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Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh

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ABSTRACT

Contamination of heavy metals in sediment is regarded as a global crisis with a large share in developing countries like Bangladesh. Four heavy metals such as arsenic (As), chromium (Cr), cadmium (Cd) and lead (Pb) in sediments and water were investigated from Karnaphuli River in Bangladesh. The decreasing trend of metals were observed in water as Cr > As > Pb > Cd and in sediment Cr > Pb > As > Cd. The ranges of heavy metals in water were 13.31–53.87, 46.09–112.43, 2.54–18.34 and 5.29–27.45 μg/L and in sediments were 11.56–35.48, 37.23–160.32, 0.63–3.56 and 21.98–73.42 mg/kg for As, Cr, Cd and Pb. The level of studied metals in water samples exceeded the safe limits of drinking water, indicated that water from this river is not safe for drinking and/or cooking. Contamination factor (CF) confirmed that the sediment samples were moderate to high contamination by As, Cd and Pb. The pollution load index (PLI) values were above one (>1) indicates advanced decline of the sediment quality. This study recommended that continuous monitoring of As, Cd and Pb in water; sediment and other aquatic biota of Karnaphuli River should be directed to assess the risk of these vital metals to safe the ecology in the vicinity of this river.

1. Introduction

Contamination of heavy metals in the aquatic environment has attracted global attention owing to its abundance, persistence and environmental toxicity (Islam et al., 2015a; Ahmed et al., 2015a,b). Both natural and anthropogenic activities are responsible for the abundant of heavy metals in the environment (Wilson and Pyatt, 2007; Khan et al., 2008). However, anthropogenic activities can effortlessly generate heavy metals in sediment and water that pollute the aquatic environment (Sanchez-Chardi et al., 2007). The increasing pollution by heavy metals have a significant adverse health effects for invertebrates, fish, and humans (Yi et al., 2011; Islam et al., 2014; Martin et al., 2015; Islam et al., 2015b,d; Ahmed et al., 2015c). The metal pollution of aquatic ecosystems is increasing due to the effects from urbanization and industrialization (Sekabira et al., 2010; Zhang et al., 2011; Bai et al., 2011; Grigoratos et al., 2014; Martin et al., 2015).

In the aquatic environment, sediments have been widely used as environmental indicators for the assessment of metal pollution in the natural water (Islam et al., 2015c). The principal comportment of metals is a function of the suspended sediment composition and water chemistry in the natural water body (Mohiuddin et al., 2012). During transportation of heavy metals in the riverine system, it may undergo frequent changes due to dissolution, precipitation and sorption phenomena (Abdel-Ghani and Elchaghaby, 2007), which affect their performance and bioavailability (Nicolau et al., 2006; Nouri et al., 2011). Sediment is an essential and dynamic part of the river basin, with the variation of habitats and environments (Morillo et al., 2004). The investigation of heavy metals in water and sediments could be used to assess the anthropogenic and industrial impacts and risks posed by waste discharges on the riverine ecosystems (Zheng et al., 2008; Yi et al., 2011; Saleem et al., 2015). Therefore, it is important to measure the concentrations of heavy metals in water and sediments of any contaminated riverine ecosystem.

Nowadays heavy metal pollution is a main problem in many developing countries like Bangladesh (Islam et al., 2015c). The unplanned urbanization and industrialization of Bangladesh have detrimental effects on the quality of water and sediment as well as

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other aquatic fauna. The disposal of urban wastes, untreated effluents from various industries and agrochemicals in the open water bodies and rivers has reached alarming situation in Bangladesh which are continually increasing the metals level and deteriorating water quality (Khadse et al., 2008; Venugopal et al., 2009; Islam et al., 2015a,c). In Bangladesh, Karnaphuli River is the largest and important river in the Chittagong City and sea port area. Because of the industrially developed area the heavy metal pollution of the Karnaphuli River is increasing day by day. The studied river receives huge amount of untreated effluents from industries such as spinning mills, dying, cotton, textile, steel mills, oil refineries and others. High concentration of heavy metals such as arsenic (As), chromium (Cr), cadmium (Cd) and lead (Pb) are discharged into the Karnaphuli River which pollute the water and sediments. To date, no scientific research regarding heavy metal pollution in water and sediment of the study river has been conducted so far. Therefore, the objectives of this study are to evaluate the water quality parameters of the Karnaphuli River; to determine the levels of heavy metals in water and sediment; and to assess the heavy metal pollution status in sediments.

