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Heavy Metals in Industrial Effluents (Tannery and Textile) and Adjacent Rivers of Dhaka City, Bangladesh

Monika Das[1] • Md. Kawser Ahmed[1*] • Md. Shahidul Islam[2] • Md. Monirul Islam[1] • Mosammat Salma Akter[1]

[1] Department of Fisheries, University of Dhaka, Dhaka-1000, Bangladesh
[2] Analytical Research Division, BCSIR Laboratories, Dhaka-1205, Bangladesh

Corresponding author: * **kawser_du@yahoo.com.**

ABSTRACT

The concentrations of heavy metals were determined in tannery and textile effluents and water of adjacent rivers (Buriganga and Karnatoli, Dhaka) from September 2006 to August 2007 at three different locations. Concentrations of Zn, As, Cd, Pb, Ni, Cr and Cu of tannery effluents seasonally varied from 7.65-14.82, 0.45-1.07, 0.25-1.91, 2.89-4.03, 4.02-9.5, 1256-2173.13 μg/L and BDL respectively. In textile effluents Zn, As, Cd, Pb, Ni, Cr and Cu concentrations were seasonally varied from 14.26-39.86, 4.5-6.6, 0.23-0.65, 0.96-3.89, 3.5-6.83, 1.16-3.85 and 11.6-39.23 μg/L respectively. The variation in concentration of heavy metals was due to the use of different raw materials and variation of production level. The concentrations of Zn, As, Cd, Pb, Ni, Cr and Cu of Buriganga River water seasonally and spatially varied from 5.2-62.07, 1.76-3.53, 0.11-2.37, 1.18-8.59, 1.15-6.44, 9.45-293.08 μg/L and BDL respectively whereas in Karnatoli River the concentrations of Zn, As, Cd, Pb, Ni, Cr and Cu were seasonally and spatially varied from 0.62-68.47, 0.56-1.91,0.13-1.53, 0.53-6.8, 4.2-8.2, 2.75-7.0 and 8.6-48.14μg/L respectively. Lowest concentrations of heavy metals were observed during rainy season which might be due to the dilution effect of rainfall whereas the highest concentration of these metals were found during dry season as industrial effluents are less diluted due to recede water in the river in this season. Some of the heavy metals concentrations are higher than the recommended value, which suggest that the Buriganga and Karnatoli River are to a certain extent heavy metal polluted river.

Keywords: aquatic pollution, trace metal, river water, sludge, toxicity

INTRODUCTION

Industrial pollution is an area of growing environmental concern and one of the problems presently facing Bangladesh. Since early sixties, industries of various kinds started to spring up slowly mainly along the bank of the rivers causing a high risk of environmental pollution in our country (Khaleque and Elias 1995; D'Monte 1996). In recent years values assess industries, such as textiles, engineering and electronics, tanneries etc. are flourishing in Bangladesh (Islam *et al*. 1997). These industries have limited effluent processing arrangement and reported to alter the physical, chemical, and biological properties of aquatic environment (Huq 2004). Textile industries are one of the largest water users and polluters resulting in high wastewater generation (Nemerow 1978; Ghoreishi and Haghighi 2003). The tannery operation consists of converting of the raw hide or skin in to leather; consequently, this industry is a potentially pollution intensive industry.

The treated and untreated waste effluents from different industries contain toxic metals as well as metal chelates (Ammann *et al.* 2002) and among the chemical pollutants, heavy metal being non-biodegradable, they can be concentrated along the food chain, producing their toxic effect at points after far removed from the source of pollution (Tilzer and Khondkar 1993). Textile dyes are toxic, highly stable and heavy metals contained in these effluents have been found to be carcinogenic (Tamburlini *et al*. 2002). Chemical impurities of tannery effluents mostly comprises of the following heavy metals: Cr, Zn, Fe, Ca, etc. (APHA 1995), which can not removed by conventional wastewater treatment methods. Along with these problems tannery and textile effluent might change the physicochemical properties like pH, dissolved oxygen level and electric conductivity, etc. of the water bodies.

