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Deciphering the source of heavy metals in industrially affected river sediment of Shitalakshya river, Bangladesh, and potential ecological and health implications

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ABSTRACT

Heavy metals (HMs) in sediment samples (Dry and Rainy seasons) of industrially affected rivers were quantified by Energy Disperse X-ray Fluorescence in the Shitalakshya river of Bangladesh. This study assesses the potential health concerns provided by various HMs manganese (Mn), zinc (Zn), copper (Cu), arsenic (As), lead (Pb), cadmium (Cd), nickel (Ni), and chromium (Cr). Mean concentration of HMs ranked as Mn > Zn > Cu > Cr > Ni > Pb > As > Cd for both seasons, where almost all the elements were found within the standard limit, except for Cd and As. In the dry season, the concentrations of all HMs were slightly higher than in the rainy season, which can be attributed to the fact that pollutants in rivers may be diluted by rainwater, thus lowering the value. Enrichment factor, geo-accumulation index, contamination factor, and pollution load index indicated a high level of contamination by HMs and moderate levels of ecological risk. The hazard index was < 1 for adults and children in both seasons, revealing no possible non-carcinogenic health risk. Hazard Quotient for individual exposure path can be ranked as ingestion > dermal > inhalation for both seasons, regardless of age group. Carcinogenic risk via the entire three exposure path was ascertained safe for adults and children except for ingestion in children for both seasons. However, total carcinogenic risk value indicated low to medium risk for children in both seasons, while it is within a safe limit for adults. Multivariate statistical analysis indicated possible sources were anthropogenic primarily due to untreated wastes discharge from metal and waste dumping sites, oil and refinery industries, and glass and ceramic industries close to the sampling sites of the Shitalakshya river.

1. Introduction

Heavy metals (HMs) pollution of rivers and other water bodies has become a prime concern worldwide, which is more acute in a river-oriented country like Bangladesh (Rakib et al., 2022c). Basically, rivers and other water bodies are the natural resources that people have exploited the most. Basic and dispersive sources from natural and anthropogenic activities are responsible for introducing various contaminants into the water bodies (,). However, industries are considered the prime polluters because a huge amount of untreated wastes, both solid and liquid, are discharged throughout the production cycle in the water bodies; in a sense, the aquatic ecosystem becomes the ultimate recipient of almost all kinds of waste, including HMs (Proshad et al., 2021; Rakib et al., 2021a). Due to the non-degradable character, the accumulation of HMs in water bodies causes serious water and sediment pollution. Moreover, HMs are carcinogenic, teratogenic, and mutagenic; thus, they pose se-

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rious human health implications (Sharma et al., 2021). Depending on the types of pollutants, it can be extremely hazardous to flora and fauna in the riverine system, which by virtue of their nature, can easily contaminate the environment and affect human health for a long time. HM-contaminated sediments can be threatened human health via direct and indirect pathways. Fish usually uptake HMs from sediment rather than water. Moreover, seafood, including seaweed nowadays, are trendy food items worldwide, which uptake HMs from sediments; thus, there raised the probability of introducing HMs in those objects and hence HMs can penetrate in the food web and affect the human body. Besides, river water is usually used for cooking, bathing, washing, and other recreational purposes; thus, the user can come in contact with the HM contaminated sediments near the water sources, which can directly affect human health (Rakib et al., 2022c; Jolly et al., 2022a). However, the intensity of the negative impact of the HMs is relative to the toxicity, persistency, complex degradation capability, bio-accumulation capacity by organisms, and bio-magnification mechanism through the food chain (Zheng et al., 2013; Zahra et al., 2014; Wei et al., 2016; Huang et al., 2020; Jolly et al., 2022b).

HMs usually originate from artificial or natural sources: weathering, erosion, forest fires, and volcanic eruptions are the major natural contributory sources, while mining and smelting, domestic discharges, industrial effluents, Metallo–pesticides, combustion of fossil fuel, agricultural runoff are the principal anthropogenic sources (Islam et al., 2021; Malik et al., 2010; Reza et al., 2010; Martin et al., 2015; Gautam et al., 2016; Mirza et al., 2019; Rahman et al., 2021; Jolly et al., 2022). Once HMs and MPs enter a river system, they can be dispersed between the aqueous phase and bed sediments by leaching, diffusion, and infiltration and accumulate in sediment and biota (Rakib et al., 2022b, 2022c). However, sediments are the home of many habitats; thus, increasing the level of HMs makes their life vulnerable. Ahmad et al. (2020) reported that invertebrates, fishes, and humans are vulnerable to HMs above certain concentrations. HMs can alter morphologic and physiologic parameters in invertebrates (Martinez et al., 2002), and are responsible for mortality, and hatching delay in fishes (Sfakianakis et al., 2015), cause lung cancer, bone fracture, nerve tissue damage, skin cancer, liver and kidney failure, etc., in human (Sarker et al., 2022; Rahman et al., 2019b).

The Shitalakshya river flows east of the Narayanganj district of Bangladesh, which originated from one of the distributaries of the old Brahmaputra River and falls into the Dhaleshwari river near Kalagachhiya, in Barguna district, Barishal division, Bangladesh (Abdul, 2016). The river has historical and economic importance. Sonargaon, once the capital of the region, stood on the bank of the river. Several historical mosques and Sonargaon fort are also there, where a huge number of visitors visit every day. However, a port in Narayangonge connects Dhaka city to other parts of the country. Wide varieties of industries and thermal power plants are located along the river, which definitely contributes to the economy, but alongside, the industrial effluent dumped into the river resulting a high level of pollution (Khan et al., 2021). The excessive pollution caused by the disposal of various wastes into the river has made the river's future uncertain, and thus an urgent need for research on the potential HMs has been raised. Moreover, rivers are interlinked, and HMs are ubiquitous; thus, river sediment pollution by HMs is not a regional problem but a global one. Sediment is considered an adsorptive sink for metals; thus, measuring HMs concentration in sediment may give ideas about the environmental and geochemical pollution status (Uluturhan et al., 2011; El-Said et al., 2014).