2. Materials and methods

2.1. Study area and sampling

This study was conducted on the Karnaphuli River, which passes through Chittagong City, close to the Bay of Bengal, Bangladesh (Fig. 1). The name of the sampling sites with their GIS coordinates is presented in Table S1. Karnaphuli River is one of the major and most important rivers in Chittagong and the Chittagong hill tracts, originating in the Lushai hills in Mizoram State of India. It travels through 180 km of mountainous wilderness formation of a slight circle at Rangamati and then follows a zigzag course before it forms two other prominent loops, the Dhuliachhari and the Kaptai. It runs over the district in a zigzag path and after a course of about 170 km falls into the Bay of Bengal and about 16 km southwest of Chittagong town. About 40 composite sediment and water samples were collected from 10 sampling locations of Karnaphuli River in September, 2014 (summer) and in March, 2015 (winter). During winter, there is no rainfall, and river water levels decrease; during summer, river water levels increase due to heavy rainfall. Considering the water flow in the studied river, summer season exhibited higher than winter season which can cause the variation of metals concentration in water and sediment. Water samples were filtered (0.45 μm filters, cellulose nitrate, Millipore) into polypropylene tubes using a plastic syringe (BD Plastipak, 50 mL) for dissolved metal concentrations. Samples were acidified to 0.24 M with HNO_3 (65% supra pure, Merck) and kept at 4 °C in the dark until analysis. Sediment samples were collected by Ekman dredge from different stations of the Karnaphuli River at same sites of water samples. The collected samples were put into the polythene bag (sediment) and PVC bottle (water). After collection samples were brought to the Fish Inspection and Quality Control (FIQC) Chemistry Laboratory, Khulna, Bangladesh. The collected sediment samples were dried at room temperature ground and sieved with 2 mm sieve.

2.2. Water quality parameters

Physico-chemical parameters like temperature, pH and dissolved oxygen (DO) of the river water were measured. Water samples were collected on spot using water sampler for the detection of physicochemical parameters. Temperature and pH were determined using a microprocessor pH meter (Model No. HI 98139, HANNA Instruments Ltd., Germany). Salinity was measured by potable Refractometer (Model: EXTECH RF20). Other parameters like hardness (mg/L), dissolved oxygen (mg/L), alkalinity (mg/L), ammonia (mg/L), were analyzed on using kits (HANNA Test kits, Hanna Instruments Ltd., Germany).

2.3. Chemicals and sample digestion

All standard solution for target element was supplied by Merck Germany with highest purity level (99.98%). Ultra-pure HNO_3 was used for sample digestion. All other acids and chemicals were either supra pure or ultra-pure received form Merck Germany or Scharlau Spain. After collection, water samples were filtered through Millipore Filtration Assembly, using 0.45 mm membrane filter. The filtrate was then acidified with concentrated HNO_3 to make a pH of <2. Measured volume (50 mL) of well mixed, acidified sample was taken in a beaker. About 5 mL of concentrated HNO_3 was added and boiled at 130 °C on hot plate till the volume came to about 25–30 mL and light color. Addition of HNO_3 and boiling were repeated till solution becomes light colored or clear. After cooling, volume was made to desired level with DIW passing through the Whatman no. 41 filter paper. About 2.0 g portion of dried sediment was taken in 100 mL beaker and 15 mL of concentrated HNO_3 was added. The content was heated at 130 °C for 5 h until 2–3 mL remaining in the beaker. After digestion materials were passed through Whatman no. 41 filter paper, washed with 0.1 M HNO_3 solution and made up to 100 mL volume with deionized water.

2.4. Analytical technique and accuracy check

All the matrixes were analyzed for Pb, Cd, Cr and As by atomic absorption spectrophotometer (Model ZEEnit 700P# 150Z7P0110, AnalytikJena, Germany) using GF-AAS and Hydride Generator system. All the methods are in-house validated following EC567/2002. Analytical conditions for the measurement of the heavy metals in sample using AAS were tabulated in Table S2. The instrument calibration standards were made by diluting standard (1000 ppm) supplied by Sigma–Aldrich, Switzerland. The results were expressed as mg/kg for fish and sediment while μg/L for water sample. De-ionized ultrapure water was used for the experimental procedure. All glassware and containers were cleaned by 20% nitric acid, finally rinsed with De-ionized ultrapure water for several times and oven-dried prior to use. The analytical procedure was checked using certified reference material DORM-4 Fish protein for heavy metals. This fish samples were prepared and provided by the National Research Council, Canada. The standard deviations of the means observed for the certified materials were between 0.65–8% and the percentage recovery was between 89 and 99% as shown in Table S3. The results indicated a good agreement between the certified and observed values.

