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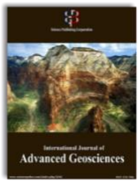

Assessment of pollution and sources of heavy metals in the sediments of the Shitalakhya river, Bangladesh

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Abstract

The Shitalakya River, located near Dhaka City of Bangladesh, supplies water to the city dwellers and hence it is essential to determine pollu-tion condition, ecological risk and sources of heavy metals in the river sediments. Sediment works as the sink and source of heavy metals in the riverine ecosystem. The samples collected from the ten sites of the Shitalakhya River were investigated in the study. Average concentra-tion of different heavy metals in the sediments are Cu>Zn>Ni>Pb>Cr>Cd. Geo-accumulation index reveals moderately pollute Cu concen-tration, unpolluted to moderately pollute Ni concentration and unpolluted for the rest of the heavy metals. The order of geo-accumulation index are Cu>Ni>Pb>Cd>Zn>Cr. Overall, the heavy metals render low potential ecological risk and the order of potential ecological risk index are Cd>Cu>Ni>Pb>Cr>Zn. Though the concentration of Cd is low in sediment, it poses higher ecological risk. Posi-tive matrix factor-ization (PMF) identifies two sources of pollution, S1 and S2. Where, S1 consists with Cu, Ni, Pb, Zn; which come from industrial wastewater. S2 consists with Cr, Cd, Pb, Zn; which originate from natural sources. The outcomes of the study provide as a reference to plan, control and manage heavy metal pollution and protect the water source of the Shitalakhya River.

Keywords: *Heavy Metal Concentration; Sediment; Ecological Risk; River Pollution; Positive Matrix Factorization.*

1. Introduction

Heavy metals accumulate in sediment of river and they act as the reservoirs to contain heavy metal for a long time. The toxic pollutants bearing heavy metals mix with upstream water, suffer the downstream inhabitants severely. Since, large numbers of agricultural, domestic and industrial activities utilize river waters, it is essential to study river sediment quality for public health safety (Li et al. 2013, Pejman et al. 2015, Huang et al., 2020). Moreover, heavy metals accumulated in sediment and water of river form a dynamic equilibrium and are closely related to each other (Saha et al. 2001). Heavy metal in sediment are non-degradable and easily accumulate in biota. As a result, heavy metal pollution in sediment pose ecological risk due to their severe toxicity to mix with food chain and biota. Sediments of river bed act as a sink to accumulate, receive, absorb pollutants, release pollutants into water due to disturbance and therefore, consider as an important indicator of water pollution. Heavy metals, such as, Pb, Cd, Cr, Cu, Ni and Zn can accumulate in fine grained sediment easily and subsequently, carried to the river downstream (Banerjee et al. 2016).

The Shitalakhya River supplies water to the City Corporation of Dhaka. This river flowing through the Dhaka, Narayanganj and Gazipur districts and receives huge amount of waste discharges from the industries located along the river bank. These untreated industrial waste is the major sources of heavy metals and sediment pollution. The water of Shitalakhya River is highly polluted and various water quality parameters, such as, turbidity, total dissolve solid, dissolve oxygen, biochemical oxygen demand are in poor status (Rahman 2011, Islam et al. 2015, Chowdhury et al. 2015). Moreover, the water of the river is so polluted that it is unsuitable for fishes (Rahman et al. 2020).

This study delved to characterize the concentration and spatial distribution of six heavy metals, i.e. Pb, Cr, Cu, Ni, Cd and Zn at ten different sites of Shitalakhya River; assess pollution status in terms of geo accumulation index (I_{geo}), potential ecological risk index (PERI) and determine the sources of heavy metal pollution using positive matrix factorization (PMF). The findings of the study reveal the geo-chemical characteristics of heavy metals and provide a guideline to control and remedy environmental pollution for the similar types of rivers.