Chemicals found in industrial effluents are not only poisonous to human beings but also found to be toxic to aquatic life (WHO 2002) rendering serious environmental problems and posing threats on sustaining aquatic biodiversity (Das *et al.* 1997; Ghosh and Vass 1997). The deadlier diseases like edema of eyelids, tumor, congestion of nasal mucous membranes and pharynx, stuffiness of the head and gastrointestinal, muscular, reproductive, neurological and genetic malfunctions caused by heavy metals have been documented (Abbasi *et al.* 1998; Johnson 1998; Tsuji and Karagatzides 2001). The presence of dyes in surface and subsurface water makes fish not only aesthetically objectionable but causes many water borne diseases, viz. nausea, hemorrhage, ulceration of skin and mucous membrane, dermatitis, perforation of nasal septum and severe irritation of respiratory tract. The problem may be exacerbated due to increased concentrations of toxicants during summer paddy cultivation when rivers have low discharge (Karim 1994). Due to elevated concentration of heavy metals sludge can not be used as soil conditioner or fertilizer in the agricultural soil (Islam *et al.* 2009).

The textile and leather industry of Bangladesh now earns more than 75% of the country's total export income. Bangladesh's Ready Made Garments exports to the world markets reached over US$ 9.35 billion at the end of 2007 (BGMEA 2008). The textile and leather industries now viewed as a major environmental threat in the industrial area of Bangladesh and they contribute large amounts of sludge in waste water treatment processes (Karim *et al.* 2006). Sludge, depending on the wastewater treatment process and sludge stabilization methods, contains substantial amounts of toxic heavy metals (Singh *et al.* 2004; Chen *et al.* 2005). Elevated levels of heavy metals in vegetables are found from the areas having long term uses of treated or untreated wastewater (Sharma *et al.* 2006, 2007). Excessive

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Table 1 The study sites and their abbreviations.

Name of the study sites	**Abbreviation used**
Effluents discharged from tannery through discharge pipe	Ta1
Water from tannery discharged point into the river near Sikder Medical College, Rayer bazaar, Dhaka	Ta2
Water from river Buriganga near Gabtoli, Dhaka	Ta3
Effluents discharged from textile through discharge pipe	Te1
Water from textile discharged point into the river Karnatoli, Savar, Dhaka	Te2
Water from river Karnatoli near Mirpur, Dhaka	Te3

accumulation of heavy metals in agricultural soils through wastewater irrigation may not only result in soil contamination but also affect good quality and safety (Muchuweti *et al.* 2006). Some research also confirmed that heavy metals such as Cd, Pb, Zn and Ni have carcinogenic or toxic effects on human and environment (Turkdogan *et al.* 2002). Frascasso *et al.* (2002), Medina *et al.* (2007) and Frenzilli *et al.* (2009) have shown genotoxic effects of heavy metals on aquatic organisms. Therefore, monitoring of heavy metal pollution is important for safety assessment of the environment and its biodiversity. The objectives the current study was to monitor the heavy metals' concentrations in two industrial effluents (tannery and textile) as well as in their adjacent rivers (Buriganga and Karnatoli) in Dhaka district considering seasonal variations and spatial changes.

MATERIALS AND METHODS

Two industries i.e., tannery and its adjacent river Buriganga in Dhaka as well as textile and its adjacent river Karnatoli at Savar were selected. Water samples were collected from three stations from each set; one from the effluent and another two samples from two different locations (point source and surface water) of the adjacent river (**Figs. 1, 2**). The study sites and their abbreviated field demarcations are shown in **Table 1**.

Water samples were collected from the stations in rainy, dry and summer seasons during September 2006 to August 2007. The water samples were collected from a depth of 0.5m below the surface using Nansen type water sampler and kept in polyethylene containers (washed with dilute HNO_3 and distilled de-ionized water). For heavy metals detection the collected water samples were acidified immediately with the addition of 2 ml concentrated HNO_3 acid per liter of water sample, shacked homogeneously and then carefully preserved in a refrigerator at 4°C. In the laboratory the water samples were filtered using fine filter paper (Whatman Filter Paper 41, Diameter 125 mm) to remove the suspended materials. Concentrations of lead (Pb), zinc (Zn), cadmium (Cd) and copper (Cu) was determined by anodic striping voltametry (AVS) and concentrations of chromium (Cr), nickel (Ni) and arsenic (As) was determined by an atomic absorption spectrophotometer (Shimadzu, AA-6401 F). The data were presented as mean ± standard deviation of the replicated samples.