2.5. Assessment of heavy metals in sediment

In the interpretation of geochemical data, choice of background values plays a significant contribution. Several researchers have used the average shale values or the average crustal abundance data as reference baselines (Loska and Danuta, 2003; Singh et al., 2005; Islam et al., 2015a). The degree of contamination from heavy metals could be evaluated by determining the contamination factor (CF), pollution load index (PLI) and geoaccumulation index (I_{geo}).

2.5.1. Pollution load index (PLI) and contamination factor (CF)

To evaluate the sediment quality, combined approaches of pollution load index of the four metals were calculated according to Islam et al. (2015c). The PLI is defined as the nth root of the multiplications of the contamination factor of metals (CF).

$$(1)\mathrm{PLI} = (\mathrm{CF}_1 \times \mathrm{CF}_1 \times \mathrm{CF}_1 \times \ldots \times \mathrm{CF}_n)^{1/n}$$

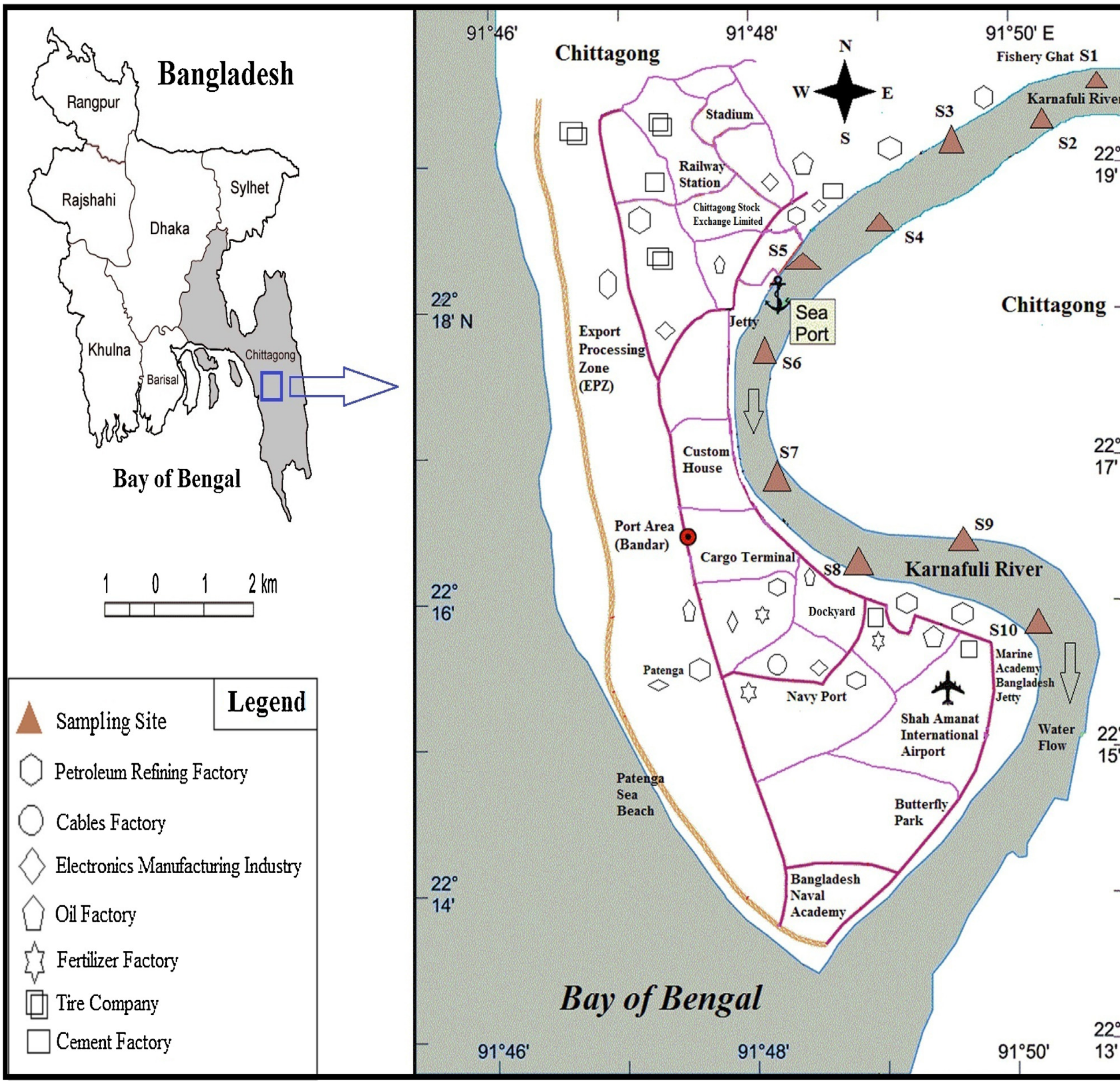

Fig. 1. Map of the study area of Karnaphuli River, Bangladesh.

