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Assessing Heavy Metal Contamination in the Bottom Sediments of Shitalakhya River, Bangladesh; Using Pollution Evaluation Indices and Geo-spatial Analysis

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ABSTRACT: The contamination of riverbed sediments by heavy metals has assumed serious problems due to their toxicity and accumulative behavior. The present study investigated the concentrations of heavy metals from the bottom sediments of Shitalakhya River to understand the level of contamination and their distribution. The average concentrations of heavy metals Al, K, Ca, Mg, Fe, As, Cu, Co, Cr, and Zn are 30432.41, 10929.21, 391139.13, 23148.14, 38697.37, 14.02, 143.69, 13.37, 74.82, and 200.59 mg/kg respectively in river sediments, and their abundance decreased in the following order: Ca (79.05%)>Fe (7.82%)>Al (6.15%)>Mg (4.68%)>K (2.21%)>Zn (0.04%)>Cu (0.03%)>Cr (0.015%)>As (0.0028%)>Co (0.0027%). In most cases, the mean concentrations of the heavy metals exceed the permissible limit. Significantly higher concentrations of Ca, Mg, Zn, and Cu were found in sediment samples. The heavy metals contaminations in the sediments were also evaluated by applying index of geo-accumulation (I_{geo}), contamination factor (C_f), degree of contamination (C_d), and pollution load index (PLI) etc. These indices indicated that most of the samples were moderate to strongly pollute by heavy metals and the spatial distribution showed that the northern and southern parts of the study area are more contaminant than middle portion.

Keywords: Bangladesh, geo-accumulation index, heavy metals, pollution load index, sediments.

INTRODUCTION

In recent years, metal contamination in the aquatic environment has attracted global attention owing to its environmental toxicity, abundance, long-term persistence, and subsequent accumulation in aquatic habitats (Sin *et al.*, 2001; Armitage *et al.*, 2007; Yuan *et al.*, 2011). Large quantities of hazardous chemicals, especially heavy metals, have been released into rivers worldwide due to global rapid population growth and intensive domestic activities as well as expanding industrial and agricultural production (Srebotnjak *et al.*, 2012; Su *et al.*, 2013; Islam *et al.*, 2014). River systems normally function within the natural ranges of flow,

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sediment movement, temperature, and other variables, maintaining a dynamic equilibrium, however accommodating extremes both above and below thresholds. When changes in these variables go beyond their natural ranges, dynamic equilibrium may be lost, often resulting in adjustments that are detrimental to the integrity of the ecosystem, which includes ecosystem structure, ecological structure, ecological process, regional and historical context, and sustainable cultural practices (Karim, 2004).

Due to rapid urbanization and industrialization in Bangladesh, economic growth may enhance but change the environment drastically (Chowdhury, 2006; Islam, 2014). Shitalakhya River is running by the side of Narayanganj city. Water quality of this river is to worsen to the extent that is not suitable for drinking, irrigational and others household use (Islam and Azam, 2015). Phytoplankton diversity as well as the productivity of this river is now fallen in threatened condition (Islam and Huda, 2016). Many industries have been set up in and around the city during last decade and the number of new industries is continually increasing (DOE, 1997).

Major indicators of pollution in aquatic environments are contaminated sediments that can be defined as soils, sand, organic matter, or minerals accumulated at the bottom of a water body (USEPA, 1998). Heavy metals such as cadmium, mercury, lead, copper, and zinc are regarded as serious marine pollutants because of their toxicity, tendency to be incorporated into food chains, and ability to remain in the environment for a long time (Puyate *et al.*, 2007). River sediments, derived as a result of weathering, are major carriers of heavy metals in the aquatic environment; the physicochemical processes involved in their association being precipitation, adsorption, chelation, etc. Besides natural processes, metals may enter into the aquatic system due to anthropogenic factors such as mining operations, disposal of industrial wastes, and applications of biocides for pest. The concentration in sediments contamination depends not only on anthropogenic and lithogenic sources but also upon the textural characteristics, organic matter contents, mineralogical composition, and depositional environment of the sediments (Trefry and Parsley, 1976). These metals released into aquatic systems are generally bound to particulate matter, which eventually settle down and become incorporated into sediments.

Surface sediment, therefore, is the most important reservoir or sink of metals and other pollutants in aquatic environments. Sediment bound pollutants can be taken up by rooted aquatic macrophytes and other aquatic organisms (Peng *et al.,* 2008). Because a major fraction of the trace metals introduced into the aquatic environment eventually become associated with the bottom sediments, environmental degradation by metals can occur in areas where water quality criteria are not exceeded; yet organisms in or near the sediments are adversely affected (Gurrieri *et al.*, 1985). Once heavy metals are accumulated by an aquatic organism, they can be transferred through the upper classes of the food chain (Morin *et al.,* 2007). Carnivores at the top of the food Chain, including humans, obtain most of their heavy metal burden from the aquatic ecosystem by way of their food, especially where fish are present so there exists the potential for considerable biomagnifications (Jongea *et al.,* 2009).

