in water samples of urban rivers namely Buriganga, Turag and Shitalakha in Bangladesh. The concentration of Pb in samples varied between 0.10 and 0.63 mg/L, with a mean value of 0.36 mg/L (Table 3). These values were far below the maximum permissible value (5.00 mg/L; FAO, 1992) and, therefore, the amount of Pb in the water does not have harmful effects for

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**Fig. 2** Diagram for classifying river water used for irrigation (Wallender and Tanji, 2011).
irrigation use. The concentration of Pb varied from 5.00 to 72.45 µg/L in water samples of Buriganga River in Bangladesh (Alam et al., 2003; Ahmed et al., 2010). Islam et al. (2015) found that Pb concentration in water samples of Karatoa River in Bangladesh varied from 8.0 to 64.0 µg/L. All these values were lower than findings of the present study. The concentration of Cd in water samples was very low (≤0.001 mg/L, trace concentration) and Cd content was considered safe (maximum acceptable value is 0.01 mg/L; FAO, 1992) (Table 3). Similarly, very low concentration of Cd was detected in water samples of Buriganga, Turag and Shitalakha Rivers, Bangladesh (Ahmed et al., 2010; Islam et al., 2014). River water samples contained Ni ranging from ≤0.001 to 0.028 mg/L, with an average value of 0.016 mg/L (Table 3). This revealed that Ni content of river water was considered safe for irrigation (safe limit value is 0.20 mg/L; FAO, 1992). In Bangladesh, Ni concentration in water samples of Buriganga River was found to vary between 7.15 and 10.32 µg/L (Ahmed et al., 2010). These values were lower than the detected levels of this study. Islam et al. (2015) studied the heavy metal concentration in water samples of Karatoa River, Bangladesh and found the concentration of Ni ranging from 9.3 to 66.0 µg/L, some of which were similar to the current study.

Table 3 Metal concentration in Turag River water samples

| Sample ID | Zn  | Fe  | Cu   | Mn  | Cr   | Pb   | Cd   | Ni   |
|-----------|-----|-----|------|-----|------|------|------|------|
|           | µg/L| µg/L| µg/L | µg/L| µg/L | µg/L | µg/L | µg/L |
| 1         | 0.07| 1.24| Trace| 0.36| 0.23 | 0.10 | Trace| Trace|
| 2         | 0.07| 0.93| Trace| 0.35| 0.47 | 0.13 | Trace| Trace|
| 3         | 0.07| 0.85| Trace| 0.38| 0.47 | 0.17 | Trace| Trace|
| 4         | 0.15| 13.01| 0.012| 0.64| 0.23 | 0.22 | Trace| 0.009|
| 5         | 0.14| 13.18| 0.014| 0.66| 0.26 | 0.22 | Trace| 0.018|
| 6         | 0.07| 1.07| 0.012| 0.44| 0.26 | 0.25 | Trace| Trace|
| 7         | 0.06| 1.02| 0.028| 0.43| 0.24 | 0.27 | Trace| Trace|
| 8         | 0.06| 1.23| 0.017| 0.43| 0.23 | 0.31 | Trace| Trace|
| 9         | 0.07| 1.35| 0.031| 0.45| 0.25 | 0.33 | Trace| Trace|
| 10        | 0.07| 0.99| 0.034| 0.46| 0.45 | 0.33 | Trace| Trace|
| 11        | 0.08| 1.90| 0.03 | 0.48| 0.45 | 0.38 | Trace| Trace|
| 12        | 0.11| 6.93| 0.05 | 0.56| 0.25 | 0.39 | Trace| Trace|
| 13        | 0.07| 1.02| 0.05 | 0.47| 0.31 | 0.42 | Trace| Trace|
| 14        | 0.07| 0.77| 0.04 | 0.47| 0.46 | 0.45 | Trace| Trace|
| 15        | 0.19| 14.79| 0.09 | 0.90| 0.25 | 0.47 | Trace| 0.028|
| 16        | 0.06| 1.72| 0.06 | 0.48| 0.30 | 0.50 | Trace| Trace|
| 17        | 0.18| 14.71| 0.09 | 0.92| 0.27 | 0.52 | Trace| 0.024|
| 18        | 0.06| 1.09| 0.07 | 0.49| 0.29 | 0.56 | Trace| Trace|
| 19        | 0.30| 11.73| 0.08 | 0.73| 0.29 | 0.55 | Trace| 0.020|
| 20        | 0.13| 1.56| 0.09 | 0.53| 0.46 | 0.63 | Trace| 0.010|
| Min.      | 0.06| 0.77| Trace| 0.35| 0.23 | 0.10 | -    | Trace|
| Max.      | 0.30| 14.79| 0.09 | 0.92| 0.47 | 0.63 | -    | 0.028|
| Mean      | 0.10| 4.55| 0.046| 0.53| 0.32 | 0.36 | -    | 0.016|
| SD        | 0.06| 5.48| 0.028| 0.16| 0.10 | 0.15 | -    | 0.010|
| CV (%)    | 59.71| 120.29| 60.52 | 30.39| 29.93| 42.25 | -    | 62.82|
| FAO Guideline Value | 2.00<sup>a</sup> | 5.00<sup>a</sup> | 0.20<sup>a</sup> | 0.20<sup>a</sup> | 0.10<sup>a</sup> | 5.00<sup>a</sup> | 0.01<sup>a</sup> | 0.20<sup>a</sup>