where CF_{metals} is the ratio between the content of each metal to the background values (background value from the average shale value) in sediment, $CF_{metals} = C_{metal}/C_{background}$. Therefore, PLI value of zero indicates excellence, a value of one indicates the presence of only baseline level of pollutants and values above one indicate progressive deterioration of the site and estuarine quality (Tomilson et al., 1980). The PLI gave an evaluation of the overall toxicity status of the sample and also it is a consequence of the contribution of the studied four metals. The ratio of the measured concentration to natural abundance of a given metal had been proposed as the contamination factor (CF) being classified into four grades for monitoring the pollution of one single metal over a period of time (Islam et al., 2015c): low degree (CF < 1), moderate degree ($1 \leq CF < 3$), considerable degree ($3 \leq CF < 6$), and very high degree ($CF \geq 6$). Thus, the CF values can monitor the enrichment of one given metal in sediments over a period of time.

2.5.2. Geoaccumulation index (I_{geo})

The degree of contamination from the heavy metals could be assessed by measuring the geoaccumulation index (I_{geo}). The index of geoaccumulation has been widely used to the assessment of sediment contamination (Santos Bermejo et al., 2003; Saleem et al., 2015). In order to characterize the level of pollution in the sediment, geoaccumulation index (I_{geo}) values were calculated using the equation,

$$I_{geo} = \text{Log}2\left[\frac{C_n}{1.5B_n}\right] \tag{2}$$

where C_n is the measured concentration of metal n in the sediment and B_n is the geochemical background value of element n in the background sample (Yu et al., 2011; Rahman and Ishiga, 2012; Islam et al., 2015a). The factor 1.5 is introduced to minimize the possible variations in the background values which may be qualified to lithogenic effects. Geoaccumulation index

(I_{geo}) values were interpreted as: $I_{geo} \leq 0$—practically uncontaminated; $0 \leq I_{geo} \leq 1$—uncontaminated to moderately contaminated; $1 \leq I_{geo} \leq 2$—moderately contaminated; $2 \leq I_{geo} \leq 3$—moderately to heavily contaminated; $3 \leq I_{geo} \leq 4$—heavily contaminated; $4 \leq I_{geo} \leq 5$—heavily to extremely contaminated; and $5 < I_{geo}$—extremely contaminated.

2.5.3. Statistical analysis

The data were statistically analyzed by the statistical package, SPSS 16.0 (SPSS, USA). The means and standard deviations of the heavy metal concentrations in water and sediments were calculated.

3. Results and discussion

3.1. Water quality parameters

The physico-chemical parameters of the water column such as dissolved oxygen (DO), pH, temperature etc. are presented in Table 1. The physicochemical parameters are very important because they have a significant effect on the water quality. Furthermore, aquatic life also suffers due to degradation of water quality. Among the external factors temperature is one of the most important factors which influence the aquatic ecology (Huet, 1986). The values of temperature were ranged from 28.8 °C to 33.9 °C and 20.1 °C to 23.9 °C during summer and winter, respectively. The mean value of water temperature was found within the permissible limits set by (WHO, 2004), which was between 25 and 30 °C. The average pH was 7.89 and 8.17 during summer and winter, respectively (Table 1). Salinity is a measure of the salt content of the water. The salinity of freshwater is always less than 0.5%. This range of salinity is generally termed brackish as distinct from marine or freshwaters. Mean values of salinity were observed 8.61 ppt in summer and 9.06 ppt in winter. In the present study, the highest hardness 780 mg/L was observed in site S10 during winter due to higher level of salinity where lower hardness 325 mg/L during summer was observed in site S3 (Table 1) due to the lower salinity concentration (Lawson, 2011). Dissolved oxygen refers to the oxygen gas that is dissolved in the water and made available to aquatic life. The solubility of oxygen increases with decrease the temperature (Singh et al., 1990). As was expected the highest value of DO was recorded during winter season might be due to temperature in this season was low (Macan, 1980). The dissolved oxygen (DO) was found 4.58–11.75 mg/L during summer and 5.12–14.1 mg/L in winter. The lowest value of DO was observed during summer that could be due to the less or no rainfall and increase in temperature that lead to decrease in dissolved oxygen results due to the rate of oxygen consumption from aquatic organisms and high rate of decomposition of organic matter. Joseph et al. (1993) reported that a suitable range of alkalinity is 20–300 mg/L for fish. In the present study the highest alkalinity range was (114.4 ± 3.782–189 ± 16.355 mg/L), it indicates that the level of alkaline is a suitable condition.