Many researchers studied the HMs pollution level of coastal and terrestrial sediment and assessed ecological risk, but health risk (carcinogenic and non-carcinogenic) due to exposure to HM-contaminated sediment is very scant (Varol, 2011; Li et al., 2013; Jolly et al., 2018; Rakib et al., 2021b). Thus the study was sketched to i) determine the concentration of HMs (Cu, Pb, Cr, Zn, Ni, Cd, Mn, and As) in the surface sediment collected from industrially affected river Shitalakshya, ii) calculate the Enrichment factor (EF), Geo-accumulation index (I_{geo}), Contamination factor (CF), and Pollution Load Index (PLI) to measure pollution degree, iii) apportionment of possible source in this terrestrial ecosystem, applying multivariate statistical analysis, and iv) evaluate health risk posed by HM-contaminated sediment of Shitalakshya river.

2. Materials and method

2.1. Sample collection and preparation

A total of ten (10) surface sediment samples (namely S-1, S-2, S-3, S-4, S-5, S-6, S-7, S-8, S-9, and S-10) were collected in two different seasons; March (Dry season) and October (Rainy season) from 10 preferred sampling point (0 to 10 cm depth) of Shitalakshya river, near Narayanganj area, Bangladesh (Fig. 1). From each point (apart from each other by around half km), around 2 gm of sediment samples were collected in triplicates following standard method (APHA, 2005), kept in fresh zipper poly bag separately and tagged with sample location name and date of collection. Sampling was started from Sultana Kamal Bridge Demra (23° 43′ 18.462″ N-Latitude and 90° 30′ 2.1348″ E-Longitude) and ended at Kanchpur Landing Station (23° 42′ 3.96″ N° N-Latitude and 23° 42′ 3.96″ NE-Longitude) (Fig. 1). Notably, sampling location was chosen preferring the area should be a representative one of the polluted area by all sorts of HMs.

2.2. Preparation of sample for elemental analysis by EDXRF

Visible roots and plant fragments were manually removed from the sediment samples and discarded. Small portions of each sample were placed in a cleaned and acid-treated porcelain dish, dried at 60 °C for 48 h in an oven till constant weight, grounded initially in a ball mill, and finally with a mortar-pestle (carbide) to get fine particles of homogeneous mixture for the formation of pellets using the hydraulic press pellet maker machine (Specac, UK) applying 10-ton pressure (Hossain et al., 2021; Tamim et al., 2016; Rakib et al., 2021a). To avoid contamination, the grinder and pellet maker machine was cleaned properly before the next sample was prepared.

2.3. Sample irradiation and method validation

Sediment samples were analyzed for HMs concentration using a nuclear analytical technique called Energy Dispersive X-ray Fluorescence Spectroscopy (EDXRF) (Epsilon 5, Panalytical, the Netherlands). A Gadolium radioactive source, which excites the sample causes the atoms of the samples to absorb the radiation and emit radiations of a specific frequency corresponding to the character of the elements present in the sample (Jolly et al., 2013). As such, comparing the obtained spectral lines or frequency to the reference values of various HMs gives the constituent elements present in the sample (Gilfrich, 1994). However, for the validation of the method, quality assurance and quality control tests were performed using the standard reference material (Marine Sediment IAEA 433). The precision and accuracy were found within the acceptable limit (10%), as Jolly et al. (2018) described in detail.

2.4. Pollution load assessment of sediment

Evaluation of sediment contamination status was conducted by calculating different indices, and details of those indices with references are presented in Table 1.

2.5. Multivariate statistical analysis

The interrelationship and dependency can well define the complex ecotoxicological processes among the variables and their relative weights (De Bartolomeo et al., 2004). The multivariate statistical method is the most suitable tool for finding the relationships among the variables and parameters. In the present study, Cluster analysis (CA),