Contaminants in aquatic systems, including heavy metals, stimulate the production of reactive oxygen species (ROS) that can damage the fish and other aquatic organisms (Stern *et al.,* 2009). Heavy metals have toxic properties, leading to adverse effects on human and ecosystem health even in small doses.

Another problem causing property is their non-degradability: once they enter the environment they will remain there for long time (Sin *et al*., 2001). Metals tend to accumulate in soils and sediments, with immobilization due only to geological and therefore extremely slow processes. Accumulation in the food chain may lead to an increase stock in biota, thereby magnifying the human dose (Khan, 2008). Their accumulation and distribution in soil, water, and environment is increasing at an alarming rate causing deposition and sedimentation in water reservoirs and affecting aquatic organisms as well (Cataldo *et al.*, 2001; Hobbelen *et al.*, 2004; Koukal *et al.*, 2004; Okafor and Opuene, 2007; Mohiuddin *et al.*, 2010; Banu *et al.*, 2013; Bhuiyan *et al.*, 2015; Hassan *et al.*, 2015).

So, the identification and quantification of heavy metal in aquatic environment is an important environmental issue (Manoj *et al.*, 2012). Data from sediments can provide information on the impact of distant human activity on the wider ecosystem (Ogbeibu *et al.*, 2014). The aim of the present study was to assess the heavy metal contamination and their distribution of Shitalakhya River by calculating various pollution indices which provides quantitative measure of the degree of metal contamination in aquatic environment.

MATERIALS AND METHODS

Study Area

Shitalakhya River originates from the old Brahmaputra. It flows east of Narayanganj town. The length of the river is about 110 km and the width near Narayanganj is about 300 m but reduces to about 100 m in the upper reach. Its highest discharge has been measured at 2,600 cubic meters per second (m^3/s). The river is navigable throughout the year and shows little erosional tendency. A number of textiles, dyeing, pharmaceuticals, power plants, and many other industries stand on the banks of river. The sampling points of Shitalakhya River, shown in Figure 1, are located between 23º36´ and 23º44´ N latitudes and between 90º28´ and 90º36´ E longitudes. The sampling point areas are selected in the locations near Narayangong Pourasava textile cluster and Rupgong textile cluster.

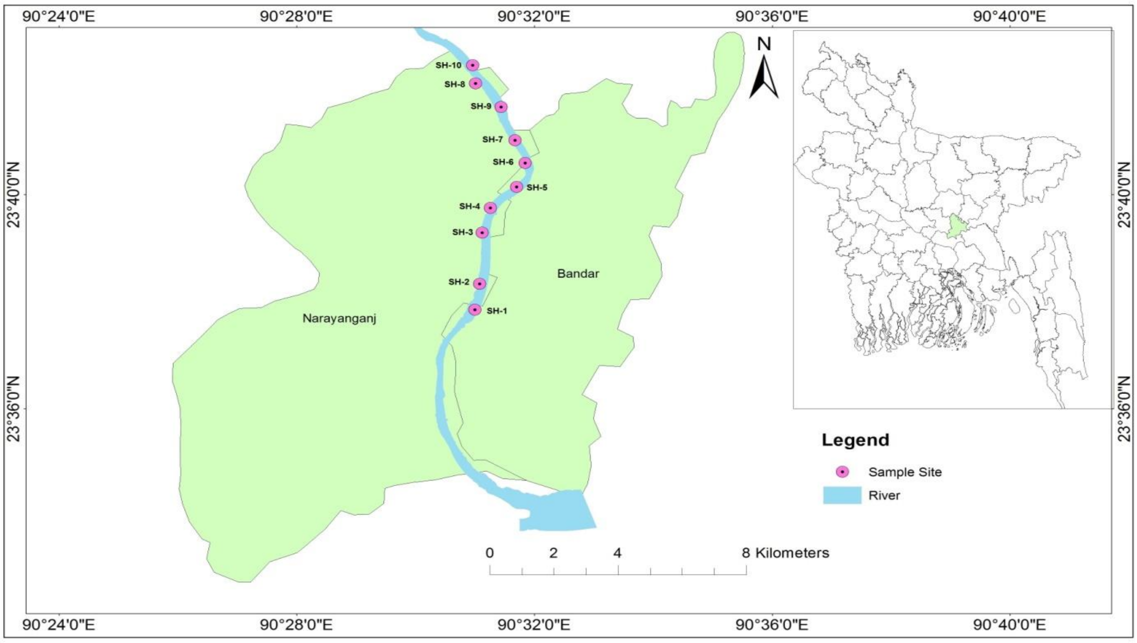

Fig. 1. Map showing the sampling points of study area

Sample Collection and Preservation

A total of 10 sediment samples (about 200 gm. of each) were collected from the study area. The geographical location of each sampling points was determined with a GARMIN handheld global positioning system (GPS). The river bed sediment samples were collected from upper layer of sediment (about 0-5 cm depth) using a portable Ekman grab sampler. Then, the upper 2 cm of each sample was taken from the center of the catcher with an acid-washed plastic spatula to avoid any contamination from the metallic parts of the sampler and immediately transferred into zipper poly bags. Prior to sampling, the poly bags were washed with 10% HNO_3 acid solution and ringed with distilled water (Manoj *et al.,* 2012; Ogbeibu *et al.,* 2014). Samples were tightly zipped and transported using ice box to the laboratory to determine metal contents using Energy Dispersive X-ray Fluorescence (EDXRF). The samples were properly labeled and kept in room temperature.

