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Impact of urbanization and industrialization on irrigation water quality of a canal - a case study of Tongi canal, Bangladesh

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Abstract. The Dhaka city, the capital of Bangladesh is one of the most densely populated cities in the world. Tongi canal is situated on the north of the city, which connected the Turag river to the west and the Balu river to the east. A total of 26 water samples were collected from the canal to measure irrigation water quality on the basis of their trace metal and major ionic constituents. Trace metals concentrations in water samples were determined using an Atomic Absorption Spectrophotometer. The amount of Fe, Mn, Zn and Pb in water samples ranged from 0.01-0.80, trace-1.02, trace-0.054 and 0.43-0.64 μg mL^{-1}, respectively. The mean concentration of Ca, Mg, Na, K, HCO_3^-, Cl^-, BO_3^{3-}, PO_4^{3-} and SO_4^{2-} in water samples were 45.32, 15.33, 151.65, 11.98, 516.06, 94.69, 0.33, 14.02 and 56.21 μg mL^{-1}, respectively. In respect of HCO_3^-, SO_4^{2-}, PO_4^{3-} and K contents, most of the water samples were found problematic for irrigation. In context of RSC and hardness, 96 and 92% of water samples were graded as unsuitable and hard class, respectively. The study concluded that Pb content in canal water was comparatively high, so it is desirable to take necessary initiative to minimize the contamination level and to monitor its concentration in water routinely.

Keywords: urbanization and industrialization; metals; irrigation water quality; Tongi canal; Bangladesh

1. Introduction

The rigorous expansion of anthropogenic activities over the last few decades in Bangladesh has contributed to an increase in the fluxes of different toxic metals to water, soil and sediments. Different kinds of industrial activities and urbanization have greatly increased the various metal burdens in the environment. The list of sites contaminated with various metals increases every year in the country, presenting a serious problem for human health and formidable danger to the environment (Zakir *et al*. 2015, Zakir *et al*. 2014, Zakir *et al*. 2013, Bakali *et al*. 2014). Normally, different metals are present in water, soils and sediments but their concentration is usually very low i.e. within the permissible limit. Enhance concentration are found in different component of environment from naturally mineralized areas, but more commonly arise where metals have become dispersed as a result of human activities such as industrialization, urbanization, underground deposition of waste, discharge of effluent without treatment, mining and others

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(Zakir and Shikazono 2008, Shikazono *et al*. 2008, Kuranchie-Mensah *et al*. 2013, Moingt *et al*. 2013, Pan *et al*. 2013). According to Devi and Bhattacharyya (2013), the metal contamination of the runoff may be attributed to leaching from the top layers of soil which has served as a receptor for various wastes generated by anthropogenic activities in the rapidly urbanized city.

The urban soil is the receptor of significant quantities of pollutants accumulating from traffic and industry related emissions and deposition, and dumping of wastes. According to Bhattacharyya and Mahanta (2014), Cd and Co concentrations in different soils of Guwahati city were same while Cr, Mn and Pb contents were higher in soils of industrial land use. In Bangladesh, major industrial areas are situated close or in the major cities and are preferably located adjacent to rivers, canals or other water bodies that facilitates disposal of effluents. Satter and Islam (2005) reported that presently 10% of wastewater generated from different industrial sources is being treated and the rest is discharged as it into the nearest water bodies. Improper discharge of untreated wastewater from various industries adulterates surface water quality (Zakir and Shikazono 2011, Mohiuddin *et al*. 2011, Shikazono *et al*. 2012, Zakir *et al*. 2012, Zakir *et al*. 2013, Bakali *et al*. 2014).

Tongi canal is situated in between the northern border of the mega city Dhaka and Tongi area of Gazipur, Bangladesh. The canal is a stream of about 15 km in length, which is connected the Turag river to the west and the Balu river to the east and located at an elevation of 4 meters above sea level. Its coordinates are 23°51'25" N and 90°28'33" E (Khan 2012). This canal plays an important role by providing drainage system, water for different usage, different kinds of fishes and also waterways for traveling to the surrounding areas. From the northern part of the capital city Dhaka and different industrial zones of the area, contamination of canal water and sediments by various metallic and non-metallic chemicals are very common. Besides this, different toxic waste and sewerages of more than hundred factories are being added to this canal. Nowadays, offensive odor from this canal are making nuisance to the people living surrounding area. As a result, environmental hazards are occurring with different health hazards. Considering the above facts, the present research study was planned to determine trace metal and major ionic constituents in waters of Tongi canal and to assess its suitability for irrigation usage.

2. Materials and methodology

A total of 26 water samples were collected from the whole area of the Tongi canal, Dhaka, Bangladesh following the sampling techniques as outline by APHA (1995) and Sincero and Sincero (2004) (Fig. 1 and 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 water to be sampled. For trace metal analysis, 100 mL samples were acidified with HNO_3 and preserved separately in refrigerator.