RESULTS AND DISCUSSION

The data presented in **Tables 2** and **3** showed the average concentrations of heavy metals Zn, As, Cd, Cu, Pb, Ni, and Cr of tannery and textile effluents and their adjacent rivers (Buriganga and Karnatali). The seasonal and spatial variation of each parameter is presented in this section.

Zn concentration in tannery effluents was lower than in textile effluents while in adjacent river water it varied both seasonally and spatially in the range of 5.22 to 22.83 µg/L in the Buriganga River and 0.62 to 68.47 µg/L in the Karnatoli River. Alam *et al.* (1993) reported that Zn concentration in the Buriganga River was 13.1 µg/L, which lies in the range of our findings. In both rivers Zn concentration was highest during the dry season and lowest during the rainy season. In Buriganga the observed value was higher in non-point sources than in point sources whereas in Karnatoli a higher concentration was observed at the point source than at the non-point source. However, Zn concentrations in the studied locations were below the Department of Environment standard (5.0 mg/L) (DoE 2003), which implies that both tannery and textile industries are not causing Zn pollution in that area.

The concentration of As in tannery effluents varied from 0.45 to 1.07 µg/L. However, in the adjacent river, the concentration varied from 1.76 to 3.53 µg/L. In textile effluents it varied from 4.5 to 6.6 µg/L. However, in the adjacent river, the concentration varied from 0.56 to 1.91 µg/L. It varied spatially in both rivers and the highest concentration was always observed at the point source. The highest As concentration (3.53 µg/L) was observed during the dry season in the Buriganga River; in the Karnatoli River it was 1.91 µg/L; the lowest concentration was observed during summer in Karnatoli (0.56 µg/L) and during the rainy season in the Buriganga River (1.76 µg/L).

Cd concentration in tannery and textile effluents varied from 0.25 to 1.91 µg/L and 0.23 to 0.65 µg/L, respectively. In Buriganga, Cd concentration varied from 0.12 µg/L in the rainy season to 2.37 µg/L in the dry season. Cd concentration varied from beyond a detectable limit to 1.01 µg/L in the Karnatali River. Alam *et al.* (2003) found that Cd concentration varied between BDL (beyond detection limit = 0.2 µg/L) to 1.0 µg/L in the rainy season and 1.7-10.60 µg/L in the dry season in both the Buriganga and Shitalakhya Rivers. The concentration of Cd in the dry season was higher than in the rainy season, which agrees with the present study. Ahmed *et al.* (2009) found that the concentration of Cd varied from 7.12 to 10.11 µg/L in the monsoon season, which is much higher than the present findings. However, these variations might be due to different collection spots and seasons. Alam *et al.* (1993) studied heavy element contaminants in aquatic ecosystems and found that Cd concentration in the Buriganga River was 2.1 ± 0.1 µg/L and in the Sitalakhya River was 3.4 ± 0.0 µg/L. The findings also agreed with the present investigations. Cd concentration also varied spatially. The highest concentration (2.37 ± 0.3 µg/L) was observed at the point source of the Buriganga River whereas in tannery effluent and surface water it was 0.3 ± 0.1 µg/L and 0.65 ± 0.42 µg/L, respectively. In the Karnatoli River, the highest concentration (1.01 µg/L) was recorded at the point source during the dry season. Khan *et al.* (1998) found that the concentration of Cd ranged from 0.001 to 0.107 µg/ml in the water of the Ganges-Brahmaputra-Meghna (GBM) Estuary, which is much lower than the present study. Mehedi (1994) found that the concentration of Cd in water ranged from 0.8 to 0.88 µg/g in the ship-breaking area of Chittagong. Cd is a non-essential element. It is both bioavailable and toxic. It interferes with metabolic processes in plants and can bioaccumulate in aquatic organisms and enters into the food chain (Adriano 2001). However, the maximum amount of Cd found during the study period was 3.65 µg/L, which was below the DoE standard (0.05 mg/L) (DoE 2003).