Preparation of Samples for Analysis

Samples were prepared for analysis in order to determine the metal contents in sample using EDXRF. Before preparation of sediment samples, 10 watch glasses were cleaned with detergent and washed by tap water and rinsed. The sediment samples were then removed from the zipper bag and 5 gm of samples were kept in watch glass. Collected sediment samples were homogeneously mixed, unwanted portions, like plant root were removed, and they were kept in microwave oven for about 24 hours at 60°C. Sediment samples were then kept in room temperature and grinding with mortar and pestle. After that, 2.2 gm grinding sample were taken for pellet formation. SPECAC pressing machine (15 ton pressure) was used to form pellet. Then, the pellet was kept in a box and preserved in desiccators and finally placed in EDXRF for metal analysis.

Elemental Analysis and Data Acquisition by EDXRF

After the pellet formation, samples were ready for the elemental analysis which was performed by PANalytical EPSILON 5 EDXRF spectrometer. This instrument uses an X-ray tube excites source and a solid state detector to provide simultaneous spectroscopic analysis of element ranging from Na-U in atomic number and in concentration in atomic number and in concentration ranging from a few parts per million to 100%. The measurements were carried out in air. The data acquired were processed with the help of an attached computer using Epsilon 5 software. The data is generated in percentage value which was converted to ppm with multiplying by 10000 (conversion process described in the software system) and then mg/kg.

Data Processing Tools

SPSS (version 16.00) was used for statistical correlation among identified heavy metals. Geo-spatial analysis and sample location mapping was done using Arc.GIS (version 10.1). Besides, MS excel (2007) is used for sediment data analysis and presentation.

RESULTS AND DISCUSSION

Heavy Metal Concentrations

The results of metal concentrations for each sampling site found in sediments in this study are presented in Table 1. Metal contents ranged over the following intervals; Al: 28587.24-31545.44 mg/kg (mean 30432.41), K: 9167.49-14240.71 mg/kg (mean 10929.21), Ca: 201051.60-2145762.00 mg/kg (mean 391139.13), Mg: 11593.55-46073.06 mg/kg (mean 23148.14), Fe: 21451.81-70598.76 mg/kg (mean 38697.37), As: 12.63-14.99 mg/kg (mean 14.02), Cu: 19.78-501.77 mg/kg (mean 143.69), Co: 2.49-18.74 mg/kg (mean 13.37), Cr: 63.47-83.29 mg/kg (mean 74.82), and Zn: 77.09-631.36 mg/kg (mean 200.59). It has been observed that the relative concentrations of the metals decreases in the following order: Ca (79.05%)>Fe (7.82%)>Al (6.15%)>Mg (4.68%)>K (2.21%)>Zn (0.04%)>Cu (0.03%)>Cr (0.015%)>As (0.0028%)>Co (0.0027%).

The heavy metal concentrations in sediment of the Shitalakhya River were compared with other rivers of Bangladesh (Table 2). The mean concentrations of As and Cr were higher and Cu, Co, and Zn were lower for the Buriganga River, as reported by Majumder *et al.* (2015), than the present investigation. Cu, Cr, and Zn mean concentrations were also found higher in Shitalakhya River than Turag, studied by Banu *et al.* (2013). As, Cu, and Zn concentrations of Bangshi River were lower than the present study, but higher in case of Cr (Islam *et al.*, 2014). Meghna River was studied by Hassan *et al.* (2015) which was also much lower from the present study. According to Islam *et al.* (2015), the mean concentrations of As and Cu is higher, but Cr concentration is lower than the present study.

Table 1. Concentration of metals (mg/kg) at Shitalakhya River bed sediment

Sample ID	Al	K	Ca	Mg	Fe	As	Cu	Co	Cr	Zn
SH-1	28587.24	11412.12	282611.10	20429.51	51383.35	12.63	201.11	18.18	73.63	147.53
SH-2	31251.31	10148.31	201051.60	22011.41	21441.61	14.46	nd	14.16	76.41	231.45
SH-3	30242.91	10568.22	292814.0	28192.35	51883.55	13.48	501.77	18.74	83.29	631.36
SH-4	31545.44	11447.95	201051.60	11593.55	21451.81	14.99	nd	8.72	79.11	77.09
SH-5	31480.07	12121.37	86115.33	12294.57	24390.47	14.72	19.78	7.44	72.51	87.49
SH-6	29555.61	9167.49	92891.15	20427.61	62004.20	13.77	nd	17.19	71.70	109.24
SH-7	30350.09	10698.85	302550.50	22023.42	46243.71	14.56	nd	14.11	76.42	137.52
SH-8	31484.49	14240.71	2145762.0	46073.06	15123.36	15.43	363.09	2.49	63.47	239.50
SH-9	29505.86	9074.94	92368.55	28412.44	70598.76	12.83	nd	18.57	75.22	107.28
SH-10	30321.12	10412.13	214176.10	20023.52	22452.81	13.38	351.12	14.10	76.49	237.45
Max	31545.44	14240.71	2145762.0	46073.06	70598.76	14.99	501.77	18.74	83.29	631.36
Min	28587.24	9167.49	201051.60	11593.55	21451.81	12.63	19.78	2.49	63.47	77.09
Mean	30432.41	10929.21	391139.13	23148.14	38697.37	14.02	143.69	13.37	74.82	200.59
Percentage (%)	6.15	2.21	79.05	4.68	7.82	0.0028	0.03	0.0027	0.015	0.04
TRV	14000	-	-	-	2	8.2	16	50	81	110