In the laboratory, 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), major cations (Ca, Mg, Na and K), major anions (Cl^-, CO_3^-, HCO_3^-, SO_4^{2-}, BO_3^{3-} and PO_4^{3-}) and trace metals (Fe, Mn, Pb, Zn, Cd and Cu) following standard analytical methods. Calcium and magnesium were determined titrimetrically using standard Na_2EDTA. Chloride was measured by standard $AgNO_3$ titration, carbonate and bicarbonate by titration with standard H_2SO_4, sodium and potassium by flame photometry. Sulphate, borate and phosphate were determined by spectrophotometry. The concentrations of Fe, Mn, Pb, Zn, Cd and Cu in water samples were analyzed by AAS by using single hallow cathode lamp at the wavelengths of 248.3, 279.5, 283.3, 213.9, 228.8 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×(cations–anions)/(cations+anions), which is generally within ±5% (Srinivasamoorthy *et al*. 2011).

The parameters such as sodium adsorption ratio (SAR), soluble sodium percent (SSP), residual sodium carbonate (RSC) and hardness (H_T) were calculated following the formula as mentioned below to evaluate the suitability of the water quality for irrigation. Further the results of the analyses were interpreted using graphical representations like SAR vs salinity hazard as described by Richards (1968).

$SAR=Na^{+}/\sqrt{(Ca^{2+}+Mg^{2+})/2}$ [all concentrations in meq L^{-1}]

$SSP=[(Na^{+}+K^{+})\times100]/(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})$ [all concentrations in meq L^{-1}]

$RSC=(CO_3^{2-}+HCO_3^{-})-(Ca^{2+}+Mg^{2+})$ [all concentrations in meq L^{-1}]

Hardness $(H_T)=2.5\times Ca^{2+}+4.1\times Mg^{2+}$ [all concentrations in mg L^{-1}]

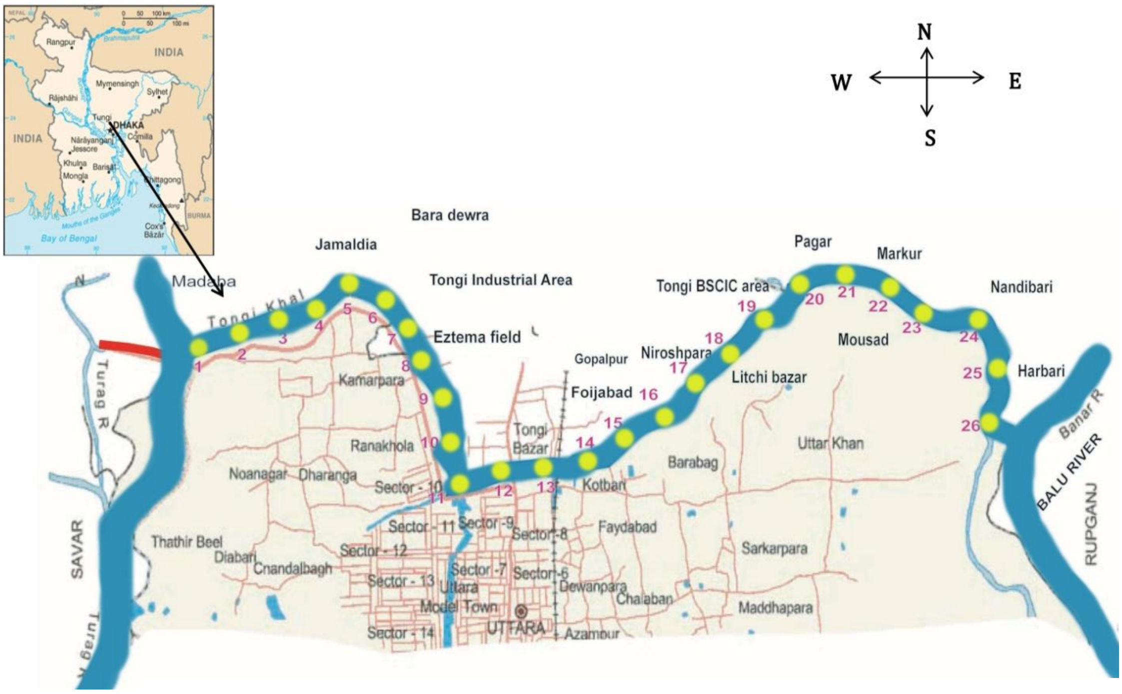

Fig. 1 Location of water sampling site of Tongi canal, Dhaka, Bangladesh

Table 1 List of sampling sites with possible sources of contamination of water collected from Tongi canal, Dhaka, Bangladesh

Sample ID	Name of the place	Possible sources of contamination
1.	Ashulia Bridge	Galaxy sweaters and yarn dyeing ltd., Anontex group
2.	Ashulia	Steel pipe industry

Table 1 Continued

Sample ID	Name of the place	Possible sources of contamination
3.	Prottasha bridge area, Madaba	Dhalai and oil industry
4.	Kamarpara	Garments industry
5.	Kamarpara	Washing industry
6.	Station road area, bridge	Agricultural and municipal wastes
7.	Tongi industrial area	Bata shoe company, Honda company
8.	Eztema field (west zone)	Blade industry
9.	Nishad nagar	Municipal and city wastes
10.	Eztema field (South zone)	Fisheries market waste, Municipal waste
11.	Rasdia mouza	Medical and municipal wastes
12.	West Abdullapur	Sewage and sludge wastes
13.	East Abdullapur	Municipal and city wastes
14.	Dhaka-Mynensingh highway	Municipal waste
15.	Tongi bazaar	Agricultural waste
16.	Kotbari	Dacca dyeing
17.	Foizabad	Ajmeri garments
18.	Nirospara	BSCIC Nodi Bandar
19.	Litchu bazaar	Domestic waste
20.	Tongi BSCIC area (Pagar)	Shapla dyeing
21.	Tongi BSCIC area (Pagar)	Polythene/ Packaging industry
22.	Pagar (East zone)	Biological Effluent Treatment
23.	Murkur	Ananta dyeing industry
24.	Nandibari	Paradise washing plant ltd**.**
25.	Mousad	Municipal waste
26.	Harbari	Municipal waste