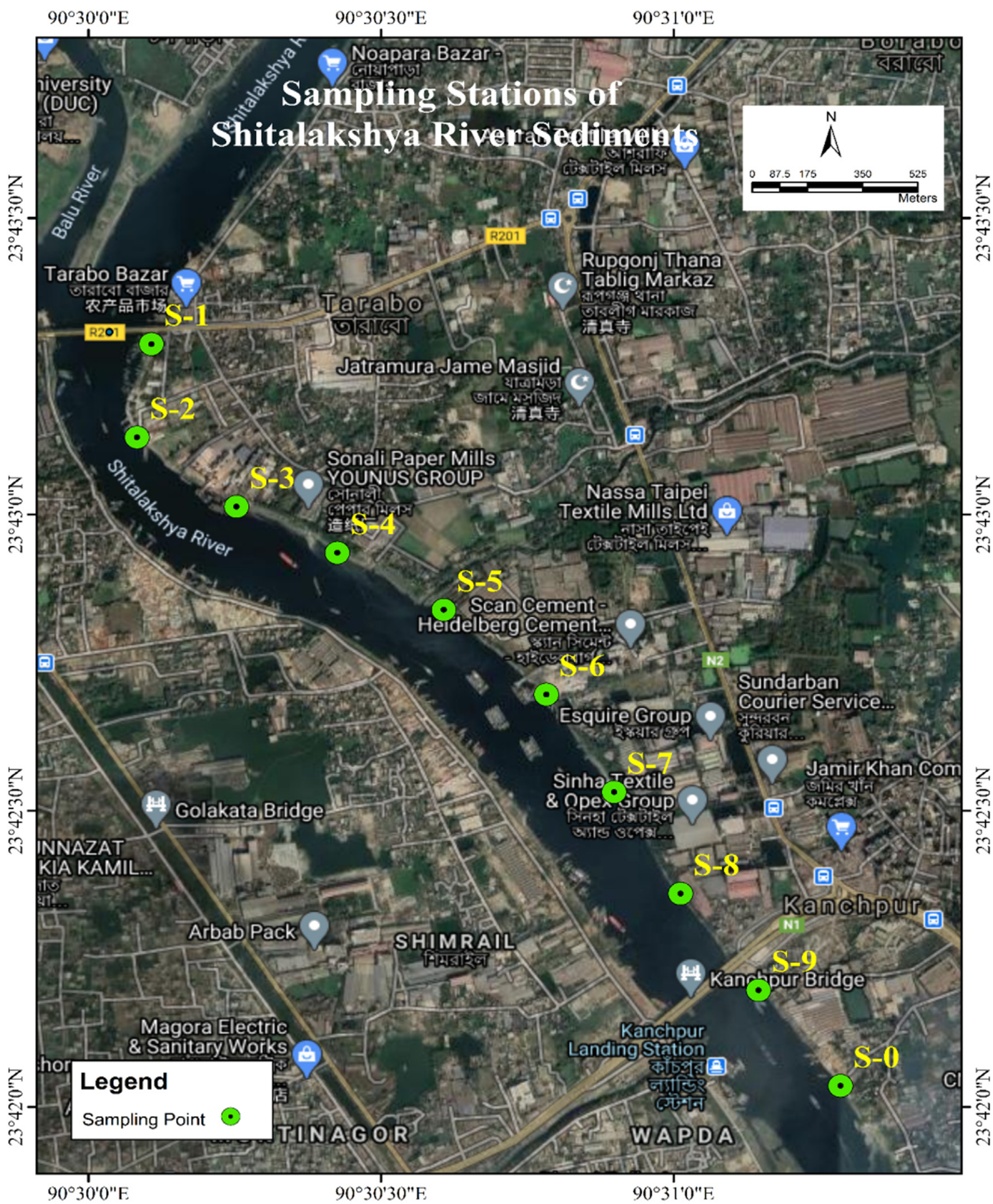

Fig. 1. Sampling location map of the Shitalakshya river of Bangladesh (Source: Google map).

Principal Component analysis (PCA), and the Pearson correlation analysis were applied (Li and Zhang, 2010; Varol, 2011), where PCA was applied to the dimensionless standardized data set of HMs for dry and rainy seasons. And Cluster analysis (CA) was used to identify spatial variability among the sites (Mao et al., 2013) for both seasons. All the statistical analyses were done using the free statistical software R and IBM SPSS Statistics 25.

2.6. Evaluation of health risks associated with the contaminated sediment

Ingestion, dermal contact, and respiration are the three major routes usually considered in human health risk issues regarding soil dust. It is assumed that surface sediment has a similar impact on human health as it may come to contact with the human through different ventures, *viz.*, various household works, recreational activities, land parts, or transportation Hossain et al., 2021a; Rovira et al., 2011; Iqbal et al., 2013; Jewel et al., 2020) and can be measured by considering the three-exposure pathway. This study thus focused on health risk assessment (non-carcinogenic and carcinogenic) owing to hand-oral ingestion, inhalation, and dermal contact by HMs-contaminated sediment with humans (adult and child). The exposure through three major pathways (ingestion, inhalation, and dermal contact) can be calculated for non-carcinogenic effect using the Eqs. (1)–((3) (USEPA, 1989, 2004; Rahman et al., 2019a).

$$\mathrm{ADD_{ing}} = C \times \frac{IngR \text{ x } CF \text{ x } EF \text{ x } ED}{BW \text{ x } AT} \quad (1)$$

Table 1
Sediment contaminations indices with classifications.