2. Methodology

2.1. Study area and sampling

The Shitalakhya River flowing south through Gazipur and Narayanganj districts and finally meet Meghna River at Munshigang. The study area of the river is between 23˚43' to 23˚37 N latitudes and 90˚30' to 90˚32' E longitudes. The sediment samples were collected from ten sites (S1-S10) in the investigated area. The sample sites were-- Shah Cement (S-1), Premier Cement (S-2), Bandar (Narayanganj) (S-3), Adamjee EPZ (S-4), ATI (S-5), Kachpur Bridge (S-6), Sinha Textile (S-7), Demra Bridge (S-8), South Rupshi (S-9) and Kanchon Bridge

(S-10). The detail location of the sites are shown in Figure 1. The sediment samples were collected through Ekman grab sampler (Figure 2) from top 30 cm from riverbed on 18 January, 2019.

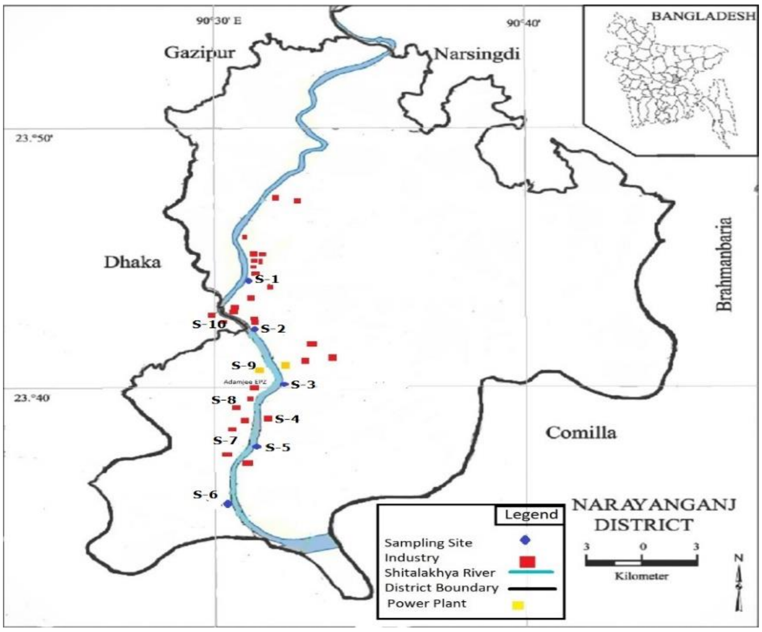

Fig. 1: Location of Sampling Sites Along the Shitalakhya River Shown in Map.

(A) (B)