3. Results and discussion

3.1 Physicochemical properties of water (pH, EC and TDS)

The pH values of all water samples were almost neutral to slightly alkaline (7.15 to 8.28) (Table 2). These might be due to the presence of higher amount of ions such as Ca, Mg and Na in water (Rao *et al.* 1982). According to proposed Bangladesh Standards, the acceptable range of pH for irrigation water is 6.5 to 8.5 (DoE 2005). The acceptable range of pH for fish culture is from 6.5 to 8.0 (ADB 1994). On the basis of the measured pH, all samples were within the acceptable range. Similar observations were reported for the seasonal variations in the water quality of the Turag river and Tongi area (Rahman *et al*. 2012, Bakali *et al*. 2014). The electrical conductivity (EC) of the water samples ranged from 812 to 1288 µS cm^{-1} with an average value is 988.66 µS cm^{-1} (Table 2). Water samples under test were rated in the category permissible (EC=750-2000 µS cm^{-1}) for irrigation purposes (Wilcox 1955). According to Richards (1968), samples under test were rated in the category C3 (EC=751-2250 μS cm^{-1}) indicating high salinity. Higher EC value reflected the higher amount of salt concentration which affected irrigation water quality related to salinity hazard (Agarwal *et al.* 1982). The measured EC of water samples collected from the Tongi industrial area and Turag river were also at par with the present study (Bakali *et al*. 2014, Rahman *et al*. 2012).

The amount of total dissolved solids (TDS) of water samples in the study area were within the limit of 480 to 759 mg L^{-1} with the average value of 593.35 mg L^{-1} (Table 2). FAO standard range of TDS value for irrigation practices is 450 to 2000 mg L^{-1} (Ayers and Westcot 1985). On the basis of measured TDS all samples collected from the Tongi canal was within the acceptable range i.e. containing TDS<1000 mg L^{-1} (Table 2) and rated as fresh water (Freeze and Cherry 1979). Bakali *et al*. (2014) also reported a similar observation for Tongi industrial area water quality.

3.2 Major anionic constituents in water

The concentration of HCO_3^- in water samples were within the range of 4.0-12.0 me L^{-1} with the mean value of 8.46 me L^{-1} or 516.06 mg L^{-1} (Table 2). In respect of HCO_3^- content, all water samples were found unsuitable for irrigation, which exceeded the permissible limit (1.51 me L^{-1}) (Ayers and Westcot 1985). Bicarbonates are derived mainly from the soil zone CO_2 and dissolution of carbonates and reaction of silicates with carbonic acid (Singh *et al*. 2009). But all samples of the present study were found free from carbonate. Water samples collected from Tongi canal contained Cl^- ranging from 74.93-130.63 mg L^{-1} with an average value of 94.69 mg L^{-1} (Table 2). For public health, chlorides up to 250 mg L^{-1} is not harmful but a value is greater than this indication of organic pollution (Huq and Alam 2005). The large lateral variations in the Cl^- concentrations in some sites indicate local recharge and are attributed to contamination by industrial effluents. Chloride may result from anthropogenic sources including agricultural runoff, domestic and industrial wastes and leaching of saline residues in the soil (Appelo and Postma 1993). Maximum permissible limit of Cl^- in irrigation water is 4.00 me L^{-1} (141.80 mg L^{-1}) (Ayers and Westcot 1985) and all samples collected from the Tongi canal were within the permissible limit.

The PO_4^{3-} content in water samples collected from Tongi canal varied from 7.78-26.81 mg L^{-1}. The permissible limit of phosphate for irrigation water is 2.00 mg L^{-1} (Ayers and Westcot 1985) and considering this limit as standard, the PO_4^{3-} values in all water samples were above permissible limit for irrigation that might be harmful for crop production. If too much phosphate is present in the water, the algae and weeds will grow rapidly, which may choke the waterway and use up large amounts of precious oxygen. The result may the death of many aquatic organisms such as the zooplankton and fish. Phosphates are not toxic to people or animals unless they are present in very high levels (Paul 2011). The SO_4^{2-} content in water samples under study ranged from 32.16-91.68 mg L^{-1} with a mean value of 56.21 mg L^{-1} (Table 2). The maximum permissible limit of SO_4^{2-} in irrigation water is 20.00 mg L^{-1} (Ayers and Westcot 1985) and all water samples collected from the Tongi canal exceeded the acceptable range of irrigation water quality. On a global basis, one third of the SO_4^{2-} in aquatic systems derived from rock weathering (include two major forms of sulphur sedimentary rocks, pyrite and gypsum), about 60% from fossil fuel combustion and minor amounts from volcanism (5%) and cycling salts (2%) (Singh *et al*. 2010). The concentration of BO_3^{3-} present in the water samples varied from 0.01 to 2.57 mg L^{-1} having a mean value of 0.328 mg L^{-1} (Table 2). The recommended highest BO_3^{3-} concentration for irrigation water use continuously on soil is less than 0.75 mg L^{-1} (Ayers and Westcot 1985), and considering