Cu content was not detected in the tannery effluent. However, the concentration of Cu was in the range of BDL to 1.15 µg/L in the adjacent Buriganga River. In textile effluent Cu content varied from 11.6 to 39.23 µg/L and in the Karnatoli River, it varied seasonally and spatially from 8.6 to 48.14 µg/L showing a highest value in the surface water during the dry season. Ahmed *et al.* (2010a) studied the heavy metal concentration in sediment of the Dhaleswari River and found that the concentration of Cu was 56.07 to 91.51 mg/kg on a dry weight basis, which is higher than the present investigation. Recent reports of Ahmed *et al.* (2009, 2010b) showed that in the monsoon Cu concen-

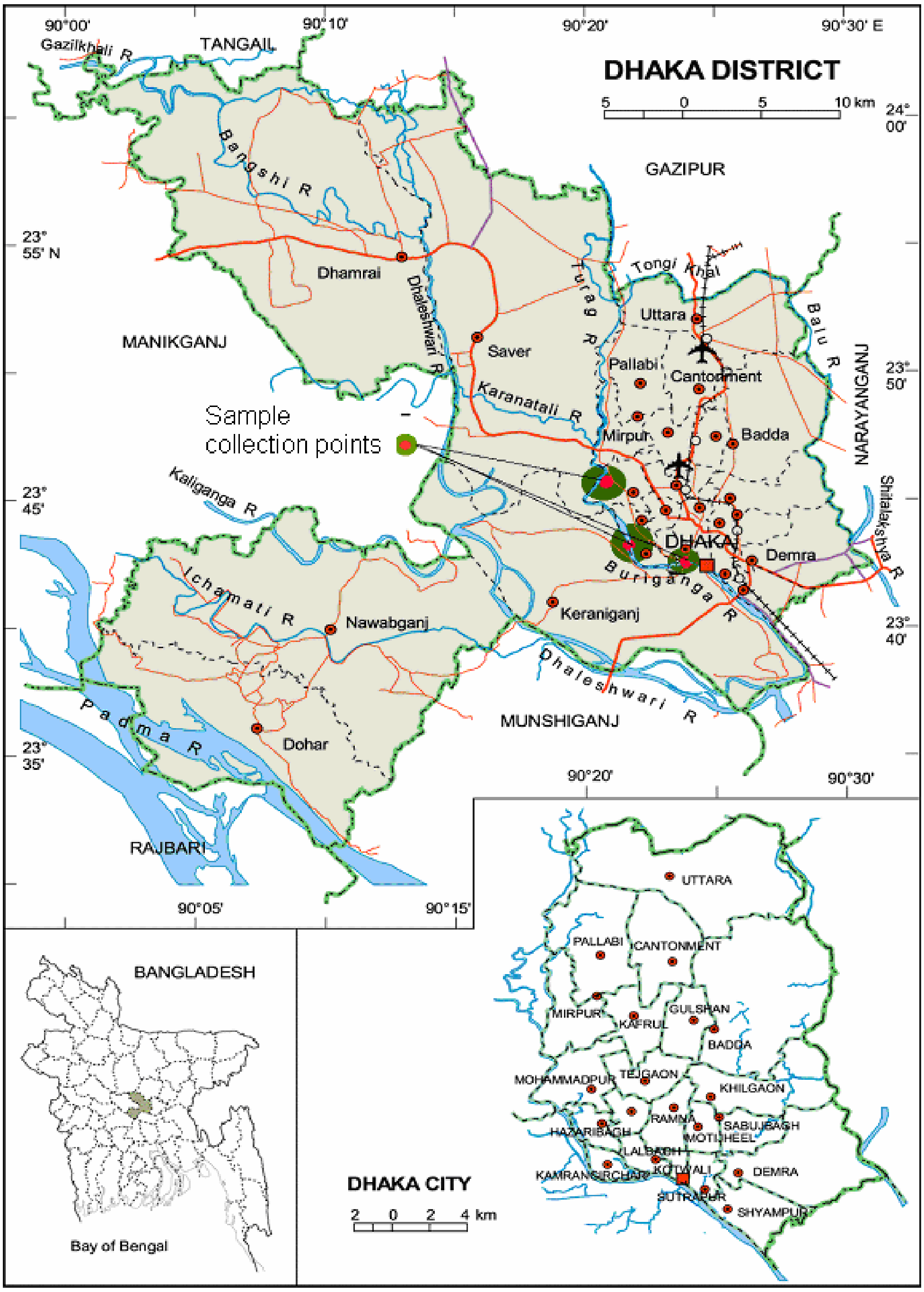

Fig. 1 Map of sampling sites in Buriganga River, Dhaka.