Trace means 0.001 mg/L; <sup>a</sup>FAO (1992).

The relationship between chemical parameters and metal ions in river water.

SAR, SSP, RSC, and hardness. SAR, SSP, and RSC values varied between 0.27 and 0.33, 12.45 and 15.70%, and −5.53 and −8.15 me/L, respectively (Table 4). Water samples containing SAR values lower than 10 were considered excellent in terms of alkalinity hazard (Fig. 2). In terms of SSP values, all samples were considered excellent (SSP <20%), according to Todd and Mays (2005). The estimated RSC values showed that all samples were suitable for irrigation purpose (RSC <1.25 me/L) because all calculated values were negative (Gupta, 2013). As regards to SAR and SSP values, water samples collected from Buriganga River in Bangladesh were excellent in quality and were free from RSC indicating suitability for irrigation (Zaman et al., 2002). Hardness (H<sub>T</sub>) values varied between 336.68 and 465.15 mg/L (Table 4). All samples were classified as very hard (H<sub>T</sub> >180 mg/L), according to McGowan (2000). This may be due to the abundance of divalent ions like Ca and Mg (Todd and Mays, 2005; Manahan, 2010). Similar finding was observed by Rahman and Zaman (1995), who reported that river water samples were under very hard class.

Relationship between chemical parameters and metal ions in river water. The relationship between 6 chemical parameters such
as EC, TDS, SAR, SSP, RSC, and hardness was analyzed. Only 4 out of 15 relationships were significant at the 1% probability level (Table 5). Significant relationships were found between EC and TDS, SAR and SSP, SAR and RSC, and SSP and RSC. The relationship between the detected metal ions (Ca, Mg, K, Na, Zn, Fe, Cu, Mn, Pb, and Cr) was also analyzed. Nine relationships were significant at the 1% probability level and 3 were significant at the 5% probability level (Table 6). Significant relationships were found between K and Zn, K and Fe, K and Cu, K and Mn, K and Pb, Zn and Fe, Zn and Cu, Zn and Mn, Fe and Mn, Cu and Mn, Cu and Pb, and Mn and Pb.