3.2. Metal concentration in water

The results of heavy metal concentrations in surface waters are shown in Table 2. The average concentration of studied metals in water followed the decreasing order of: Cr > As > Pb > Cd. The mean concentration of Cr in water was observed 69.56 and 86.93 μg/L during summer and winter season, respectively which was much higher than the WHO standard level for drinking water (Table 2). The average concentration of Cd was observed 6.46 and 10.64 μg/L during summer and winter season, respectively. Interestingly, the highest value of Cd was observed at S6 site (18.34 μg/L during winter) which might be attributed to the domestic sewage and effluents

Table 1
Water quality parameters of Karnaphuli River of Chittagong district, Bangladesh.

Sites	Temperature (°C)		pH		Salinity (ppt)		Hardness (mg/L)		DO (mg/L)		Alkalinity (mg/L)		Ammonia (mg/L)	
	Su	Wi	Su	Wi	Su	Wi	Su	Wi	Su	Wi	Su	Wi	Su	Wi
S1	33.7	23.9	7.8	8.1	8.5	9.1	330	570	11.23	13.1	120	160	0.23	0.35
S2	32.4	21.4	7.8	7.9	8.7	9.1	350	595	7.11	8.31	115	145	0.31	0.51
S3	30.1	20.1	7.9	7.5	8.4	8.9	325	660	10.05	11.1	110	160	0.1	0.15
S4	31.6	21.2	8.1	7.8	8.7	9.3	360	725	5.1	7.24	115	150	0.13	0.27
S5	28.6	20.5	7.5	7.7	8.7	8.9	375	665	4.58	5.12	112	155	0.1	0.18
S6	32.1	22.7	7.3	8.5	8.5	9.1	335	585	10.11	12.21	130	170	0.33	0.43
S7	33.9	20.4	7.9	8.3	8.9	9.4	465	745	11.75	14.1	92	130	0.12	0.19
S8	29.8	20.3	8.2	8.1	8.8	8.9	430	690	7.1	9.2	125	165	0.13	0.28
S9	29.7	21.1	8.1	8.7	8.8	9.4	420	755	5.3	8.56	118	135	0.21	0.29
S10	28.8	20.6	8.3	9.1	8.9	9.5	450	780	8.45	10.29	110	140	0.27	0.35
Average ± SD	31.07 ± 1.94	21.22 ± 1.21	7.89 ± 0.31	8.17 ± 0.49	8.69 ± 0.17	9.16 ± 0.23	384 ± 52.64	677 ± 75.17	8.07 ± 2.63	9.92 ± 2.78	114.7 ± 10.25	151 ± 13.29	0.193 ± 0.09	0.3 ± 0.11

Note: Su—Summer, Wi—Winter season, respectively.

Table 2
Heavy metal concentration (μg/L) in water sample of Karnaphuli River and maximum permitted concentration in water (μg/L).

Sites	As		Cr		Cd		Pb	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
S1	15.83	21.41	51.76	65.32	5.28	7.32	18.17	27.45
S2	32.43	41.53	63.91	78.54	6.87	13.49	7.32	12.67
S3	20.07	27.89	96.09	112.43	2.54	3.18	11.64	17.89
S4	27.13	33.48	46.09	55.43	3.12	6.59	9.89	13.45
S5	19.84	31.54	75.99	90.79	10.94	15.56	11.45	22.78
S6	17.29	29.83	69.27	87.45	11.71	18.34	5.73	11.56
S7	13.31	23.76	79.81	92.13	5.91	11.79	17.12	25.32
S8	30.44	53.87	93.14	107.57	4.38	8.93	5.29	10.69
S9	31.79	43.32	66.39	95.21	7.19	11.71	6.56	13.98
S10	25.49	37.98	53.18	84.38	6.62	9.53	5.34	12.49
Average ± SD	23.36 ± 6.99	34.46 ± 9.87	69.56 ± 16.95	86.93 ± 17.39	6.46 ± 3.00	10.64 ± 4.49	9.85 ± 4.75	16.83 ± 6.17
DWSB[a]	50		50		5		50	
TRV[b]	150		11		2		3	
WHO (2004)	10		5		3		10	

Note: SD, standard deviation.
[a] Drinking water standard for Bangladesh proposed through ECR (Department of Environment, Government of the People's Republic of Bangladesh, 1997).
[b] TRV (toxicity reference value) for fresh water proposed by USEPA (1999).