**nd= Not detected*
**TRV=Toxicity Reference Value guided by USEPA*

Table 2. Comparison of heavy metal concentrations of the Shitalakhya River sediment with other rivers of Bangladesh

Rivers	Al	K	Ca	Mg	Fe	As	Cu	Co	Cr	Zn	References
Shitalakhya	30432.41	10929.21	391139.13	23148.14	38697.37	14.02	143.69	13.37	74.82	200.59	Present study
Buriganga	-	-	-	-	-	34.90	49.80	8.90	101.2	50.70	Majumder *et al.*(2015)
Turag	-	-	-	-	-	-	50.40	-	43.02	139.48	Banu *et al.* (2013)
Bangshi	-	-	-	-	-	1.93	31	-	98.10	117.15	Rahman *et al.* (2014)
Meghna	-	-	-	-	1281.42	-	-	-	31.739	79.021	Hassan *et al.* (2015)
Korotoa	-	-	-	-	-	25	76	-	109	-	Islam *et al.* (2015)

Pearson's correlation coefficient matrix among the selected heavy metals of Shitalakhya River bed sediments is presented in Table 3. It shows significant correlations between the contaminates of Al with K (r=0.53), Ca (r=0.35), and As (0.89); K shows correlation with Ca (r=0.79), Mg (r=0.39), and As (0.63); Ca shows correlation with Mg (r=0.84), As (r=0.51), and Cu (0.30); Mg shows correlation with Cu (r=0.61) and Zn (r=0.39); Fe shows correlation with Co (r=0.81); Cu shows correlation with Cr (r=0.34) and Zn (r=0.85); Co shows correlation with Cr (r=0.59); and Cr shows strong correlation with Zn (r=0.43), which indicate the same or similar source input.

Assessment of Heavy Metal Contamination

Assessment According to USEPA

According to the United States Environmental Protection Agency (USEPA, 1998), the chemical contaminations in the river sediments were evaluated by comparison with the sediment Toxicity Reference Value (TRV), as shown in Figure 2. It is a toxicological index generally used for evaluating risks to receptors that have direct contact with the contaminated medium. The study shows that all the sites are polluted by Al, Fe, and As which exceeds the TRV value (Fig. 2a, 2b, and 2c). In study area, Cu is detected in five locations and all the values exceed the TRV values (Fig. 2d). Co is found in acceptable limit among all the sites (Fig. 2e). For Cr, except in SH-3, all the sites value is below TRV (Fig. 2f), but, for Zn, only three samples are within the TRV of Zn (Fig. 2g).

Geo-accumulation Index (I_{geo})

A common criterion to evaluate the heavy metal contamination in sediments is the geo-accumulation index. Geo-accumulation index, proposed by Muller (1979), is used to determine metals contamination in sediments, by comparing current concentrations with pre-industrial period using the following formula:

$$I_{geo} = \log_2 [C_n / 1.5B_n] \quad (1)$$

where C_n is the measured concentration of the element 'n' and B_n is the geochemical background value. In this study, B_n = world surface rock average given by Martin and Meybeck (1979). The factor 1.5 is incorporated in the relationship to account for possible variation in background data due to lithogenic effect. The geo-accumulation index (I_{geo}) scale developed by Pekey (2006) is used to evaluate the contaminant level as shown in Table 4.

Table 3. Correlation matrix between heavy metals in riverbed sediment from Shitalakhya River

	Al	K	Ca	Mg	Fe	As	Cu	Co	Cr	Zn
Al	1									
K	0.53	1								
Ca	0.35	0.79	1							
Mg	0.01	0.39	0.84	1						
Fe	-0.82	-0.68	-0.43	0.007	1					
As	0.89	0.63	0.51	0.12	-0.72	1				
Cu	-0.11	-0.20	0.30	0.61	0.22	-0.14	1			
Co	-0.81	-0.85	-0.67	-0.22	0.81	-0.87	0.30	1		
Cr	-0.12	-0.56	-0.71	-0.52	0.24	-0.36	0.34	0.59	1	
Zn	-0.004	0.02	0.16	0.39	0.04	-0.16	0.85	0.26	0.43	1