Index	Equation	Classification	Refs.
Enrichment Factor (EF)	$EF = \frac{(\frac{Me}{Mn})_{sample}}{(\frac{Me}{Mn})_{background}}$...(1) $(Me/Mn)_{sample}$ = the ratio of concentration between the studied metal and Mn in the sample of interest; $(Me/Mn)_{background}$ = the natural background value of measured metal to Mn ratio. In this study, manganese (Mn) was chosen as the reference material of normalization as it has a great abundance in the Shitalakshya river sediment.	EF = 1, crustal materials or natural weathering processes, EF < 2 (Deficiency to minimal enrichment), $2 \le E < 5$ (Moderate enrichment), $5 \le$ EF < 20 (Significant enrichment), $20 \le$ EF < 40 (Very high enrichment) and EF $\ge$ 40 (Extremely high enrichment).	Birch & Olmos (2008).
Contamination Factor (CF)	$CF = \frac{C_{m_{sample}}}{C_{m_{background}}}$........(2) $C_{m\ sample}$ = concentration of a given metal, $C_{m\ background=}$ background value of the metal equals to the world surface rock average.	CF < 1 (low contamination), $1 \le$ CF < 3 indicates moderate contamination, $3 \le$ CF < 6 indicates considerable contamination and CF $\ge$ 6 indicates very high contamination.	Hakanson (1980); Martin and Meybeck (1979).
Pollution Load Index (PLI)	$PLI = (CF_1 \times CF_2 \times CF_3 \times \cdots CF_n)^{1/n}$........(3) n = the number of metals to be analyzed	PLI < 1 denotes perfection; PLI = 1 denotes baseline levels of pollutants PLI >1 indicate deterioration of site quality.	Tomlinson et al. (1980); Tamim et al. (2016).
Geo-accumulation index (I_{-geo})	$I_{-geo} = Log_2 \frac{Cn}{1.5Bn}$........(4) C_n is the individual HM concentration. B_n is the geochemical background value (world surface rock average) and the factor 1.5 is introduced to include possible variations of the background values due to the lithogenic effect.	$I_{geo} \le 0$ (unpolluted), I_{-geo} = 0–1 (unpolluted to moderately polluted), I_{-geo} = 1–2 (moderately polluted), I_{-geo} = 2–3 (moderately to strongly polluted), I_{-geo} = 3–4 (strongly polluted), I_{-geo} = 4–5 (strongly to extremely polluted) and I_{-geo} = 5–6 (extremely polluted).	Muller (1979); Martin and Meybeck (1979).
Potential Ecological Risk Index (RI)	$RI = \sum_{i=1}^{n}(E_r^i)$......(5) $E_r^i = T_r^i X \frac{C_i}{C_o}$...........(6) $C_{i=}$ concentration of metal i,, C_o = concentration of the same element in background sediment, T_r^i= biological toxicity factor of an individual element,Which is in this study, Cu = Pb = Ni = 5, Zn = 1, As = 10, Cr = 2, and Cd = 30.	Single-factor pollution $E_r^i \le 40$ (low risk); $40 < E_r^i \le 80$ (moderate risk); $80 < E_r^i \le 160$ (considerable risk); $160 < E_r^i \le 320$ (high risk); $E_r^i > 320$ (very high risk). RI < 110 (low risk), $110 \le$ RI < 200 (moderate risk), $200 \le$ RI < 400 (considerable risk), RI $\ge$ 400 (severe risk).	Zheng-Qi et al. (2008); Rakib et al. (2021a) Hou et al. (2013); Chen et al. (2020); Hakanson (1980).

where, ADD_{ing} = average daily intake of HMs, ingested via sediment, mg/kg-day, C = concentration of HMs mg/kg; Ing_R = ingestion rate; EF = exposure frequency; ED = exposure duration; BW = body weight; AT = time period; and CF = conversion factor.

$$ADD_{inh} = C \times \frac{Inh \times EF \times ED}{PEF \times BW \times AT} \tag{2}$$

where, ADD_{inh} = intake of HMs, inhaled from the sediment, mg/kg-day; In_h = inhalation rate; PEF = particulate emission factor; C, EF, ED, BW, and AT are as defined earlier in Eq. (7).

$$ADD_{dermal} = \frac{C \times CF \times SA \times SL \times ABS \times EF \times ED}{BW \times AT} \tag{3}$$

where, ADD_{dermal} = exposure dose via dermal contact, mg/kg/day; SA = exposed skin area; SL = adherence factor; ABS = fraction of the applied dose absorbed across the skin, C, CF, EF, ED, BW, and AT are as defined earlier in Eq. (1).

Health risk assessment guideline (USEPA, 2004) described Hazard quotient (HQ) as non-carcinogenic health effect due to HM exposure to contaminated soil, which is applied for sediment in this study and can be calculated by the equation:

$$HQ_{soil} = \frac{ADD}{Rf_d} \tag{4}$$

where, Rf_d is the oral reference dose of the respective contaminants and ADD = (ADD_{ing} + ADD_{inh} + ADD_{derm}). HI is the Hazard Index via direct sediment contact and calculated by the summation of the corresponding HQ value as:

$$HI = \sum_{k=0}^{n} HQ \tag{5}$$

when HI < 1, it represents highly unlikely significant toxic interaction, and HI > 1 represents potential non-cancer health effects (Enuneku et al., 2018).

Whereas, Carcinogenic risk assessment was carried out by multiplying exposure doses with slope factor component, and exposure doses are calculated by the Eqs. (6)–(8) as:

$$LADD_{ing} = C \times \frac{IngR\ X\ CF \times\ EF\ X\ ED}{BW\ X\ AT} \tag{6}$$

$$LADD_{inh} = C \times \frac{Inh\ X\ EF\ X\ ED}{PEF \times\ BW\ X\ AT} \tag{7}$$

$$LADD_{dermal} = C \times \frac{SA\ X\ SL\ X\ CF \times\ ABS \times EF \times ED}{BW\ X\ AT} \times 10^{-6} \tag{8}$$

Lifetime cancer risk for an individual from the average contribution for individual carcinogen is calculated by the Eq. (9):

$$CR_{soil} = LAAD \times SF \tag{9}$$

where, LAAD = $LADD_{ing}$+ $LADD_{inh}$ + $LADD_{dermal}$ and SF is the carcinogenicity slope factor (per mg/kg-day). In the case of multiple carcinogenic contaminants, the cancer risk can be calculated by summation of all chemicals and routes (Wang et al., 2021) by the Eq. (10):

$$TCR = \sum CR \tag{10}$$

Notably, risks lying between 1.0E−04 and 1.0E−06 are considered acceptable (USEPA, 1989), while risks exceeding 1.0E−04 are considered a lifetime carcinogenic risk to the human body. Detailed informa-

Table 2
Exposure parameters used to calculate health risk assessment via direct HM contaminated sediment contact.