Table 2 Physicochemical properties (pH, EC, TDS and major anions) of water samples collected from Tongi canal, Dhaka, Bangladesh

Sample ID	pH	EC $\mu S\ cm^{-1}$	TDS $mg\ L^{-1}$	HCO_3^- $me\ L^{-1}$	Cl^- $mg\ L^{-1}$	BO_3^{3-} $mg\ L^{-1}$	PO_4^{3-} $mg\ L^{-1}$	SO_4^{2-} $mg\ L^{-1}$
1	7.24	892	533	6.0	84.29	0.15	9.30	63.36
2	7.32	921	558	6.0	93.66	0.98	7.92	62.72
3	7.51	985	592	4.0	103.03	0.98	8.06	63.04
4	7.56	1030	597	10.0	103.03	0.01	8.89	62.88
5	7.65	1035	616	6.0	112.39	0.08	7.78	65.76
6	7.52	997	601	10.0	93.66	0.07	8.75	61.12
7	7.51	990	589	4.0	93.66	0.32	8.06	61.12
8	7.33	876	533	4.0	84.29	0.03	9.72	49.76
9	7.27	812	480	8.0	74.93	0.04	12.36	38.08
10	7.31	820	505	6.0	74.93	0.01	10.97	46.24
11	7.29	817	484	6.0	74.93	0.02	10.69	40.80
12	7.20	820	492	8.0	74.93	0.03	11.53	41.44
13	7.25	833	502	10.0	74.93	0.02	7.72	42.40
14	7.16	904	529	10.0	84.29	0.87	26.81	32.16
15	7.15	922	542	10.0	93.66	0.21	23.47	52.00
16	7.40	915	535	6.0	84.29	0.02	13.61	53.44
17	7.27	1009	595	8.0	103.03	0.10	19.03	58.40
18	7.41	1178	720	10.0	121.76	0.01	14.86	91.68
19	7.39	1053	638	10.0	103.03	0.13	19.86	66.88
20	7.36	1024	620	10.0	121.76	2.27	18.61	56.32
21	7.81	1027	638	12.0	93.30	0.18	15.56	64.00
22	8.25	1106	672	12.0	93.30	0.08	15.42	66.24
23	8.27	1120	687	10.0	84.29	0.62	16.94	70.88
24	8.28	1068	667	12.0	84.29	0.62	17.50	73.28
25	7.98	1263	743	12.0	121.76	0.84	21.39	72.00
26	7.97	1288	759	10.0	130.62	0.80	17.78	71.52
Range	**7.15-8.28**	**812-1288**	**480-759**	**4.0-12.0**	**74.93-130.63**	**0.01-2.27**	**7.78-26.81**	**32.16-91.68**
Mean	**7.53**	**988.66**	**593.35**	**8.46**	**94.69**	**0.33**	**14.02**	**56.21**
IWGV*	6.0~8.4[a]	750[b]	450~2000[a]	1.51[a]	141.80[a]	0.75[a]	2.00[a]	20.00[a]

IWGV: Irrigation Water Guideline Value, *a - Ayers and Westcot (1985); b- ADB (1994)

this result as standard, 6 water samples were found unsuitable for irrigation usage. However, it can be inferred from the study results that about 76.92% water of the study area might not be harmful for successful crop production. Because boron is weakly absorbed in soil, marginal levels in irrigation water reportedly may not be immediately toxic, but continued use exceeding the specified levels cannot be tolerated by the plant (Gibeault and Cockerham 1985).

3.3 Major cationic constituents in water

The content of Ca^{2+} in water samples collected from different sites of Tongi canal varied from 24.05 to 64.13 μg mL^{-1} with an average value of 45.32 μg mL^{-1} (Table 3). The contribution of Ca^{2+} content in water was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ (Karanth 1994). Irrigation waters containing less than 20 me L^{-1} (800 μg mL^{-1}) Ca^{2+} is suitable for irrigating crops (Ayers and Westcot 1985). Considering this value as standard, Ca content in all water samples could safely be used for irrigation and would not affect soils. The concentration of Mg^{2+} in water samples was within the range of 4.86 to 24.30 μg mL^{-1} with an average value of 15.33 μg mL^{-1} (Table 3). Irrigation water containing below 5.0 me L^{-1} (121.5 μg mL^{-1}) Mg^{2+} was suitable for crops and soils (Ayers and Westcot 1985) and all water samples were within this limit and could safely be used for irrigation without any bad impact on soils. A similar observation was reported for both Ca^{2+} and Mg^{2+} of Tongi industrial area water quality by Bakali *et al*. (2014).

The concentration of Na^{+} in water samples of Tongi canal varied from 117.86 to 200.00 μg mL^{-1} with a mean value of 151.65 μg mL^{-1} (Table 3). Sodium in the aquatic system is mainly derived from atmospheric deposition; evaporate dissolution and silicate weathering (Berner and Berner 1987). Irrigation water generally containing less than 40 me L^{-1} (919.6 μg mL^{-1}) Na^{+} is suitable for crops and soils (Ayers and Westcot 1985). The observed Na content in all water samples had far below this specified limit. A wide variety of waste waters are produced which contain potassium. The concentration of K^{+} present in the water samples ranged from 8.46 to 16.15 μg mL^{-1} with the mean value of 11.98 μg mL^{-1} (Table 3). The recommended limit of K^{+} in irrigation water is 2.0 μg mL^{-1} (Ayers and Westcot 1985). Considering this value as standard, Tongi canal water could problematic for long-term irrigation.