from the port area (Islam et al., 2015a). The average concentration of As was higher in winter (34.46 μg/L) than that in summer (23.36 μg/L) which exceeded the WHO standard (10 μg/L) (Table 2). Arsenic originates mostly from the upland Himalayan catchments or Chittagong hill tracts which are linked with the study river (Mitamura et al., 2008). The average concentration of Pb in water was 9.85 and 16.83 μg/L during summer and winter season, respectively, which were higher than the drinking water quality standard. Considering the toxicity reference values (TRV) proposed by USEPA (1999) almost all the heavy metals especially Cr and Cd greatly exceeded the limit for safe water, indicated that water from this river is not safe for drinking and/or cooking. The metals in water were seasonally varied, where winter season exhibited higher than summer (Table 2). The lower concentration of heavy metals during summer might be due to the dilution effect of water (Mohiuddin et al., 2012; Islam et al., 2015a; Adamu et al., 2015).

3.3. *Metal concentration in sediment*

Heavy metal concentrations of sediments are presented in Table 3. Concentrations of heavy metals at sites S4–S6 were much higher than others sites because of the fact that these sites are located at the sea port area of the river and extensive discharging of untreated effluents from the port. Metals concentrations in sediment were higher in winter than summer due to the lower water flow during winter which could assistance to accumulate the heavy metals in sediment (Islam et al., 2015a,c). The average concentration of heavy metals in sediments were in the decreasing order of: Cr > Pb > As > Cd. Chromium concentration in sediment was higher than other metals as a consequence of direct discharging untreated wastes from petroleum, fertilizers and textile industries (Facetti et al., 1998; Islam et al., 2015a). However, high level of Cr for site S5 (131.09 and 160.32 mg/kg in summer and winter, respectively) indicates its higher input, which might be originated from the urban and industrial wastes (Mohiuddin et al., 2012). The mean concentration of As in sediment was observed 13.57 mg/kg in summer and 19.87 mg/kg in winter which was higher than the average shale value (ASV) (13 mg/kg) (Table 4). High As concentration in sediments might be attributed to the anthropogenic activities such as treatment from the fertilizers and arsenical pesticides industries (Fu et al., 2014; Ahmed et al., 2016), treating of wood by exhausting copper arsenate (Pravin et al., 2012; Baeyens et al., 2007) and tanning in relation to some chemicals especially arsenic sulfide (Bhuiyan et al., 2011).

The average concentration of Cd was 1.51 mg/kg in summer and 2.50 mg/kg in winter (Table 3). High level of Cd was found during winter which might be due to the differences in water capacity of the river where low water flow in winter resulted the precipitation of Cd in sediment; there by rising its concentration (Islam et al., 2015c). Average concentration of Pb was observed 38.33 and 49.04 mg/kg during summer and winter season, about 2 times higher than ASV value (20 mg/kg) which could be due to the effect from point and non-point sources; such as leaded gasoline, petroleum, municipal runoffs and atmospheric deposition (Mohiuddin et al., 2012; Shikazono et al., 2012), chemicals and electronics manufacturing, cables, oils, tire and cement factory, and steel works nearby the study river of Chittagong district. As a whole, concentrations of most of the metals exceeded some well documented standard values and in agreement with some previous studies in Bangladesh and other countries (Table 4).

Pearson's correlation (PC) matrix for analyzed sediment parameters was calculated to see if some of the parameters interrelated with each other and the results are presented in Table 5. The elements in sediments did not show any correlation with each other where As and Cd showed significant positive correlation suggesting similar sources of input (human or natural) for these two metals in the river water (Bastami et al., 2012). High correlations between specific heavy metals in water may reflect similar levels of contamination and/or release from the same sources of pollution, mutual dependence and identical behavior during their transport in the river system (Li et al., 2009; Chen et al., 2012; Suresh et al., 2012; Jiang et al., 2014).

3.4. *Assessment of metal pollution*

The calculated pollution load index (PLI) values of metals in sediments are summarized in Fig. 2. The PLI values were ranged from 1.36 to 2.07 during summer and 1.83 to 2.91 during winter confirming that the sediment of the studied river was contaminated (PLI > 1). Higher PLI values were observed in sampling sites S4, which might be due to the effects of sea port activities. The PLI can provide some understanding to the populations about the quality of the sediment. In addition, it also delivers essential information to the decision makers on the pollution status of the study area (Suresh et al., 2012). The values of contamination factor (CF) for all metals showed moderate degree of contamination ($1 \leq CF < 3$), whereas, Cd showed very high degree of contamination ($CF > 6$) (Fig. 3). Overall, the CF for all metals were the descending order of: Cd > Pb > As > Cr. The mean CF values of As, Cd, Cr and Pb were

Table 3
Heavy metal concentrations (mg/kg dw) in sediment of Karnaphuli River, Bangladesh ($n = 3$).