tration ranged from 107.38 to 201.29 µg/L in the Buriganga River while in the Shitalakhya River it ranged from 156.38 µg/L at post monsoon season to 254.07 µg/L at monsoon. However, these two findings are much higher than the present study. Mehedi (1994) found that the concentration of Cu in water ranged from 3.8 to 60.88 µg/L in the ship-breaking area of Chittagong. Rao *et al.* (1985) found that the Cu concentration ranged between 6.8 and 30.6 µg/L in dissolved form and 822 and 1801 µg/g in particulate form in Vishakhapattam. The standard for open water Cu given by Bangladesh Environmental Quality Standard (EQS) is 0.03 µg/g, which marks the state of Cu pollution in the Karnatoli River.

The tannery effluent had a higher load of Pb than textile effluent. The concentration varied from 1.18 to 8.59 µg/L in Buriganga and from 0.53 to 6.8 µg/L in the Karnatoli River. The highest concentration (8.59 µg/L) was observed at the point source of the Buriganga River in the dry season while the lowest concentration (1.18 µg/L) was observed in the rainy season at the non-point source. Ahmed *et al.* (2009a) studied the heavy metal concentration in water of the Shitalakhya River, Bangladesh and found the concentration of Pb to be 41.24 to 63.15 µg/L, which is much higher than the present study and more or similar to the findings of Ahmed *et al.* (2010a). However, a report by Alam *et al.* (2003) revealed that in the Buriganga River Pb concentration varied between 0.1-0.7 µg/L in the rainy season and 5-14.4 µg/L in the dry season, which is close to the present study. Khan *et al.* (1998) found that the concentration of Pb ranged from 0.012 to 0.431 µg/ml, which is much lower than the current study. The maximum concentration of Pb (8.59 µg/L) found during the study period was below the DoE standard for open water (0.1 mg/L) (DoE 2003).

Ni concentration in tannery effluent was 4.02 to 9.5 µg/L, higher than the concentration of textile effluent, which was 3.5 to 6.83 µg/L. The Ni concentration varied seasonally from 1.15 µg/L in the rainy season to 6.44 µg/L in the dry season at the non-point source of the Buriganga River. Although Ahmed *et al.* (2010b) reported the lowest (7.15 µg/L) concentration of Ni to be in Buriganga during