Table 3 Concentration of trace metals and major cationic constituents in water samples collected from Tongi canal, Dhaka, Bangladesh

Sample ID	**Major nutrient concentrations (μg mL^{-1})**				**Trace metal concentrations (μg mL^{-1} ± SD)**					
	Ca	**Mg**	**Na**	**K**	**Cd**	**Mn**	**Fe**	**Zn**	**Cu**	**Pb**
1	44.09	19.44	128.57	9.23	Trace	Trace	0.01±0.01	Trace	Trace	0.64±0.02
2	48.10	9.72	139.29	8.46	Trace	Trace	0.80±0.01	Trace	Trace	0.64±0.02
3	44.09	17.01	146.43	9.23	Trace	0.10±0.01	0.30±0.02	Trace	Trace	0.61±0.09
4	44.09	12.15	157.14	10.00	Trace	0.14±0.01	0.50±0.01	Trace	Trace	0.59±0.02
5	44.09	12.15	164.29	10.00	Trace	0.14±0.01	0.38±0.01	0.01±0.001	Trace	0.58±0.07
6	40.08	14.58	160.71	10.00	Trace	0.15±0.01	0.45±0.01	Trace	Trace	0.58±0.06
7	48.10	14.58	157.14	9.23	Trace	0.16±0.01	0.40±0.02	Trace	Trace	0.52±0.02
8	44.09	14.58	142.86	10.00	Trace	0.15±0.01	0.46±0.01	0.002±0.01	Trace	0.54±0.05
9	40.08	14.58	128.57	10.00	Trace	0.15±0.01	0.37±0.01	0.003±0.01	Trace	0.55±0.02
10	40.08	4.86	132.14	9.23	Trace	0.15±0.01	0.37±0.01	0.010±0.01	Trace	0.54±0.03
11	48.10	21.87	128.57	10.00	Trace	0.15±0.01	0.45±0.02	0.007±0.01	Trace	0.55±0.02
12	44.09	12.15	121.43	10.00	Trace	0.15±0.01	0.45±0.01	0.005±0.01	Trace	0.51±0.01
13	36.09	14.58	125.00	10.77	Trace	0.15±0.01	0.41±0.01	0.001±0.01	Trace	0.50±0.02
14	44.09	17.01	117.86	13.08	Trace	0.13±0.01	0.26±0.01	Trace	Trace	0.53±0.02

Table 3 Continued

Sample ID	Major nutrient concentrations (μg mL^{-1})				Trace metal concentrations (μg mL^{-1} ± SD)					
	Ca	**Mg**	**Na**	**K**	**Cd**	**Mn**	**Fe**	**Zn**	**Cu**	**Pb**
15	48.10	12.15	125.00	12.31	Trace	0.24±0.01	0.31±0.01	0±0.01	Trace	0.48±0.03
16	36.07	24.30	142.86	11.54	Trace	1.02±0.01	0.49±0.01	0.009±0.01	Trace	0.48±0.02
17	40.08	14.58	153.57	12.31	Trace	0.43±0.01	0.48±0.01	0.013±0.01	Trace	0.44±0.02
18	24.05	2430	178.57	16.1	Trace	0.13±0.01	0.54±0.01	0.008±0.01	Trace	0.44±0.07
19	52.10	9.72	160.71	12.31	Trace	0.15±0.01	0.28±0.01	0.007±0.01	Trace	0.49±0.03
20	64.13	9.72	139.29	11.54	Trace	0.12±0.01	0.24±0.01	0.053±0.01	Trace	0.47±0.06
21	44.09	14.58	157.14	12.31	Trace	0.17±0.01	0.31±0.02	0.012±0.01	Trace	0.48±0.01
22	44.09	9.72	175.00	11.54	Trace	0.15±0.01	0.34±0.02	0.005±0.01	Trace	0.45±0.03
23	44.09	12.15	182.14	13.08	Trace	0.12±0.01	0.31±0.01	0.012±0.01	Trace	0.46±0.02
24	36.07	14.58	182.14	13.85	Trace	0.20±0.01	0.34±0.01	0.054±0.01	0.048±0.01	0.43±0.04
25	44.09	21.87	196.43	15.39	Trace	0.32±0.01	0.38±0.02	0.035±0.01	0.016±0.01	0.46±0.01
26	48.10	12.15	200.00	16.15	Trace	0.32±0.01	0.39±0.01	0.022±0.01	0.030±0.01	0.43±0.02
Range	**24.09-64.13**	**4.86-24.30**	**117.86-200.00**	**8.46-16.15**	**Trace**	**Trace-1.02**	**0.01-0.80**	**Trace-0.054**	**Trace-0.048**	**0.43-0.64**
IWGV*	**800[a]**	**121.50[a]**	**920[a]**	**2.00[a]**	**5.00[a]**	**0.20[a]**	**0.011[b]**	**< 0.052[b]**	**0.20[a]**	**0.01[c]**

IWGV: Irrigation Water Guideline Value,
*a - Ayers and Westcot (1985); b - USEPA (1999); c - DoE, 2005