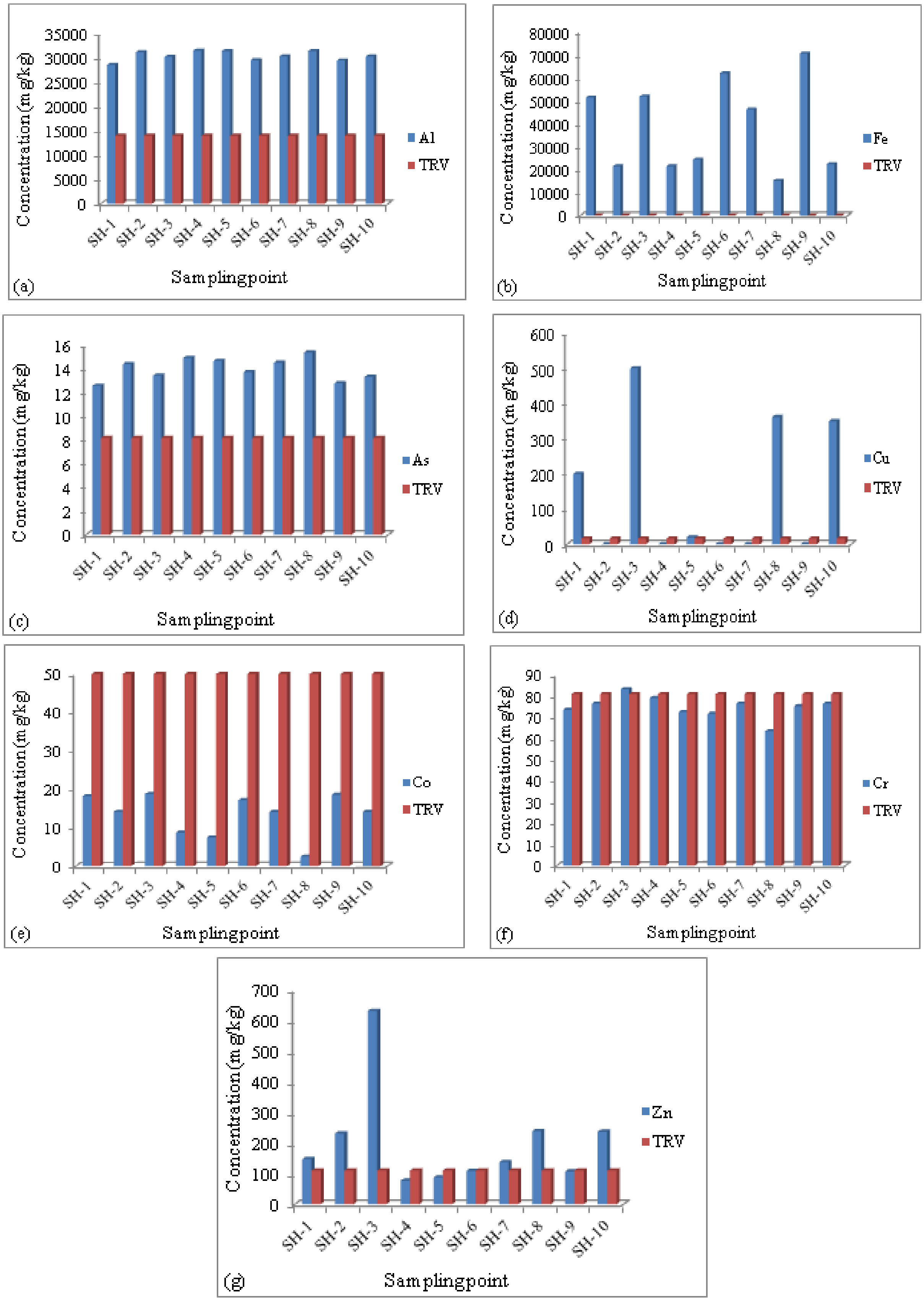

Fig. 2 (a-g). Comparison of toxic metal concentration (mg/kg) of Shitalakhya River sediment with TRV

Table 4. Pekey (2006) classification for the geo-accumulation (I_{geo}) index

Indices	Unpolluted	Low polluted	Moderately polluted	Strongly polluted	Extremely polluted
I_{geo}	<0.42	0.42–1.42	1.42–3.42	3.42–4.42	>4.42

Table 5. Geo-accumulation index (I_{geo}) of Shitalakhya River at different sampling points

Sample ID	Al	K	Ca	Mg	Fe	As	Cu	Co	Cr	Zn
SH-1	-2.07	-1.81	3.09	-0.14	-0.47	-0.63	1.58	-0.65	-0.88	0.05
SH-2	-1.94	-1.98	2.61	-0.04	-1.73	-0.44	-	-1.009	-0.83	0.69
SH-3	-1.99	-1.92	3.15	0.33	-0.45	-0.54	2.89	-0.61	-0.6	2.15
SH-4	-1.92	-1.81	2.61	-0.96	-1.73	-0.38	-	-1.71	-0.78	-0.89
SH-5	-1.93	-1.72	1.38	-0.88	-1.54	-0.41	-1.78	-1.94	-0.89	-0.71
SH-6	-2.02	-2.13	1.49	-0.14	-0.20	-0.51	-	-0.73	-0.92	-0.39
SH-7	-1.98	-1.89	3.19	-0.04	-0.62	-0.43	-	-1.02	-0.82	-0.05
SH-8	-1.94	-1.49	6.02	1.04	-2.23	-0.34	2.43	-3.52	-1.08	0.75
SH-9	-2.02	-2.14	1.48	0.34	-0.004	-0.61	-	-0.62	-0.85	-0.41
SH-10	-1.99	-1.94	2.70	-0.17	-1.66	-0.49	2.38	-1.02	-0.82	0.74