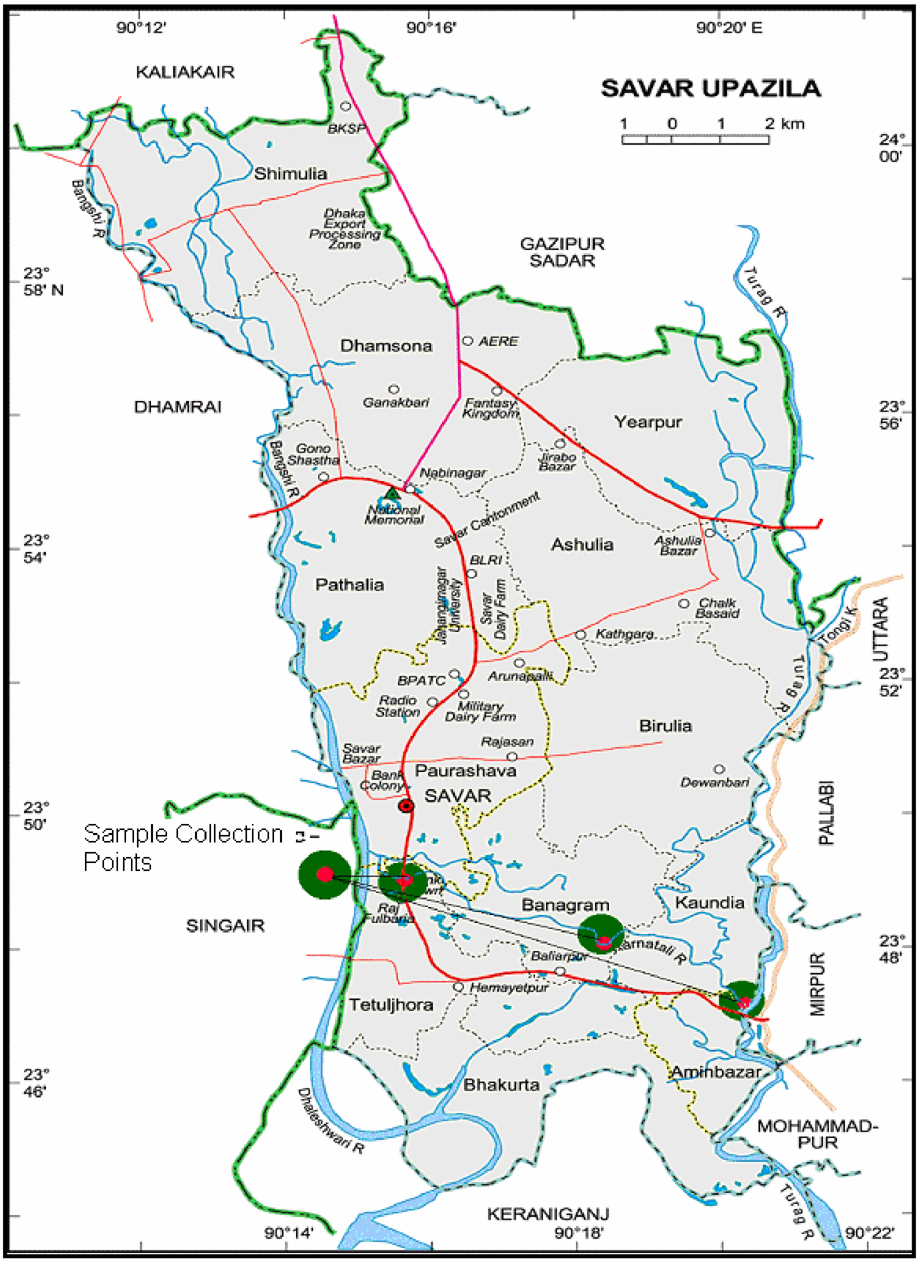

Fig 2 Map of sampling sites in Karnatoli River, Savar, Dhaka.

the dry season and the highest (10.32 μg/L) during monsoon, it is lower than our findings. In the Karnatoli River, Ni content varied from 4.2 μg/L in summer to 8.2 μg/L in the rainy season, which is more or less similar to a recent report of Ahmed *et al*. (2009a) in which the highest concentration of Ni was 7.83 μg/L in the dry season and the lowest was 4.31 μg/L in summer in the Shitalakhya River. This study found that the maximum concentration of Ni (8.05 μg/L) found during the study period was below the DoE standard for open water (0.1 mg/L) (DoE 2003).

Cr concentration in tannery effluent varied from 1256 to 1873.37 μg/L while in its adjacent river the concentration varied from 9.45 to 293.08 μg/L. The highest Cr concentration was recorded at the point source of Buriganga in summer while the lowest concentration was in the rainy season at the non-point source. Cr was the most abundant heavy metal found in Buriganga and its seasonal variation observed in this study is also supported by recent findings of Ahmed *et al*. (2010a, 2010b) who reported that Cr concentration was the most abundant in the Buriganga River (587.20 μg/L) and in the Dhaleswari River (441.34 ± 42.48 μg/L) among all the metals studied; the highest load was observed during summer and the lowest concentration was in monsoon.

In textile effluents the Cr content varied from 1.16 to 3.85 μg/L while in the adjacent river, it varied from 2.75 to 7.0 μg/L. Khan *et al*. (1998) found the concentration of Cr to range from 0.015 to 0.491 μg/ml in the water of the GBM Estuary, which is lower than the present study. However, during the rainy season the highest concentration was recorded in surface water of the Karnatoli River whereas the lowest concentration was found during the summer season in the same location. A similar variation was also observed by Ahmed *et al.* (2009a) in the Shitalakhya River in which the highest concentration (234.32 μg/L) of Cr was detected in the rainy season and the lowest concentration (192.18 μg/L) in summer with an average of 210.90 ± 16.53 μg/L. Alam *et al*. (2003) found a higher concentration of Cr in the rainy season (3-13 μg/L) than in the dry season (1.2-8 μg/L). The maximum concentration of Cr found during the study period in the Buriganga River was above the DoE standard (0.1 mg/L) for open water (DoE 2003), which marks Cr pollution in this river.