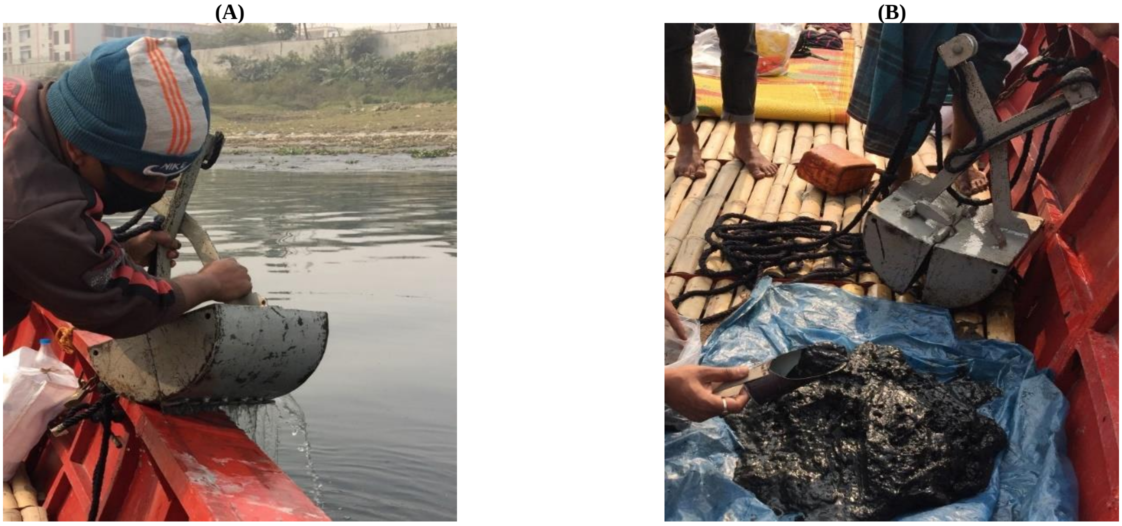

Fig. 2: Photographs of Field Sampling (A) Ekman Grab Sampler and (C) Fresh Sediments Collected by the Sampler.

2.2. Sample digestion and analysis

The collected samples were processed for digestion before analyzing using Atomic Absorption Spectrophotometry (AAS). The samples were placed in acid washed container and over dry at 105˚C for 24 hr. Then the sediment were separated by large sieve in order to remove stone and pebbles. The sediments were crushed by acid washed pestle and separated by No. 50 sieve. Then 5gm of sieved sediment were collect and transferred to an acid-washed volumetric flask and added 100ml of distilled water. After that, 7.5ml concentrated hydrochloric acid and 2.5ml concentrated nitric acid were mixed into the volumetric flask and the flask covered with a watch glass. The sample then heated at 200˚C for 1hr. After the samples had cooled to room temperature; those were stirred for 5 minutes and filtered (0.45 µm) by a glass funnel containing Whatttman No.1 filter paper. The reaction vessels and watch glasses were rinsed with distilled water thoroughly. The filtrate was reserved in a glass bottle for the analysis of metals. Then AAS were calibration by 0.2, 0.5, 2, 5 PPM stock solutions. After that, the analysis were performed by AAS attached with a graphite furnace to determination of metal concentrations within the samples. Atomic Absorption Spectrophotometry (model: Shimadzu, AA-7000) at the Environmental Engineering Laboratory of Dhaka university of Engineering and Technology was used to measure the heavy metal concentration in the sediment samples.

2.3. Pollution assessment of sediment

2.3.1. Geo-accumulation index

Geo-accumulation index (I_{geo}), formulated by Muller (1979) illustrates the enrichment of heavy metals in the sediment. It is calculated as follows:

$$I_{geo} = \log_2\left(\frac{C_s}{1.5 \times C_b}\right) \quad (1)$$

Where, C_s = concentration of heavy metal in sediment sample (mg/kg), C_b = geochemical background concentration of heavy metal (mg/kg). 1.5 is correction factor. In this study, we have used Toxic rating value (TRV) as background concentration (USEPA 1999). I_{geo} classified the sediment pollution into following categories: Class 0 stands for unpolluted ($I_{geo} \leq 0$), Class 1 stands for unpolluted to moderately polluted ($0 < I_{geo} \leq 1$), Class 2 stands for moderately polluted ($1 < I_{geo} \leq 2$), Class 3 stands for moderate to heavily polluted ($2 < I_{geo} \leq 3$), Class 4 stands for heavily polluted ($3 < I_{geo} \leq 4$), Class 5 stands for heavy to extremely polluted ($4 < I_{geo} \leq 5$) and Class 6 stands for extremely polluted ($I_{geo} > 5$).

2.3.2. Pollution ecological risk index

The pollution ecological risk index (PERI), introduced by Hakanson (1980) quantifies the ecological risk of heavy metals in sediment. The PERI is expressed as:

$$E^i_r = T^i_r \times \frac{C_s}{C_b} \quad (2a)$$

$$PERI = \sum E^i_r \quad (2b)$$

Where, E^i_r = potential ecological risk factor, T^i_r = toxic response factor. T^i_r value for Pb, Cr, Cu, Ni, Cd and Zn are 5, 2, 5, 5, 30 and 1 respectively. $E^i_r < 40$ represents low, $40 \leq E^i_r < 80$ represents moderate, $80 \leq E^i_r < 160$ represents considerable, $160 \leq E^i_r < 320$ represents high and $E^i_r > 320$ represents very high. PERI < 150 represents low, 150≤ PERI <300 represents moderate, 300 ≤ PERI <600 represents considerable and PERI ≥ 600 represents high.