The geo-accumulation index (I_{geo}) of Shitalakhya River sediments at different sampling points is given in Table 5. The I_{geo} values of Shitalakhya River indicates that the sampling points SH-5 is low polluted; SH-1, SH-2, SH-3, SH-4, SH-6, SH-7, SH-9, and SH-10 are moderately polluted and SH-8 is extremely polluted by calcium (Ca). Three sampling points of SH-3, SH-8, and SH-9 of study area are slightly polluted by magnesium (Mg). Sampling points of SH-1, SH-3, SH-8, and SH-10 are moderately contaminated by cupper (Cu). Zinc (Zn) is another pollutant in study area, found in five sampling areas of SH-1, SH-2, SH-3, SH-8, and SH-10. Among them, sampling point SH-3 is moderately polluted and the rest of them are slightly polluted by Zn according to Pekey (2006) classification of geo-accumulation index.

All the sampling points were polluted by Ca and Ca, Mg, Cu, and Zn are the main threats in study area for sediment contamination. Overall, sampling point SH-1 is contaminated by Ca, Cu, and Zn, and uncontaminated by all other analyzed parameters of Al, K, Mg, Fe, As, Co, and Cr. Similarly, sampling points of SH-3 and SH-8 were contaminated by Ca, Mg, Cu, and Zn and SH-10 is contaminated by Ca, Cu, and Zn.

Contamination Factor (C_f) of the Toxic Metals in Shitalakhya River

The contamination factor (C_f) is used to determine the contamination status of the sediment in study area, which was calculated according to Thomilson e*t al.* (1980) by the following;

$$C_f = \frac{C_{metal}}{C_{background}} \tag{2}$$

where C_{metal} is the measured concentration of a specific metal and $C_{background}$ is the background value of the metal. In this study, world surface rock average proposed by Martin and Meybeck (1979) is considered as background concentration. The contamination levels were classified based on their intensities on a scale ranging from 1 to 6 as shown in Table 6. The highest number indicates that the metal concentration is 100 times greater than what would be expected in the crust. The range of contamination factor of toxic metals at different sampling points of Shitalakhya River is given in Table 7.

Table 6. Contamination factor and level of contamination (Hakanson, 1980)

C_f value	Contamination Factor level
$C_f < 1$	Low contamination factor indicating low contamination
$1 \leq C_f < 3$	Moderate contamination
$3 \leq C_f < 6$	Considerable contamination
$6 \leq C_f$	Very high contamination

Table 7. Contamination factor (C_f) of the sampling areas of Shitalakhya River

Sample ID	Contamination Factor									
	Al	K	Ca	Mg	Fe	As	Cu	Co	Cr	Zn
SH-1	0.36	0.43	12.79	1.37	1.089	0.98	4.47	0.96	0.82	1.56
SH-2	0.39	0.39	9.09	1.47	0.46	1.12	0	0.75	0.85	2.44
SH-3	0.38	0.4	13.25	1.88	1.09	1.04	11.16	0.99	0.93	6.65
SH-4	0.4	0.44	9.09	0.78	0.46	1.16	0	0.46	0.88	0.82
SH-5	0.39	0.46	3.9	0.82	0.52	1.14	0.44	0.39	0.81	0.93
SH-6	0.37	0.35	4.21	1.37	1.32	1.06	0	0.91	0.79	1.15
SH-7	0.38	0.41	13.7	1.47	0.98	1.12	0	0.75	0.85	1.45
SH-8	0.39	0.54	97.09	3.07	0.33	1.19	8.07	0.14	0.71	2.53
SH-9	0.37	0.35	4.18	1.9	1.49	0.99	0	0.98	0.84	1.13
SH-10	0.38	0.39	9.7	1.34	0.48	1.03	7.81	0.75	0.85	2.5

In present study, contamination factor (C_f) values at different points shows that all the sampling sites were contaminated by Ca and Ca, Mg, Fe, As, Cu, and Zn are the major threats. Sampling point SH-1 is highly contaminated by Ca and moderately contaminated by Mg, Fe, and Zn. Cu value in this point is within considerable contamination level and the contamination level of Al, K, Co, and Cr is very low (Table 7). Similarly, sampling point SH-2 is highly contaminated by Ca and moderately contaminated by Mg, As, and Zn. Sampling point SH-3 is highly contaminated by Ca, Cu, and Zn and moderately contaminated by Mg, Fe, and As. In sample SH-4, high contamination is caused by Ca and moderate contamination by As. Considerable contamination is occurred by Ca and moderate contamination by As in sampling point SH-5. Moderate contamination is found in sampling point SH-6, but the major contaminants are Ca, Mg, Fe, As, and Zn. Sampling point SH-7 is highly contaminated by Ca and moderately contaminated by Mg, As, and Zn. Sampling point SH-8 is highly contaminated by Ca and Cu, considerably contaminated by Mg, and moderately contaminated by As and Zn. Sample SH-9 is considerably contaminated by Ca and moderately contaminated by Mg, Fe, and Zn. Finally, sampling point SH-10 is highly contaminated by Ca and Cu and moderately contaminated by Mg, As, and Zn. Besides, all the sampling points are contaminated by Al, K, Co, and Cr but in low concentration.