Parameter	Unit	Child	Adult	Reference
Body weight (BW)	kg	15 kg	70 kg	USEPA (1989), USEPA, 2002, 2004)
Exposure frequency (EF)	(days/year)	180	180	USEPA, 2002; Rahman et al., 2021
Exposure duration (ED)	(years)	6	30	USEPA, 1996); USEPA, 2001
Ingestion rate (IR_{ing})	(mg/day)	200	100	USEPA, 2001
Inhalation rate (IR_{inh})	(m^3/day)	7.6	20	Van den Berg (1995)
Skin surface area (SA)	(cm^2)	1150 cm^2	2145 cm^2	USEPA (2004)
Adherence factor (SL)	(mg/cm^2)	0.2	0.07	USEPA (2004)
Dermal Absorption factor (ABS)	–	0.001, for As = 0.03	0.001	USEPA, 2002, 2004); US DOE 2011
Particulate emission factor (PEF)	(m^3/kg)	1.36×10^9	1.36×10^9	USEPA (2004)
Conversion factor (CF)	(kg/mg)	10^{-6}	10^{-6}	
Average time (AT) For carcinogens	(days)	365 × 70	365 × 70	USEPA, 2002, 2004)
For non-carcinogens (AT)	(days)	365 × ED	365 × ED	USEPA (2004)
RfD for ingestion (RfD_{ing})	mg/kg/day	Cr: 3.00E-03; Ni: 2.00E-02; Cu: 4.00E-02; Zn: 3.00E-01; Cd: 1.00E-03; Pb: 3.50E-03; As: 3.00E-04		Ferreira-Baptista and De Miguel (2005)
RfD for inhalation (RfD_{inh})	mg/kg/day	Cr: 2.86E-03; Ni: 2.06E-02; Cu: 4.02E-02; Zn: 0.30E-01; Cd: 1.00E-03; Pb: 3.52E-03; As: 3.01E-04		Ferreira-Baptista and De Miguel (2005)
RfD for dermal (RfD_{derm})	mg/kg/day	Cr: 6.00E-05; Ni: 5.40E-03; Cu: 1.20E-02; Zn: 6.00E-02; Cd: 1.00E-05; Pb: 5.25E-04; As: 1.25E-04		Ferreira-Baptista and De Miguel (2005)
Slope factor for ingestion (SF_{ing})	mg/kg/day	Pb: 9.00E-03; As: 1.50E+00		Ferreira-Baptista and De Miguel (2005)
Slope factor for inhalation (SF_{inh})	mg/kg/day	Cr: 4.20E+01; Ni: 8.40E-01; Cd: 6.30E+00; As: 1.51E+01		Ferreira-Baptista and De Miguel (2005)
Slope factor for dermal contact (SF_{derm})	mg/kg/day	Cr: 2.00E+01; As: 3.66E+00		Ferreira-Baptista and De Miguel (2005)

Table 3
HM concentration (mg/kg) in the Shitalakshya river sediments during the dry and rainy season.

Sample & Area	Elements, mg/kg							
	Cr	Mn	Ni	Cu	Zn	Cd	Pb	As
Mean (dry season)	69.42±0.56	611.90±4.90	39.45±0.32	147.03±1.18	162.70±1.30	5.03±0.04	20.01±0.16	13.94±0.11
Range (dry season)	61.00–73.71	563.00–658.00	33.30–46.28	130.00–158.00	132.00–195.00	4.55–6.32	18.31–22.65	12.50–15.22
Mean (rainy season)	66.85±0.53	555.90±4.45	35.09±0.28	140.71±1.13	153.00±1.22	4.74±0.04	19.60±0.16	13.37±0.11
Range (rainy season)	61.00–72.36	502.00–613.00	29.99–42.99	122.00–157.60	131.00–192.00	4.18–6.00	18.25–21.91	12.04–14.70
Avg.Conc. (Shitalakshya)	68.14±0.55	583.90±4.67	37.27±0.30	143.87±1.15	157.85±1.26	4.88±0.04	19.80±0.16	13.65±0.11
ERL	81	–	20.9	34	150	1.2	46.7	8.2
ERM	370	–	51.6	270	410	9.6	218	70
TEL	52.3	–	15.9	18.7	124	0.68	30.2	7.24
PEL	160	–	42.8	108	271	4.21	112	41.6
USEPA (1997)	77.2	–	16	16	110	0.6	0.6	7.24
Shitalakshya	63.22	–	39.22	–	75	5.01	28.36	–
Buriganga	297		240	280	–	7.7	731	21
Meghna	31.74	442.6	76.1	–	79.02	0.23	9.47	–

ERL = Effects range low (Long et al., 1995).
ERM = Effects range median (Long et al., 1995).
PEL = Probable effect level (MacDonald et al., 2000).
TEL = Threshold effect level (MacDonald et al., 2000).
Shitalakshya river (Islam et al., 2014).
Buriganga river Bangladesh (Islam et al., 2018).
Meghna river Bangladesh (Hasan et al. 2015).

tion for the calculation of non-carcinogenic and carcinogenic risk assessment is projected in Table 2.