The correlation matrix presented in **Tables 4** and **5** shows both positive and negative significant correlations among heavy metal concentrations. In tannery effluent and adjacent river among the heavy metals themselves, Pb showed a significant positive correlation with As (r = 0.796)

Table 2 Seasonal and spatial variations of heavy metal concentrations (Mean ± SD) (μg/L) of tannery effluents and adjacent river water (Buriganga River).

Sites and seasons		Zn	As	Cd	Pb	Cu	Ni	Cr
Ta1	Rainy	BDL	0.52 ± 0.15	0.91 ± 0.80	2.98 ± 4.20	BDL	8.05 ± 2.40	1873.37 ± 715.20
	Dry	14.82 ± 9.95	1.07 ± 0.30	0.3 ± 0.1	4.03 ± 3.40	BDL	4.02 ± 2.30	2173.13 ± 917.60
	Summer	7.65 ± 0.77	0.45 ± 0.25	0.25 ± 0.07	2.89 ± 0.12	BDL	9.5 ± 2.7	1256 ± 461.60
Ta2	Rainy	7.1 ± 1.0	3.25 ± 2.39	1.5 ± 1.3	8.05 ± 3.70	0.69 ± 0.01	2.7 ± 0.7	90.3 ± 20.3
	Dry	18.02 ± 8.80	3.53 ± 0.70	2.37 ± 0.30	8.59 ± 2.52	BDL	5.7 ± 4.6	293.08 ± 239.79
	Summer	15.23 ± 6.46	2.23 ± 0.32	0.11 ± 0.50	3.9 ± 0.6	BDL	2.3 ± 0.9	251.45 ± 20.63
Ta3	Rainy	6.07 ± 1.16	1.76 ± 1.15	0.12 ± 0.11	1.18 ± 1.60	1.15 ± 0.70	1.15 ± 0.30	9.45 ± 2.80
	Dry	22.83 ± 9.80	1.81 ± 0.06	0.13 ± 0.08	5.67 ± 2.40	BDL	6.44 ± 3.30	38.65 ± 28
	Summer	5.2 ± 1.4	2.26 ± 0.36	0.65 ± 0.42	5.77 ± 0.84	0.85 ± 0.1	4.5 ± 1.5	45.3 ± 7.8

BDL: beyond detection limit

Table 3 Seasonal and spatial variations of heavy metal concentrations (Mean ± SD) (μg/L) of textile effluents and adjacent river water (Karnatoli River).

Sites and seasons		Zn	As	Cd	Pb	Cu	Ni	Cr
Te1	Rainy	28.14 ± 2.70	6.6 ± 0.56	0.6 ± 0.14	1.35 ± 0.90	11.6 ± 8.45	5.85 ± 5.30	3.85 ± 2.70
	Dry	39.86 ± 12.70	6.2 ± 0.84	0.65 ± 0.07	3.89 ± 3.60	20.18 ± 7.90	6.8 ± 2.8	1.16 ± 0.35
	Summer	14.26 ± 0.09	4.5 ± 0.70	0.23 ± 0.11	0.96 ± 0.83	39.23 ± 10.56	3.5 ± 1.34	2.3 ± 0.23
Te2	Rainy	42.18 ± 15.59	1.87 ± 0.30	0.92 ± 0.10	5.27 ± 4.69	17.8 ± 9.94	2.7 ± 0.70	2.75 ± 1.60
	Dry	68.47 ± 26.31	1.91 ± 0.13	1.01 ± 0.14	5.8 ± 0.83	40.34 ± 10.34	5.7 ± 4.6	5.23 ± 8.75
	Summer	24.23 ± 2.80	1.76 ± 0.60	BDL	2.63 ± 0.04	25.36 ± 32.39	2.3 ± 0.90	4.2 ± 2.05
Te3	Rainy	0.62 ± 0.4	0.62 ± 0.3	0.53 ± 0.25	0.53 ± 0.07	8.6 ± 5.04	1.15 ± 0.30	7.0 ± 4.3
	Dry	41.86 ± 22.80	0.7 ± 0.14	0.45 ± 0.17	6.8 ± 4.31	48.14 ± 33.39	6.44 ± 3.37	4.63 ± 1.48
	Summer	24.23 ± 2.80	0.56 ± 0.05	0.13 ± 0.02	4.12 ± 0.39	36.26 ± 4.5	4.5 ± 1.5	3.2 ± 4.04

BDL: beyond detection limit

Table 4 Correlation matrix of heavy metal concentrations of tannery effluents and adjacent river water (Buriganga River).