2.3.3. Positive matrix factorization

The positive matrix factorization is a receptor modeling technique to determine the sources of heavy metals in sediments. We have used EPA PMF v. 5.0 software (USEPA 2014) developed by USEPA for source apportionment in the study.

3. Results and discussion

3.1. Spatial distribution of heavy metals

In this study, the acceptable heavy metal concentration in sediments were considered as per Toxicity reference value (TRV) and USEPA sediment standards (USEPA 1999). The Pb concentration in sediment sample was high at S-1 (Shah Cement) site exceeded USEPA sediment standards and slightly high at S-5 (ATI) site, exceeding TRV. Cr concentration in samples were within 4.14-17.64 mg/kg, which were far below pollution limit and safe. Cu concentrations were high in most of the sites and maximum (130.02 mg/kg) at S-4 (Adamjee EPZ). Ni concentration in sediment were high at S-9 (Kachpur Bridge), S-4 (Adamjee EPZ) sites and USEPA and TRV recommended values. Cd concentration in sediments were ranges from 0.18-0.59 mg/kg. Zn concentration were almost uniform in all sites ranging 48.71-53.30 mg/kg. The descending order of average heavy metal concentration was Cu>Zn>Ni>Pb>Cr>Cd. Cu concentration was maximum in the sediment samples.

Table 1: Concentration of Heavy Metal (Mg/Kg) in Sediment Samples of Various Locations in the Shitalakhya River

Site	Pb	Cr	Cu	Ni	Cd	Zn
S-1	40.24	8.42	48.50	29.21	0.41	50.65
S-2	19.74	13.78	20.73	18.33	0.56	48.95
S-3	24.24	10.84	25.43	23.10	0.59	48.71
S-4	19.44	17.64	130.02	35.50	0.39	52.55
S-5	31.42	11.38	46.22	26.81	0.43	51.09
S-6	28.42	8.52	63.04	32.64	0.23	52.91
S-7	21.30	7.62	42.80	27.54	0.46	50.70
S-8	20.02	4.14	70.70	31.28	0.18	53.30
S-9	20.24	11.34	49.22	36.90	0.50	51.74
S-10	21.56	7.78	47.77	29.61	0.50	50.37
Average	24.66	10.15	54.44	29.09	0.43	51.10
Range	19.44-40.24	4.14-17.64	20.73-130.02	18.33-36.90	0.18-0.59	48.71-53.30
TRV	31.00	26.00	16.00	16.00	0.60	110.00
USEPA	35.80	43.40	31.60	22.70	0.99	121.00