3. Results and discussion

3.1. Distribution of heavy metals in the sediment samples

Mean concentrations (mg/kg) of measured HMs and their ranges are summarized in Table 3 for both seasons (dry & rainy seasons). In the dry season, the mean HMs concentrations (in mg/kg) can be ordered as Mn (611.90 ± 4.90) > Zn (162.70 ± 1.30) > Cu (147.03 ± 1.18) > Cr (69.42 ± 0.56) > Ni (39.45 ± 0.32) > Pb (20.01 ± 0.16) > As (13.94 ± 0.11) > Cd (5.03 ± 0.04) and in the rainy season the same trend was observed as Mn (555.90 ± 4.45) > Zn (153.00 ± 1.22) > Cu (140.71 ± 1.13) > Cr (66.85 ± 0.53) > Ni (35.09 ± 0.28) > Pb (19.60 ± 0.16) > As (13.37 ± 0.11) > Cd (4.74 ± 0.04). In the dry season, the concentrations of all HMs were slightly higher than in the rainy season, which can be attributed to the fact that pollutants in rivers may be diluted by rainwater, thus lowering the value. To evaluate the sediment contamination level and its possible adverse impact on aquatic ecosystems, various sediment quality guidelines (SQGs) have been developed over the years (Burton, 2002; Li et al., 2013; MacDonald et al., 2000). Hence, HMs concentrations were compared with the NOAA Marine Sediment Quality Guideline (ERL and ERM), the Canadian Interim Marine Sediment Quality Guideline (TEL and PEL), the United States Environmental Protection Agency (USEPA) Sediment Quality Guidelines measured value of HMs found below the threshold effect level (TEL), adverse biological effects are expected to occur rarely, whereas HMs concentrations higher than Probable effect level (PEL) indicates the possibility of frequent adverse effects (MacDonald et al., 2000). Long et al. (1995) identified the 10th and 50th percentile of the effects data as Effect range low (ERL) and effect range median (ERM), respectively were also used to compare with the present data (Table 3). Concentration of Cr ranged from 61.00 to 73.71 mg/kg and 61.00 to 72.36 mg/kg with a mean of 69.42 and 66.85 mg/kg in dry and rainy season, respectively. From a previous study by Islam et al. (2014), the mean Cr concentration in Shitalakshya river sediment was found 63.22 mg/kg. From Table 2, it is observed that Cr concentration in Shitalakshya river was within the safety limit of USEPA, ERL, ERM and PEL recommended values but higher than the TEL suggested value. Levels of Mn in sediments ranged between 563 and 658 and 502–613 mg/kg, with a mean of 611.90 and 555.90 mg/kg in dry and rainy seasons, respectively. The level of Ni ranged from 33.30 to 46.28 and 29.99–42.99 mg/kg, with a mean of 39.45 and 35.09 mg/kg in dry and rainy seasons, respectively, but in a previous study by Islam et al. (2014) reported 39.22 mg/kg, as a mean of Ni, which agrees on the present value. In comparison to the river Buriganga (Islam et al., 2018) and Meghna (Hasan et al., 2015), the Shitalakshya river sediment contains less amount of Ni (Table 2). However, the concentration of Ni is higher than the ERL, TEL, and USEPA suggestive limits but within the standard values set by ERM and PEL. The concentration of Cu ranged from 130.00 to 158.00 mg/kg and 122.00–157.60 mg/kg with a mean value of 147.03 and 140.71 mg/kg in dry and rainy seasons, respectively, which are higher than the suggestive legislative value by USEPA (1997), TEL, PEL, and ERL but lower than ERM suggested limit. Jain et al. (2008) reported the Cu concentration of Yamuna River sediment in India as 125–140 mg/kg. The concentration of Zn ranged from 132 to 195 and 131–192 mg/kg, with a mean value of 162.70 and 153.00 mg/kg in dry and rainy seasons, respectively. Islam et al. (2014) reported that the concentration of Zn in Shitalakshya river sediments was 75 mg/kg, and the present value is much higher than the previous one, which may be due to the discharge of untreated effluent from the nearby industries. However, Zn in Shitalakshya river sediments lies within ERM and PEL limits but exceeded USEPA (1997), TEL, and ERL, which is slightly above the ERL limit but far below the ERM limit. The concentration of Cadmium (Cd) ranged from 4.55 to 6.32 and 4.18–6.00 mg/kg with a mean of 5.03 and 4.74 mg/kg in dry and rainy seasons, respectively, which are lower than Buriganga river sediment (Islam et al., 2018) but agrees with the previous study by Islam et al. (2014), as shown in Table 3. However, Cd concentration lies within the safety limit of ERM but exceeds all other recommended SQG limits (Table 3). The concentration of lead (Pb) in the sediment samples ranged from 18.31 to 22.65 and 18.25–21.91 mg/kg with a mean of 20.01 and 19.60 mg/kg in dry and rainy seasons, respectively, and lied within the safety limit of ERL, ERM, TEL, PEL values but exceeded the SQG limit of USEPA (1997) (Table 3). Islam et al. (2014) reported mean concentration of Pb was 28.36 mg/kg in Shitalakshya river sediment, which was higher than the present findings.The sediment samples from the Shitalakshya river having arsenic (As) concentration ranged from 12.50 to 15.22 and 12.04–14.70 mg/kg with mean of 13.94 and 13.37 mg/kg in dry and rainy seasons, respectively. According to USEPA (1997), the maximum limit of arsenic (As) in sediment is 7.24 mg/kg, which is lower than the present findings. The ERL and ERM limit of arsenic in sediment is 8.2 and 70 mg/kg, respectively, and the concentration of As in Shitalakshya river sediments was higher than ERL but within ERM. Tamim et al. (2016) reported the range of Cr, Mn, Cu, Zn, and Pb in Buriganga river sediment as 470–205, 423–501, 35.0–41.3, 68–210, and 13.0–16.7 mg/kg, respectively. Whereas Cr is found to show a value almost eight-fold higher than the present value as Buriganga river sediment is contaminated by Cr, coming from the nearby Tannery industry, but other elements more or less showed similar values. In another study, Rakib et al. (2021a) showed a range of Zn, Cu, and Pb in the salt marsh sediment of marine ecosystem in the Bay of Bengal as 37.71–44.95, 36.51–5.66, and 1.35–10.42 mg/kg, respectively, which are much lower than the range of the corresponding element in Shitalakshya river and hence the evidence of HMs pollution. A lower level of Cr, Mn, Cu, Zn, and Pb in sediment was also reported by (Rifaat, 2005; Hassian et al., 2021a; Pandey et al., 2014).