3.4 Trace metal concentration in water

Water samples collected from Tongi canal contained comparatively less amount of iron (Fe) and the amount varied from 0.01 to 0.80 μg mL^{-1} with a mean value of 0.39 μg mL^{-1} (Table 3). The recorded Fe concentration in water samples was far below the acceptable limit (5.00 μg mL^{-1}) for irrigation (Ayers and Westcot 1985). In respect of Fe, water quality standard for fish culture is <0.10 mg L^{-1} (Meade 1998), and considering this limit, amount of Fe in 96% of water samples were exceeded the level i.e., unsuitable for fish culture. The concentration of Mn in water samples of Tongi canal ranged from trace to 1.02 μg mL^{-1} with a mean value of 0.196 μg mL^{-1} (Table 3). The highest recommended concentration of Mn for irrigation water is 0.20 μg mL^{-1} (Ayers and Westcot (1985) and considering this limit, Mn concentration in 23% samples were exceeded the level indicating Mn toxicity in water of the study area.

The concentration of Zn in water samples collected from Tongi canal ranged from trace to 0.054 mg L^{-1} with a mean value of 0.01 mg L^{-1} (Table 3). The maximum permissible limit of Zn for irrigation water is 2.00 mg L^{-1} (Ayers and Westcot 1985) and considering this limit as standard, waters of Tongi canal were suitable for irrigation. The concentration of Pb in water samples ranged from 0.43 to 0.64 mg L^{-1} with a mean value of 0.514 mg L^{-1} (Table 3). The standard of Pb for irrigation water is 0.05 mg L^{-1} (ADB 1994). According to international standards for inland surface water, tolerance limit of Pb for public supply and bathing is 0.10 mg L^{-1} (Ayers and Westcot 1985). According to proposed Bangladesh Standards, Pb content for irrigation water is 0.01 mg L^{-1} (DoE 2005). Considering these limits, Pb concentrations in all water samples collected from the study area were found unsuitable. Similar observations were also reported for both Zn and Pb content of Turag river and Tongi industrial area water quality by Rahman *et al*. (2012) and Bakali *et al*. (2014), respectively. However, the concentration of Cu and Cd in most of the water samples were trace i.e., these waters were not problematic for irrigation in respect of Cu and Cd.

3.5 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 and residual sodium carbonate.

3.5.1 Sodium adsorption ratio (SAR)

The salinity or total concentration of soluble salts in irrigation water can be expressed for the purpose of classification of irrigation water as low (EC=<250 μS cm^{-1}), medium (250-750 μS cm^{-1}), high (750-2250 μS cm^{-1}) and very high (2250-5000 μS cm^{-1}). While high salinity (high EC) in water leads to formation of saline soil, a high sodium concentration changes soil properties and reduce soil permeability, which leads to development of an alkaline soil (Singh *et al*., 2010). The computed sodium adsorption ratio (SAR) of water samples ranged from 5.39 to 9.45 with a mean value of 7.22 (Table 4). The present investigation revealed that a good proportion of Ca and Mg existed in all water samples. 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 as described by Richards (1968), in which the EC is taken as salinity hazard and SAR as alkalinity hazard shows that out of 26 samples, 19 water samples were in the category of C3S2 and the rest 7 water samples were in the category of C3S1, indicating high salinity and low to medium alkali hazard (Fig. 2). High salinity water cannot be used for irrigation 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. Medium alkali water will present a problem in fine textured soils having a high CEC, especially under low leaching conditions. This water can be used on coarse textured or organic soils with good permeability. 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 4 Quality rating and suitability of water for irrigation collected from Tongi canal, Dhaka, Bangladesh

Sample ID	SAR	SSP %	RSC meL^{-1}	Hardness mgL^{-1}	Water class based on			
					SAR[1]	SSP[2]	RSC[3]	Hardness[4]
1	5.73	75.42	4.1	189.92	Excellent	Doubtful	Unsuitable	Hard
2	6.81	79.69	4.4	160.09	Excellent	Doubtful	Unsuitable	Hard
3	6.71	78.59	4.2	179.97	Excellent	Doubtful	Unsuitable	Hard
4	7.67	81.59	8.4	160.04	Excellent	Unsuitable	Unsuitable	Hard
5	8.02	82.22	4.4	160.07	Excellent	Unsuitable	Unsuitable	Hard
6	7.85	81.92	8.4	159.99	Excellent	Unsuitable	Unsuitable	Hard
7	7.19	79.71	2.2	180.03	Excellent	Doubtful	Marginal	Hard
8	6.75	79.19	3.2	170.01	Excellent	Doubtful	Unsuitable	Hard