Degree of Contamination (C_d)

Degree of contamination (C_d) is also calculated to determine the contamination status of the sediment in the present study. It is defined as the sum of all contamination factors and is calculated according to the following equation:

$$C_d = \sum_{i=1}^{n} C_f^i \quad (3)$$

The value of C_d is classified according to their level of contamination where $C_d < 8$ = low degree of contamination, $8 \leq C_d < 16$ = moderate degree of contamination, $16 \leq C_d < 32$ = considerable degree of contamination, and $32 \leq C_d$ = very high degree of contamination. The calculated degrees of contamination (Cd) of Shitalakhya River at different sampling points with contamination level are presented in Table 8.

Table 8. Degree of contamination (C_d) and contamination level of Shitalakhya River

Sample ID	C_d	Contamination level
SH-1	24.8	Considerable degree of contamination
SH-2	16.94	Considerable degree of contamination
SH-3	37.75	Very high degree of contamination
SH-4	14.46	Moderate degree of contamination
SH-5	9.78	Moderate degree of contamination
SH-6	11.51	Moderate degree of contamination
SH-7	21.08	Considerable degree of contamination
SH-8	114.03	Very high degree of contamination
SH-9	12.21	Moderate degree of contamination
SH-10	25.19	Considerable degree of contamination

The degree of contamination of Shitalakhya River at different points reveals that sampling point SH-3 and SH-8 are at very high degree of contamination level; SH-1, SH-2, SH-7, and SH-10 are at considerable degree of contamination level and sampling points of SH-4, SH-5, SH-6, and SH-9 are at moderate degree of contamination level. The spatial distribution of the degree of contamination is shown in Figure 3. From these, it is evident that sampling areas of Shitalakhya River SH-3 and SH-8 is no longer suitable for the fish and other aquatic organisms or for using in any other purposes. But other points of Shitalakhya River still can be managed by controlling the source of pollution through proper treatment of waste or by preventing any further discharge of waste into the river.