3.2. Assessment of sediment pollution degree

3.2.1. Enrichment factor (EF)

EF is measured to identify the level of anthropogenic impact on sediments, the contribution of each element to the enrichment of sediment of an individual site, and can be calculated by Eq. (1), shown in Table 1. The EF values of HMs in the Shitalakshya river sediments for both the dry and rainy seasons are depicted in Fig. 2(a). At every point, EF values of As and Cu in the dry and rainy seasons were significantly higher than other metals and lay in the $5 \leq EF < 20$ groups, indicating significant enrichment. EF values of As in the dry season ranged from 14.41 to 10.52; in the rainy season, it was 12.70 to 10.18. Whereas, for Cu, the range is 6.57 to 4.91 and 7.21 to 4.80 for dry and rainy seasons, respectively. The range of calculated EF values for the other studied elements was Cr: 1.28 to 1.06 and 1.35 to 1.10, Ni: 1.25 to 0.86 and 1.24 to 0.82, Zn: 1.93 to 1.23 and 2.25 to 1.30, Pb: 1.68 to 1.30 and 1.85 to 1.39, Cd: 0.03 to 0.02 and 0.03 to 0.02, in dry and rainy seasons, respectively, indicating deficiency to minimal enrichment (EF < 2). Hossain et al. (2021b) reported moderate to severe enrichment by Mn, Zn, Cu, Pb, Ni, and Cr in the sediment cores of different ship-breaking areas of Shitakundo, Bangladesh. In another study, Tamim et al. (2016) showed minimal enrichment of Cr, Zn, K, Ti, Cu, Rb, Sr, Cs, Hf, and Hg in the sediment sample of Buriganga river near Hazaribagh area, Dhaka, Bangladesh. By considering the sampling point based on the enrichment value, the most significant sites can be ordered as S-7 > *S*-3 > *S*-2 > *S*-4 > *S*-1 > *S*-8 > *S*-5 > *S*-9 > *S*-10.

3.3. Contamination factor (CF) and pollution load index (PLI)

To measure the pollution level of the environment by each studied element, the parameter contamination factor (CF) is usually calculated, and Eq. (2) is used for the estimation, expressed in detail in Table 1. The present study computed the contamination factor for Cr, Mn, Ni, Cu, Zn, Cd, Pb, and As presented in Fig. 2(b), shows the variations of the calculated CF values for various HMs analyzed at different points in both dry and rainy seasons. In the dry season, the mean CF values showed the following trends As (9.29) > Cu (4.59) > Zn (1.28) > Pb (1.25) > Cr (0.97) > Mn (0.81) > Ni (0.80) > Cd (0.05) and in rainy season a similar trend was observed as As (8.91) > Cu (4.40) > Pb (1.22) > Zn (1.20) > Cr (0.94) > Mn (0.74) > Ni (0.71) > Cd (0.04). Among all the studied HMs, As had very high contamination factors for the dry (9.29) and rainy seasons (8.91). In the case of Cu, the range of CF values in both seasons was 4.93 to 4.06 in the dry season and 4.925 to 3.81 in the rainy season, thus indicating considerable pollution in both seasons. Zn and Pb had CF values greater than > 1 in both seasons for all the sampling points, and hence sediments of Shitalakshya river are moderately polluted by Zn and Pb, whereas the mean CF values of Cr, Ni, Mn, and Cd are less than 1 and indicating low pollution. In a study, Rakib et al. (2021a) reported CF < 1 for Pb, Zn, Fe, Cu, Sr, Zr, and Ti in the salt marsh sediment of Hatiya, Chairman Ghat, and ship-breaking yards along the marine coast of Sitakundo, Bangladesh. Rahman et al. (2019b) also reported low contamination factors for Cr, Cu, As, and Sr in the sediment sample of ship breaking area of Sitakundo coast, Bangladesh.

PLI for sediment, generally calculated to estimate the level of pollution associated with more than one contaminant in a particular site, is calculated using Eq. (3), as illustrated in Table 1. The estimated value of PLI for different sampling points to evaluate the quality of the aquatic environment and the pollution status with Seasonal variation is shown