Sites	As		Cr		Cd		Pb	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
S1	13.17	19.67	57.31	78.48	1.1	1.87	35.25	42.56
S2	25.39	31.53	37.23	53.27	1.53	3.21	27.76	31.73
S3	12.57	17.82	81.18	102.57	0.95	2.16	39.13	50.59
S4	13.38	19.67	111.48	135.93	1.4	2.55	61.86	73.42
S5	11.56	15.56	131.09	160.32	0.63	0.91	25.69	35.27
S6	18.39	26.79	65.89	80.53	1.12	1.61	56.03	67.38
S7	22.67	35.48	41.31	66.93	2.45	3.56	21.98	27.69
S8	19.38	26.32	68.11	91.47	1.34	2.91	35.73	48.59
S9	17.86	25.34	67.77	86.34	2.49	3.37	35.89	54.82
S10	13.57	19.87	39.18	65.27	2.11	2.89	43.97	58.39
Average ± SD	16.79 ± 4.70	23.81 ± 6.39	70.06 ± 30.93	92.11 ± 33.16	1.51 ± 0.64	2.50 ± 0.85	38.33 ± 12.74	49.04 ± 15.06

Note: SD: standard deviation.

Table 4
Comparison of metals in sediment (mg/kg dw) with different international guidelines and other studies in the world.

River, Location	Cr	As	Cd	Pb	References
Karnaphuli River (Bangladesh)	20.3 (11.56–35.48)	81.09 (37.23–160.32)	2.01 (0.63–3.56)	43.69 (21.98–73.42)	This study
Bangshi River (Bangladesh)	98	1.93	0.61	60	Rahman et al. (2014)
Buriganga River (Bangladesh)	178	NA	3.3	70	Ahmad et al. (2010)
Paira River, Bangladesh	45	12	0.72	25	Islam et al. (2015a)
Korotoa (Bangladesh)	109	25	1.2	58	Islam et al. (2015c)
Padma River, Bangladesh	97	NA	NA	17	Datta and Subramanian (1998)
Jamuna (Bangladesh)	110	NA	NA	19	Datta and Subramanian (1998)
Gomti River (India)	8.15	NA	2.42	40.33	Singh et al. (2005)
River Ganges (India)	1.8–6.4	NA	0.14–1.4	4.3–8.4	Gupta et al. (2009)
Yellow River (China)	41–128	14–48	NA	26–78	Liu et al. (2009)
Okumeshi River (Nigeria)	0.87	NA	1.32	0.45	Raphael et al. (2011)
ASV	90	13	0.3	20	Turekian and Wedepohl (1961)
TRV	26	6	0.6	31	USEPA (1999)
LEL	26	6	0.6	31	Persaud et al. (1993)
SEL	110	33	10	250	Persaud et al. (1993)

Note: ASV, average shale value; TRV, toxicity reference value; LEL, lowest effect level; SEL, severe effect level; NA, not available.

Table 5
Correlation between the elements in water and sediments of Karnaphuli River, Bangladesh.

	As	Cr	Cd	Pb
Water ($n = 20$)				
As	1			
Cr	0.368	1		
Cd	0.269	0.204	1	
Pb	−0.196	0.192	0.162	1
Sediment ($n = 20$)				
As	1			
Cr	−0.324	1		
Cd	0.731[a]	−0.280	1	
Pb	−0.079	0.320	0.102	1

[a] Correlation is significant at the 0.01 level (2-tailed).

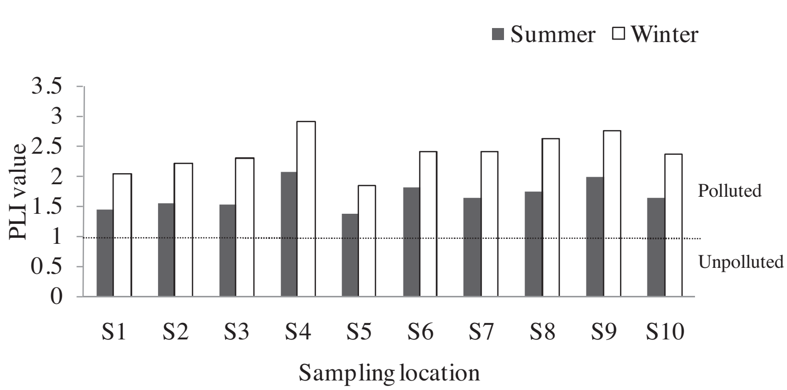

Fig. 2. Pollution load index (PLI) value of heavy metals in sediment of Karnaphuli River, Bangladesh. (Dot line of the horizontal axis indicates the baseline level of pollutants).