(A) **(B)**

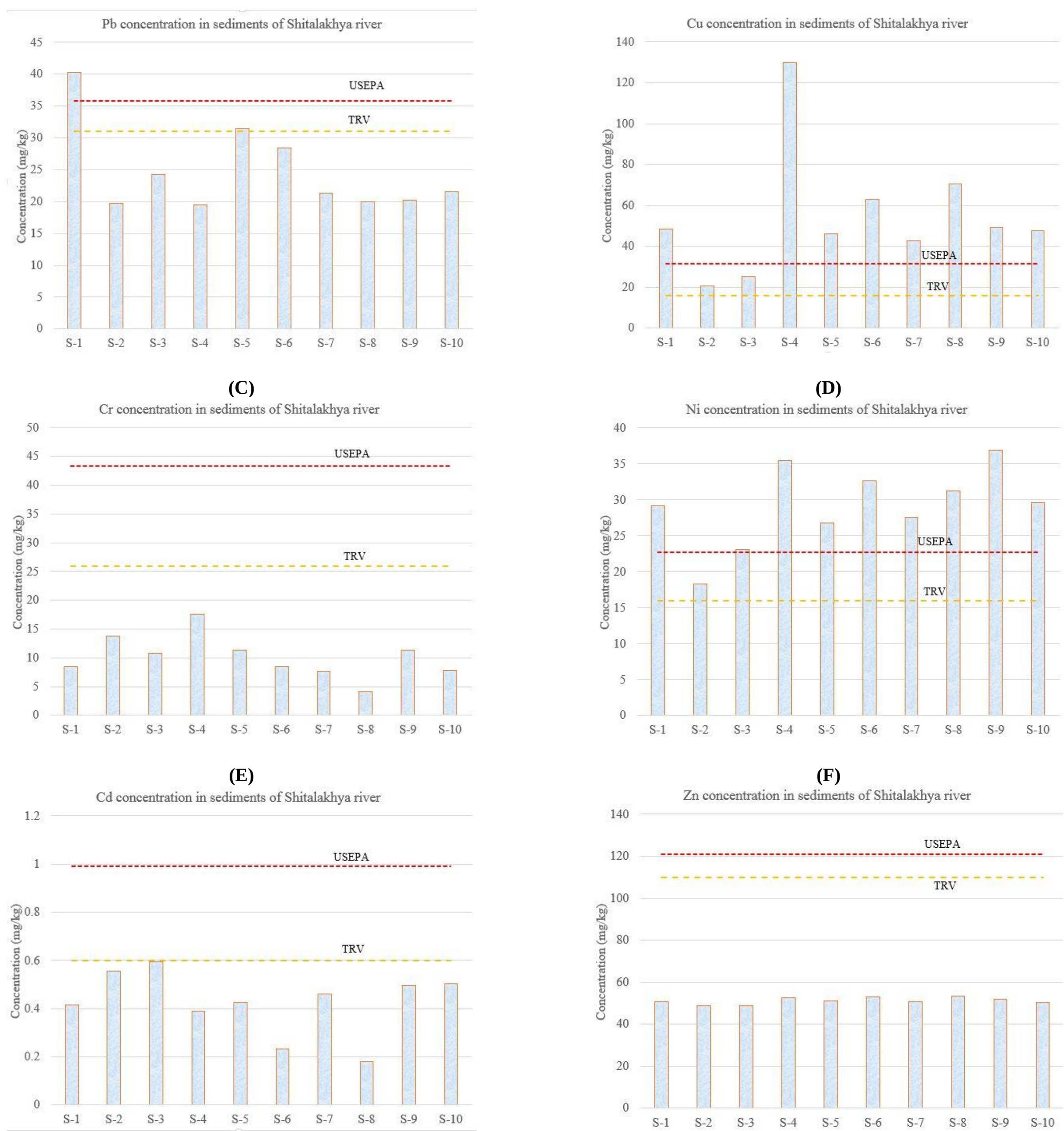

Fig. 3: Spatial Distribution of Heavy Metal (A) Pb, (B) Cu, (C) Cr, (D) Ni, (E) Cd and (F) Zn in Sediments at Different Sites of Shitalakhya River.

3.2. Assessment of geo-accumulation index

Considering average I_{geo}, Cu concentration was moderately polluted and Ni concentration was unpolluted to moderately pollute in the sediment samples. S-4 (Adamjee EPZ) site had heavy polluted Cu concentration. Overall, most of the sediments in the sites were unpolluted for heavy metal pollution. The order of I_{geo} values were Cu>Ni>Pb>Cd>Zn>Cr. Cu and Ni concentration were most severe compare to other heavy metals.