Table 4 Continued

Sample ID	SAR	SSP %	RSC meL^{-1}	Hardness mgL^{-1}	Water class based on			
					SAR[1]	**SSP**[2]	**RSC**[3]	**Hardness**[4]
9	6.28	78.52	6.4	159.99	Excellent	Doubtful	Unsuitable	Hard
10	7.47	74.97	4.8	120.13	Excellent	Doubtful	Unsuitable	Moderately Hard
11	5.48	73.58	3.9	209.91	Excellent	Doubtful	Unsuitable	Hard
12	5.93	77.59	6.4	160.04	Excellent	Doubtful	Unsuitable	Hard
13	5.90	79.19	8.5	149.97	Excellent	Doubtful	Unsuitable	Moderately Hard
14	5.39	75.17	8.2	179.97	Excellent	Doubtful	Unsuitable	Hard
15	5.90	77.15	8.3	170.06	Excellent	Doubtful	Unsuitable	Hard
16	6.40	77.38	4.1	189.82	Excellent	Doubtful	Unsuitable	Hard
17	7.51	81.37	6.4	159.99	Excellent	Unsuitable	Unsuitable	Hard
18	8.72	83.62	8.4	159.76	Excellent	Unsuitable	Unsuitable	Hard
19	7.59	81.11	8.3	170.12	Excellent	Unsuitable	Unsuitable	Hard
20	6.06	76.05	8.0	200.18	Excellent	Doubtful	Unsuitable	Hard
21	7.42	80.08	9.8	170.01	Excellent	Unsuitable	Unsuitable	Hard
22	8.75	84.04	10.5	150.08	Excellent	Unsuitable	Unsuitable	Hard
23	8.89	83.76	8.4	160.04	Excellent	Unsuitable	Unsuitable	Hard
24	9.21	84.65	10.5	149.97	Excellent	Unsuitable	Unsuitable	Hard
25	8.54	81.70	10.0	199.89	Excellent	Unsuitable	Unsuitable	Hard
26	9.45	84.25	8.3	170.06	Excellent	Unsuitable	Unsuitable	Hard
Range	**5.39-9.45**	**73.58-84.65**	**2.2-10.5**	**120.13-209.91**	Excellent	Doubtful-Unsuitable	Marginal-Unsuitable	Moderately Hard-Hard
Mean	**7.22**	**79.71**	**6.87**	**168.85**	-	-	-	-

C3=High Salinity; S1=Low alkalinity and S2=Medium alkalinity. [1, 2, 3, & 4] =Todd (1980); Wilcox (1955); Ghosh *et al*. (1983) and Sawyer and McCarty (1967), respectively

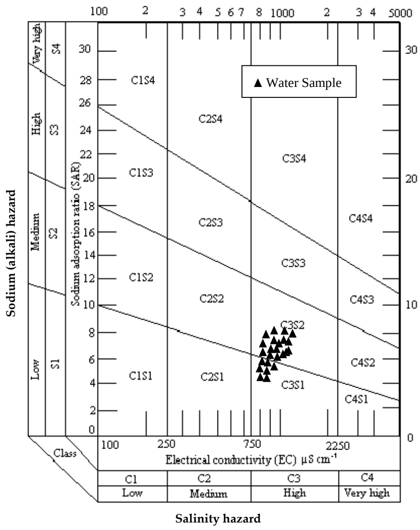

Fig. 2 Diagram for classifying irrigation waters on the basis of SAR and EC as described by Richards (1968)

3.5.2 Soluble sodium percentage (SSP)

Electrical conductivity (EC) and sodium concentration are very important in classifying irrigation water. Percentage Na is widely used for evaluating the suitability of water quality for irrigation. High Na in 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 (Saleh *et al*. 1999). The calculated soluble sodium percentage (SSP) value of water samples varied from 73.58 to 84.65% with the mean value of 79.71% (Table 4). Out of 26 water samples, 14 samples were classified as doubtful (SSP=60-80%) and the rest 12 samples were classified as unsuitable (SSP=>80%) (Wilcox 1955). In the study area, the water having doubtful to unsuitable classes might not be safe for irrigating agricultural crops.

3.5.3 Residual sodium carbonate (RSC)

The quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. When the sum of carbonates and bicarbonates is in excess of calcium and magnesium, precipitation of Ca and Mg may occur (Raghunath 1987). To quantify the effects of carbonate and bicarbonate, residual sodium carbonate (RSC) has been computed. A high RSC value in water leads to an increase in the adsorption of Na on soil. Irrigation water having RSC values greater than 5 me L^{-1} are considered harmful to the growth of plants, while water with RSC value above 2.5 me L^{-1} are not considered suitable for irrigation (Ghosh *et al*. 1983). Hence, continued usage of high RSC water will affect the yields of crop. The computed RSC in water samples collected from Tongi canal were ranged from 2.2 to 10.5 me L^{-1} with an average value of 6.87 me L^{-1} (Table 4). Out of 26 water samples, 25 samples were found in unsuitable class (RSC=> 2.50 me L^{-1}) and only one sample was found in marginal class (RSC=1.25-2.50 me L^{-1}) (Ghosh *et al*. 1983).

3.5.4 Hardness (H_T)

Hardness of water resulted due to the abundance of divalent cations like Ca^{2+} and Mg^{2+} (Todd 1980). Hard water is unsuitable for domestic use, 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 human, such as kidney failure (WHO 2008). The calculated hardness of water samples collected from Tongi canal ranged from 120.13 to 209.91 mg L^{-1} (Table 4). According to the criteria described by Sawyer and McCarty (1967), out of 26 water samples, 24 samples were graded as hard and the rest 2 samples were graded as moderately hard.

3.6 Correlation coefficient matrix for different ionic constituents of waters

The Pearson's correlation matrix for the data analyzed on different parameters of water samples collected from Tongi canal are presented in Table 5(a). Similarly, among the relationship between water quality parameters are presented in Table 5(b). Examination of the matrix provides clues about the carrier substances and the chemical association of ionic constituents in the study area (Jaquet *et al*. 1982). Positive significant correlation in between the ionic constituents indicates that the parameters were interrelated with each other and may be originated from the same source to the study area.