	Zn	As	Cd	Pb	Ni	Cr
Zn	1					
As	0.097	1				
Cd	-0.385	0.402	1			
Pb	-0.405	0.796*	0.581*	1		
Ni	-0.551*	-0.524*	0.232	-0.02	1	
Cr	-0.389	-0.717*	0.086	-0.365	0.473	1

* Values > 0.5 or < - 0.5 are significantly correlated

Table 5 Correlation matrix of heavy metal concentrations of textile effluents and adjacent river water (Karnatoli River).

	Zn	As	Cd	Pb	Cu	Ni	Cr
Zn	1						
As	0.025	1					
Cd	0.006	-0.124	1				
Pb	0.812*	-0.37	-0.066	1			
Cu	0.417	-0.326	-0.48	0.583*	1		
Ni	-0.02	-0.059	0.741*	-0.09	-0.578*	1	
Cr	-0.157	-0.588*	0.533*	-0.106	-0.103	0.543*	1

* Values > 0.5 or < - 0.5 are significantly correlated

and Cd (r = 0.581) whereas a significant negative correlation existed between Zn and Ni as well as As and Cr (r = -0.717). Ni also showed a negative correlation with As (r = -0.524). A significant positive correlation existed between Pb and Cd (r = 0.581). However, in textile effluent and its adjacent river, significant positive correlations existed between Pb and Zn (r = 0.812), Ni and Cd (r = 0.741) while a significant positive linear relationship was detected between Pb and Cu (r = 0.583). Significant negative correlations existed between As and Cr (r = -0.588), and Ni and Cu (r = -0.578).

In this study the relative dominance of heavy metals in tannery effluent was observed in the following sequence: Cr > Zn > Ni > Pd > Cd > As > Cu whereas at the point source and in surface water of the adjacent Buriganga River the order was Cr > Zn > Pb > Ni > As > Cd > Cu. High values of Cr both in the point source and river water might be due to the fact that Cr is a compound of tannery effluent emanating from the use of Cr salts (Bajza and Vrcek 2001). This study also found the highest concentration of Cr (2173.13 ± 917.6 μg/L) during the dry season, which might be due to Eid ul Azha (Muslim festival), which is the peak tanning period in Bangladesh. According to Kar *et al.* (2008) the lowest concentrations of heavy metals are observed during the rainy season which might be due to the dilution effect of rainfall and the highest concentration of these metals were found during the dry season as industrial effluents are less diluted due to receding water in the river during this season. In the case of textile effluent the relative dominance of heavy metals was observed in the sequence: Zn > Cu > As > Ni > Cr > Pb > Cd whereas in surface water of the adjacent Karnatoli River the order was Cu > Zn > Ni > Cr > Pb > As > Cd. Nupur *et al.* (2005) reported that heavy metals like Cu, Zn, Cr, Cd and Fe in the dye effluents of textile industry. Textile effluents may contain heavy metals such as chromium, copper, zinc and mercury (EPA 1979). Dyeing process usually contributes Cr, Pb, Zn and Cu to wastewater (Benavides 1992). Therefore, a high concentration of Cu and Zn at the point source and in surface water of the adjacent river might be due to the effluent discharge of the textile industries. However, Cu is also an efficient biocide and has been used in anti-fouling paints on boats (no reference available) and might be a reason for the high concentration of Cu.

In the present study the lowest concentrations of Zn, Cr, Cu, Ni, and Pb were observed during the rainy season which might be due to the dilution effect of rainfall whereas the highest concentration of these metals were found during the dry season as industrial effluents are less diluted due to receding water in the river in this season. It was found that, except for Cr and Cu, the concentrations of Zn, Ni, Pb, As and Cd were below the permitted levels recommended by DoE for open water in every season. The adoption of adequate measures to remove heavy metal loads from industrial wastewater and renovation of sewage treatment plants are suggested to avoid further deterioration of the river water quality.

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