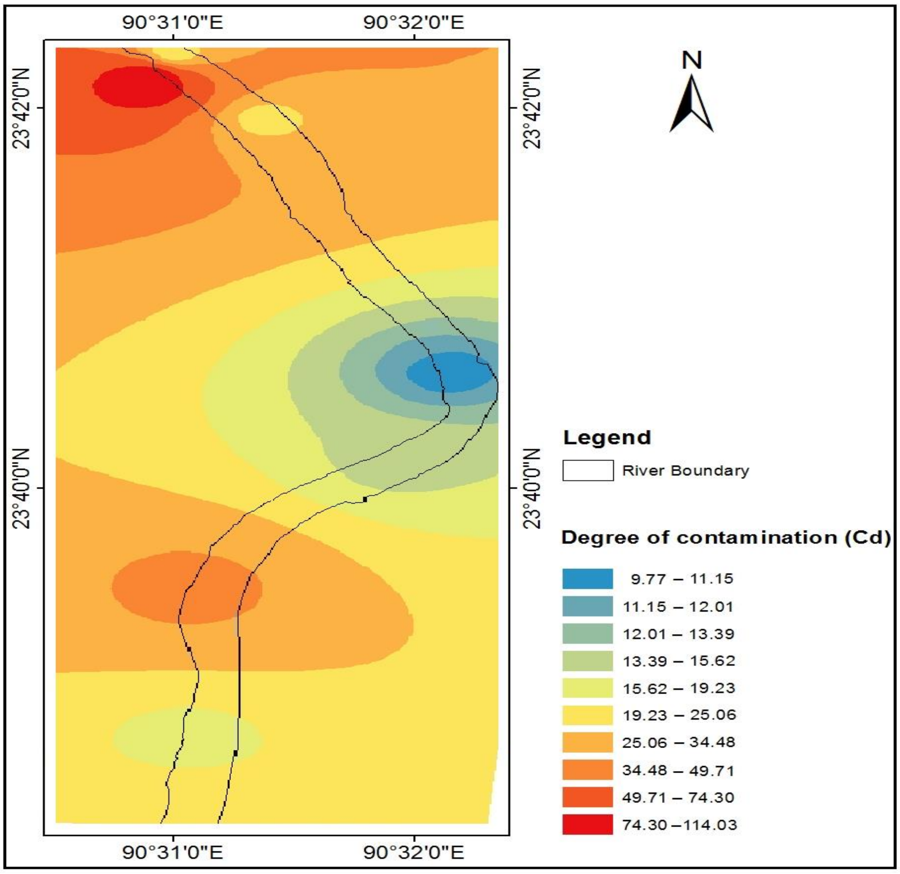

Fig. 3. Spatial distribution of the degree of contamination in study area

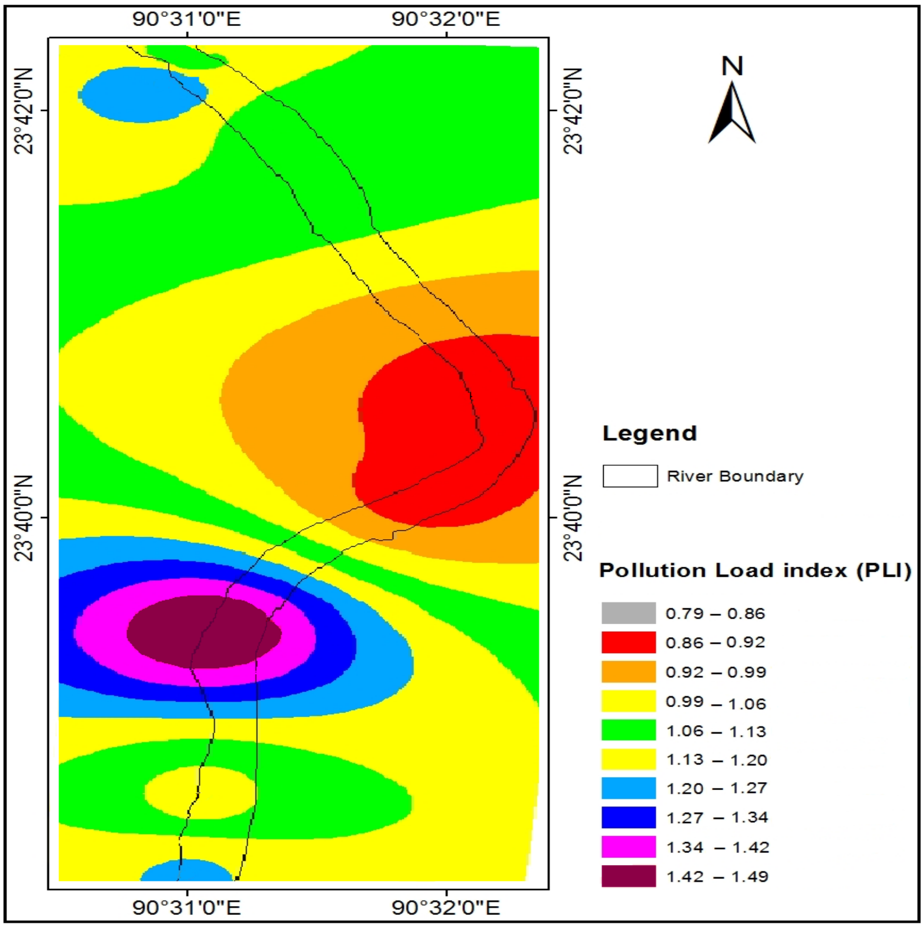

Fig. 4. Spatial distribution of the pollution load index (PLI) in study area

Pollution Load Index (PLI) of Shitalakhya River

PLI provides an understanding about the quantity of polluting component in the environment. This empirical index provides a simple, comparative means for assessing the level of heavy metal pollution. For the entire sampling site, PLI has been determined as the n^{th} root of the product of the n C_f (Usero *et al.*, 2000), using the following;

$$PLI = (C_{f1} \times C_{f2} \times C_{f3} \times ... C_{fn})^{1/n} \qquad (4)$$

The PLI value of >1 is polluted, whereas <1 indicates no pollution (Harikumar *et al.*, 2009).

Table 9. Pollution load index (PLI of Shitalakhya River bed sediments

Sample ID	PLI	Pollution status
SH-1	1.22	Polluted
SH-2	1.04	Polluted
SH-3	1.50	Polluted
SH-4	0.90	Unpolluted
SH-5	0.80	Unpolluted
SH-6	0.99	Unpolluted
SH-7	1.09	Polluted
SH-8	1.32	Polluted
SH-9	1.03	Polluted
SH-10	1.20	Polluted

The Pollution Load Index (PLI) of Shitalakhya River at different sampling points is presented in Table 9. It shows that all the sampling points, except SH-4, SH-5, and SH-6, are polluted and deteriorating progressively through different toxic heavy metals. The spatial distribution of the pollution load is presented in Figure 4 which indicates that the middle part of the study area is less polluted than northern and southern parts of the study area.

CONCLUSION

The elemental concentrations of the sediment samples were analyzed to assess the heavy metal loads in the Shitalakhya River of Bangladesh. The results revealed that sediments are considerably contaminated by Al, Fe, As, Cu, Co, Cr, and Zn, as the concentrations exceed the Toxicity Reference Value (TRV) proposed by the United States Environmental Protection Agency (USEPA). Ca, Mg, Cu, and Zn are found in significant amounts and the correlation between different metals indicates that these variables may be derived from the common origin, especially from industrial effluents and municipal waste. Geo-accumulation index, contamination factor, degree of contamination, and pollution load index were applied for the assessment of heavy metal contamination of Shitalakhya River sediments and found that most of the samples are moderately to strongly pollute. So, it is high time to protect this river from further pollution.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

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