The present study shows that the analyzed Turag River water samples have been contaminated with Cr and Mn ions. Therefore, this water is not suitable for irrigation since it may lead to heavy metal toxicity of crops and poisoning of humans through metal entry into the food chain. Regular monitoring of the heavy metal concentrations in water used for irrigation and employing the necessary environmental interventions are strongly recommended for this area. Presently, focus is being put on the discharge of untreated municipal and industrial waste into the river. Strategic management should be implemented by the relevant authorities to regulate the indiscriminate discharge of untreated industrial effluents into the Turag River and evaluate the risk of using such water for irrigation purpose. Further study should be undertaken for metal speciation under consideration for better understanding the harmful effect of specific form of metal ion in the contaminated river water.

**Table 4 Ionic contamination rating of Turag River water samples used for irrigation**

| Sample ID | SAR (%) | SSP (%) | RSC (me/L) | HT (mg/L) |
|-----------|---------|---------|------------|-----------|
| 1         | 0.30    | 13.81   | -7.40      | 407.74    |
| 2         | 0.33    | 15.70   | -5.89      | 352.93    |
| 3         | 0.30    | 14.45   | -6.46      | 380.91    |
| 4         | 0.30    | 14.54   | -5.53      | 394.71    |
| 5         | 0.28    | 13.53   | -6.42      | 438.62    |
| 6         | 0.27    | 13.31   | -7.27      | 421.40    |
| 7         | 0.28    | 13.08   | -6.90      | 422.69    |
| 8         | 0.30    | 15.66   | -5.57      | 336.68    |
| 9         | 0.28    | 14.23   | -6.78      | 376.98    |
| 10        | 0.28    | 13.58   | -7.53      | 414.39    |

**Table 5 Correlation matrix among chemical parameters of Turag River water samples**

| Parameters   | TDS | SAR | SSP | RSC | Hardness |
|--------------|-----|-----|-----|-----|----------|
| EC           | 0.843** | 0.042NS | -0.078NS | 0.120NS | 0.353NS |
| TDS          | -   | -0.063NS | -0.111NS | 0.133NS | 0.321NS |
| SAR          | -   | -   | 0.804** | 0.648** | -0.732NS |
| SSP          | -   | -   | -    | 0.716** | -0.934NS |
| RSC          | -   | -   | -    | -     | -0.681NS |

**Significant at the 1% probability level; NS Not significant.**

The tabulated values of r with 18 df are 0.444 at the 5% probability level and 0.561 at the 1% probability level.

**Table 6 Relationship between metal ions in Turag River water samples**

| Ions | Mg   | K    | Na   | Zn   | Fe   | Cu   | Mn   | Pb   | Cr   |
|------|------|------|------|------|------|------|------|------|------|
| Ca   | 0.295NS | 0.202NS | 0.370NS | -0.190NS | -0.050NS | 0.182NS | 0.037NS | 0.209NS | 0.204NS |
| Mg   | -    | -0.040NS | -0.020NS | 0.187NS | -0.050NS | 0.079NS | -0.040NS | 0.117NS | -0.040NS |
| K    | -    | -    | -0.010NS | 0.721** | 0.861** | 0.648** | 0.934** | 0.510* | -0.280NS |
| Na   | -    | -    | -    | 0.721** | 0.120NS | -0.190NS | -0.040NS | -0.310NS | 0.285NS |
| Zn   | -    | -    | -    | -    | 0.819** | 0.539* | 0.807** | 0.385NS | -0.210NS |
| Fe   | -    | -    | -    | -    | -    | 0.382NS | 0.918** | 0.174* | -0.420NS |
| Cu   | -    | -    | -    | -    | -    | -    | 0.675** | 0.937** | -0.060NS |
| Mn   | -    | -    | -    | -    | -    | -    | -    | 0.484* | -0.330NS |
| Pb   | -    | -    | -    | -    | -    | -    | -    | -    | 0.065NS |

**Significant at the 1% probability level; *Significant at the 5% probability level; NS Not significant.**

The tabulated values of r with 18 df are 0.444 at the 5% probability level and 0.561 at the 1% probability level.
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