Table 2: I_{geo} Values Calculated for Different Sites of Shitalakhya River

Site	Pb	Cr	Cu	Ni	Cd	Zn
S-1	-0.21	-2.21	1.01**	0.28*	-1.12	-1.70
S-2	-1.24	-1.50	-0.21	-0.39	-0.69	-1.75
S-3	-0.94	-1.85	0.08*	-0.06	-0.60	-1.76
S-4	-1.26	-1.14	2.44***	0.56*	-1.21	-1.65
S-5	-0.57	-1.78	0.95*	0.16*	-1.08	-1.69
S-6	-0.71	-2.19	1.39**	0.44*	-1.96	-1.64
S-7	-1.13	-2.36	0.83*	0.20*	-0.96	-1.70
S-8	-1.22	-3.24	1.56**	0.38*	-2.32	-1.63
S-9	-1.20	-1.78	1.04**	0.62*	-0.86	-1.67
S-10	-1.11	-2.33	0.99*	0.30*	-0.84	-1.71
Average	-0.96	-2.04	1.01**	0.25*	-1.16	-1.69

NB: *** represents moderate to heavily polluted, ** represents moderately polluted and *represents unpolluted to moderately polluted.

3.3. Assessment of PERI

Potential ecological risk index (PERI) value< 150 for all sites, hence the risk was low. In addition, level of single metal pollution risk factor (E^i_r) <40 for all heavy metals in the sediment samples, hence the risk factor is low also. The descending order of PERI values were Cd>Cu>Ni>Pb>Cr>Zn. Although, concentration of Cd was low, it posed more ecological threat compare to other heavy metals in the sediments.

Table 3: PERI Value and Pollution Risk Factor (E^i_r) Value for Different Sites of Shitalakhya River

Sites	Pb	Cr	Cu	Ni	Cd	Zn	PERI
S-1	6.5	0.6	9.1	9.1	20.7	0.5	46.5
S-2	3.2	1.1	3.9	5.7	27.8	0.4	42.1
S-3	3.9	0.8	4.8	7.2	29.7	0.4	46.9
S-4	3.1	1.4	24.4	11.1	19.4	0.5	59.8
S-5	5.1	0.9	8.7	8.4	21.3	0.5	44.8
S-6	4.6	0.7	11.8	10.2	11.6	0.5	39.3
S-7	3.4	0.6	8.0	8.6	23.1	0.5	44.2
S-8	3.2	0.3	13.3	9.8	9.0	0.5	36.1
S-9	3.3	0.9	9.2	11.5	24.8	0.5	50.2
S-10	3.5	0.6	9.0	9.3	25.2	0.5	47.9
Average	4.0	0.8	10.2	9.1	21.3	0.5	45.8

3.4. Identifying sources of heavy metals

Positive matrix factorization (PMF) determines two sources of heavy metal in sediment of Shitalakhya River. The S-1 source comprised with Cu, Ni, Pb, Zn and the S-2 source comprised with Cr, Cd, Pb and Zn (Figure 4). S-1 originated from industrial waste and S-2 came from natural sources. Pb and Zn contributed to both sources almost equally (Figure 5).

Table 4: Factor Profiles of Heavy Metal Concentration Obtained from PMF

Heavy metals	Factor Profiles (conc. of species)		Factor Profiles (% of species sum)		Factor Profiles (% of factor total)	
	S-1	S-2	S-1	S-2	S-1	S-2
Pb	10.18	12.58	44.72	55.28	10.45	19.36
Cr	2.51	6.75	27.09	72.91	2.57	10.38
Cu	41.37	9.05	82.05	17.95	42.45	13.92
Ni	18.02	10.72	62.71	37.29	18.49	16.48
Cd	0.08	0.33	19.77	80.23	0.08	0.51
Zn	25.29	25.59	49.71	50.29	25.95	39.35

82.05% of total Cu concentration and 62.71% of total Ni concentration originated from industrial waste (S-1). 72.91% of total Cr concentration and 80.23% of total Cd concentration originated from natural sources (S-2).