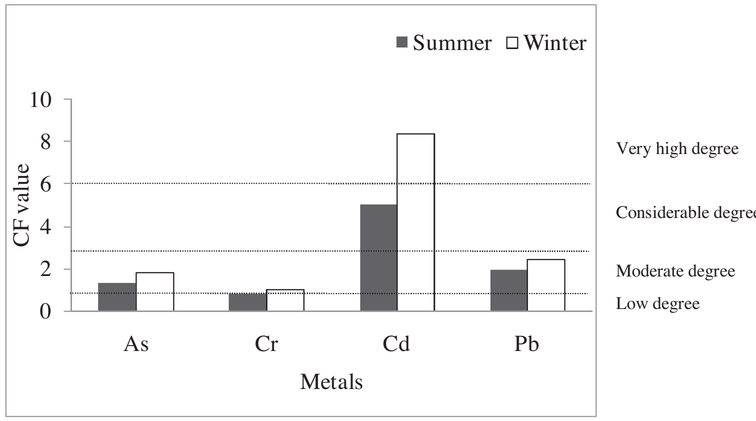

Fig. 3. Contamination factor (CF) of heavy metals in sediment of Karnaphuli River, Bangladesh.

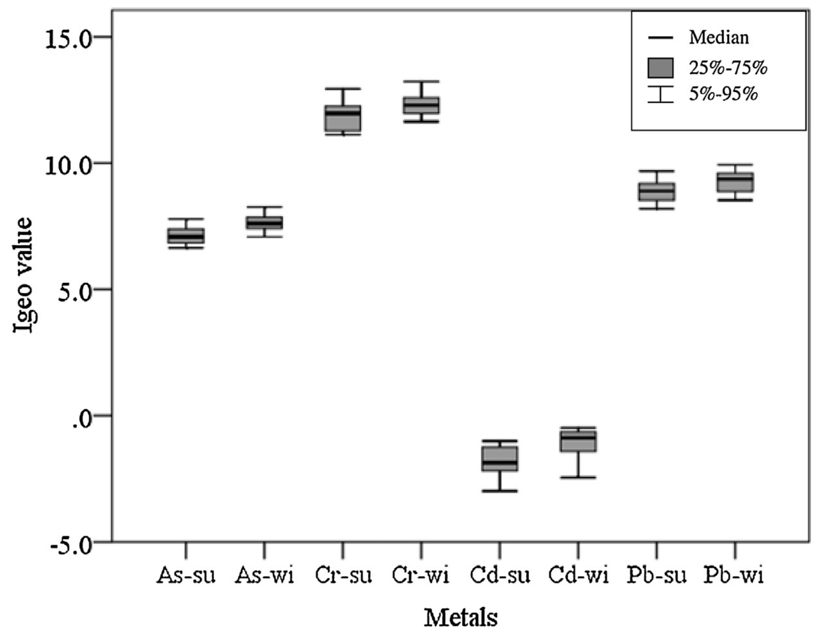

Fig. 4. Geoaccumulation index (I_{geo}) of heavy metals in sediment of Karnaphuli River, Bangladesh (su = summer season, wi = winter season).

1.29, 0.78, 5.04 and 1.92 during summer and 1.83, 1.02, 8.35 and 2.45 during winter season. The values of geoaccumulation index (I_{geo}) of the studied heavy metals are presented in Fig. 4. Among the studied metals, the I_{geo} values showed the decreasing order of: Cr > Pb > As > Cd. The I_{geo} values for the studied metals indicated unpolluted to extremely polluted.

4. Conclusions

Heavy metal pollution is a major problem for the Karnaphuli River basin, Bangladesh. In the present study concentrations of As, Cr, Cd and Pb were higher than the safe values which indicated that the river Karnaphuli is polluted by studied heavy metals and might create an adverse effect on this riverine ecosystem. The overall pollution load was remarkably higher in winter than in summer season. The contamination factor (CF), pollution load index (PLI) and geoaccumulation index (I_{geo}) exposed that sediments were unpolluted to extremely polluted by heavy metals. This study suggested that point sources of heavy metals in the water and sediments should be closely monitored; improvement of conditions and industrial effluent and domestic sewage discharge should be reduced.

Conflict of interest

The authors declare that there are no conflicts of interest. This study mainly focuses on the heavy metals content in surface water and sediments and ecological risk assessment in a coastal river of Bangladesh. We extensively monitor the present pollution status of trace metals in the samples. Our research mainly the identification of environmental problems related metals pollution and not receive any financial supports or any other relationship with other people or organizations.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.enmm.2016.01.002.

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