Among the relationship between water quality parameters pH showed highly significant positive correlation with EC (r=0.71**), TDS (r=0.76**), SAR (r=0.82**), SSP (r=0.74**), and

RSC (r=0.52**) (Table 4.7b). Similarly, EC showed highly positive significant relationship with TDS (r=0.99**), SAR (r=0.82**), SSP (r=0.77**), and RSC (r=0.53**). TDS showed significant positive correlation with SAR (r=0.86**), SSP (r=0.79**) and RSC (r=0.56**). SAR exhibited highly positive significant relationship with SSP (r=0.89**) and RSC (r=0.46**). There was also highly significant positive relationship between SSP and RSC (r=0.51**). It is evident from Table 5(b) that among the water quality parameters only hardness (H_T) showed insignificant relationship with others.

Table 5(a) Pearson correlation coefficient matrix for different ionic constituents of water samples collected from different sites of Tongi canal, Dhaka, Bangladesh

Para-meters	HCO_3	Cl	B	P	S	Ca	Mg	Na	K	Mn	Fe	Zn	Cu
Cl	0.27 ^{ns}												
B	0.14 ^{ns}	0.45*											
P	0.61**	0.27 ^{ns}	0.33 ^{ns}										
S	0.29 ^{ns}	0.67**	0.11 ^{ns}	0.04 ^{ns}									
Ca	-0.06 ^{ns}	0.20 ^{ns}	0.60**	0.17 ^{ns}	-0.21 ^{ns}								
Mg	0.12 ^{ns}	0.34 ^{ns}	-0.14 ^{ns}	0.03 ^{ns}	0.51**	-0.58**							
Na	0.43*	0.65**	0.11 ^{ns}	0.18 ^{ns}	0.83**	-0.14 ^{ns}	0.23 ^{ns}						
K	0.67**	0.55**	0.19 ^{ns}	0.72**	0.50**	-0.23 ^{ns}	0.44*	0.65**					
Mn	-0.02 ^{ns}	0.05 ^{ns}	-0.15 ^{ns}	0.22 ^{ns}	-0.03 ^{ns}	-0.23 ^{ns}	-0.07 ^{ns}	0.12 ^{ns}	0.27 ^{ns}				
Fe	-0.16 ^{ns}	0.04 ^{ns}	-0.15 ^{ns}	-0.30 ^{ns}	0.06 ^{ns}	-0.27 ^{ns}	0.23 ^{ns}	0.08 ^{ns}	-0.08 ^{ns}	0.17 ^{ns}			
Zn	0.43*	0.39*	0.60**	0.40*	0.31 ^{ns}	0.22 ^{ns}	-0.03 ^{ns}	0.44*	0.49*	0.14 ^{ns}	-0.17 ^{ns}		
Cu	0.39*	0.23 ^{ns}	0.23 ^{ns}	0.28 ^{ns}	0.35 ^{ns}	-0.12 ^{ns}	-0.07 ^{ns}	0.56**	0.54**	0.12 ^{ns}	-0.06 ^{ns}	0.69**	
Pb	-0.60**	-0.29 ^{ns}	-0.09 ^{ns}	-0.65**	-0.29 ^{ns}	0.13 ^{ns}	-0.24 ^{ns}	-0.49*	-0.80**	-0.41*	0.06 ^{ns}	-0.54**	-0.43*

Legend: **=Significant at 1% level; *=Significant at 5% level; ^{ns}=Not significant; Tabulated values of r with 24 df is 0.496 at 1% level of significance and 0.388 at 5% level of significance

Table 5(b) Relationship between quality parameters of water (n=26) collected from Tongi canal, Dhaka, Bangladesh

Parameters	EC	TDS	SAR	SSP	RSC	H_T
pH	0.71**	0.76**	0.82**	0.74**	0.52**	-0.14 ^{ns}
EC		0.99**	0.82**	0.77**	0.53**	0.09 ^{ns}
TDS			0.86**	0.79**	0.56**	0.03 ^{ns}
SAR				0.89**	0.46**	-0.37 ^{ns}
SSP					0.51**	-0.37 ^{ns}
RSC						-0.20 ^{ns}

Legend: **=Significant at 1% level; *=Significant at 5% level; ^{ns}=Not significant; Tabulated values of r with 24 df is 0.496 at 1% level of significance and 0.388 at 5% level of significance

5. Conclusions

Tongi canal is highly susceptible to environmental pollution due to high population density, rapid industrialization and urbanization. Among the trace metals, Pb was dominant in water samples and the degree of contamination of Pb in the study area was comparatively high. In respect of HCO_3^-, SO_4^{2-}, PO_4^{3-} and K contents, most of the water samples were found problematic for irrigation because their concentration exceeded the maximum recommended limit. In context of water quality rating for irrigation, 96 and 46% of sampling sites were graded as unsuitable class for RSC and SSP, respectively. As regards to hardness, 92% water samples were graded as hard, while the rest 8% samples were graded moderately hard. Present study results can be inferred that it is desirable to take necessary initiative by the appropriate authority to minimize the contamination level in water as well as to monitor the sources of contamination routinely in future. Although there are environmental protection laws and regulations now that should be strictly implemented by the Department of Environment, Bangladesh.

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