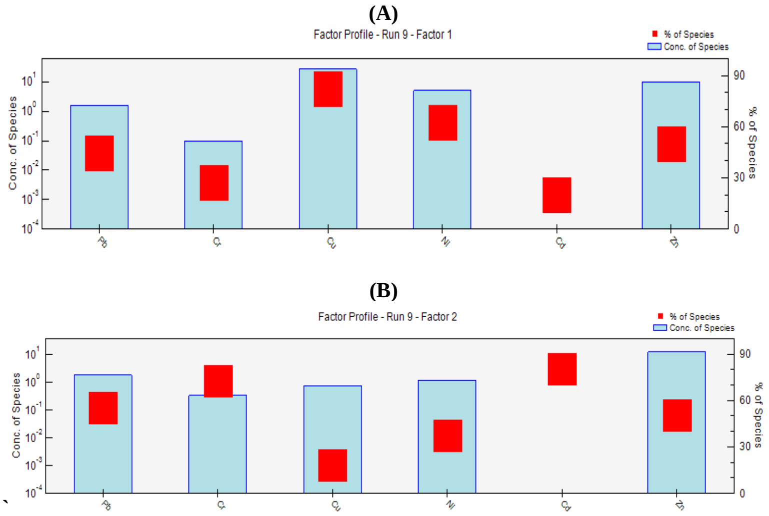

Fig. 4: Factor Profile of (A) S-1 and (B) S-2 Sources in the Sediments of Shitalakhya River.

Industrial waste (S-1) consisted with 42.45% Cu concentration and natural source (S-2) consisted with 39.35% Zn.

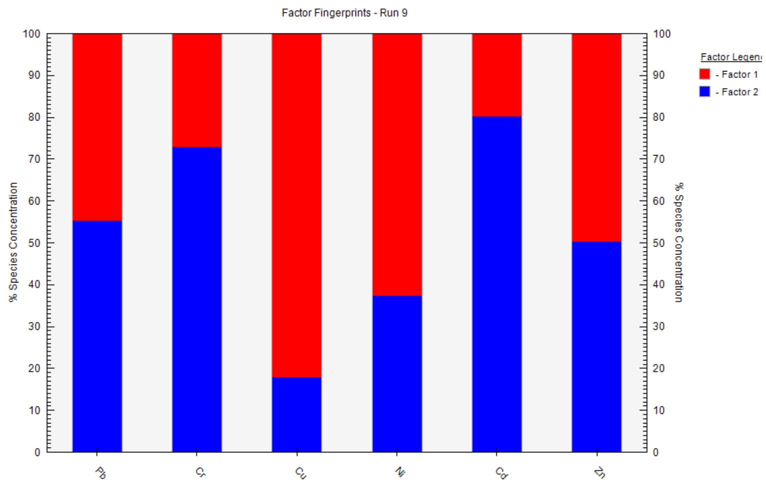

Fig. 5: Factor Figure-Prints of S-1 And S-2 Sources of the Sediments of Shitalakhya River.

4. Conclusion

Heavy metal pollution in river sediment have severe environmental impact on riverine ecosystem. The study investigates six heavy metals in the sediment of Shitalakhya River, Bangladesh. The heavy metal concentration measured at the sampling sites pose low ecological threat to human health. However, some locations such as, S-4 (Adamjee EPZ) had moderate to heavily polluted concentration, which require special attention. Overall, Cu concentration was found moderately polluted and Ni concentration was found unpolluted to moderate polluted. The average concentration of heavy metals in the descending order of Cu>Zn>Ni>Pb>Cr>Cd. Cd concentration was very small in quantity, however it had most ecological risk potential. Careful monitoring and remedial plan need to be develop to keep heavy metal concentration within USEPA sediment standards and toxicity reference index.

The study can be extended for the ecological risk assessment of heavy metal in sediments for the river with similar geomorphological features and surroundings. Influence of various physical and chemical factors, such as, pH, turbidity, temperature, concentration of solute, composition, water chemistry on the heavy metal decomposition in the sediment can be investigated. Besides, effects of organic matter content and grain size distribution on heavy metal concentration can also be studied. The proposed source identification technique PMF can be implemented for other rivers as well.

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