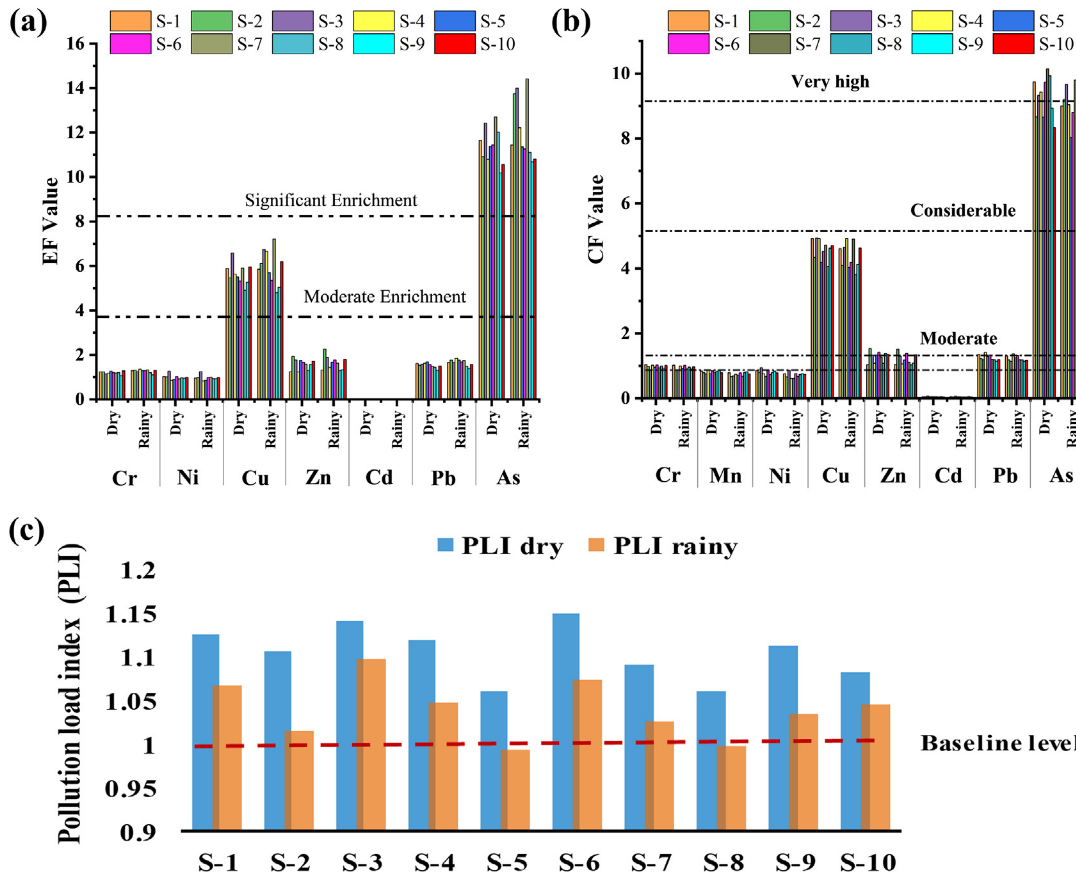

Fig. 2. Showing variation of (a) Enrichment factor (EF), (b) Contamination factor (CF), and (c) Pollution load index (PLI) of studied HMs.

in Fig. 2(c). In both seasons, the calculated PLI values for all the points are above or near one (1), indicating HMs pollute sampling sites. Comparing the seasonal variation of PLI values, it can be concluded that the sediment samples are more polluted in the dry season than in the rainy season (Fig. 2c), which was consistent with the measured HMs concentrations. From the Fig. 2(c) predicted spatial variation of PLI can be apprised as S-6 > *S*-3 > *S*-1 > *S*-4 > *S*-9 > S-2 > *S*-7 > *S*-10 > *S*-8 > *S*-5 in both the seasons.

3.4. Geo-accumulation index (I_{geo})

I_{geo} is the magnitude of the degree of pollution caused by each HM in the sediment sample, which is calculated by Eq. (4) shown in Table 1. In the present study, I_{geo} for the element Cr, Ni, Cu, Zn, Cd, Pb, and As is measured and presented in Fig. 3. Calculated I_{geo} values for both the seasons revealed that As and Cu have the maximum geo-accumulation index and showed positive I_{geo} values in all points. The mean I_{geo} values of As were 2.62 for dry and 2.57 for the rainy season, whereas, for Cu, it was 1.62 for dry and 0.69 in the rainy season, indicating moderate to strong pollution by As. In contrast, Cu showed variation in I_{geo} values appraising moderately polluted by Cu in the dry season and unpolluted to moderately polluted in the rainy season. However, all other HMs showed negative I_{geo}, and their mean I_{geo} for both the dry and rainy seasons can be attributed as Cr: −0.61 and −0.67; Ni: - 0.90 and −1.07; Zn: −0.23 and −0.32; Cd: −6.48 and −6.57; Pb:−0.26 and −0.29 in dry and rainy seasons, respectively, indicated class I_{geo} and unpolluted by the HMs. Rakib et al. (2021a) also found I_{geo} for Ti, Fe, Cu, Rb, Sr, Zr, Pb, and Zn in the sediments belonged to class zero, indicating the sediment in Hatiya, Chairman Ghat, and ship-breaking yards along the marine coast of Sitakundo were unpolluted by these HMs. Rahman et al. (2019b) showed I_{geo} value in the ship-breaking area sediment as Pb > Rb > Zn > Fe >Zr > *Y* > Ti > As > Sr > Cu > Cr.

3.5. Assessment potential ecological risk factor (E^i_r) and risk index (RI)

Table 4 represents the potential Ecological risk index of the studied HMs. Potential ecological risk factor (E^i_r)of the studied HMs calculated following Eq. (5), follows the order As > Cu > Pb > Ni > Cr > Cd > Zn. Single factor pollution (E^i_r) < 40 for Cr, Ni, Cu, Zn, Cd, and Pb in all the sites indicated no ecological risk, while As showed 80 < (E^i_r) ≤ 160, indicating considerable ecological risk. Low ecological risk for Cr, Cu, Ni, and Zn was also reported by Hossain et al. (2021a). According to the classification of Potential ecological risk (RI) calculated by Eq. (6), a moderate ecological risk (110 ≤ RI < 200) by the elements Cr, Ni, Cu, Zn, Cd, Pb, and As was observed in all the sampling points (S-1 to S-10), which is due to the elevated level of As in the samples coming from the nearby industries. However, ecological risk (RI) by the elements Cr, Cu, Ni, Mn, Pb, and Zn was also measured by Rahman et al. (2019b), Hossain et al. (2021b), and Aktaruzzaman et al. (2014) in the sediment of ship breaking area of Bangladesh and found lower than the present study.

3.6. Source identification of heavy metals

3.6.1. Pearson correlation

Table 5 shows the Pearson correlation coefficient of the studied HMs. Results reveal that the Cr-Pb pair has a strong positive correlation (0.695) at the significance level of $p < 0.01$. Cr also shows a strong positive correlation with Mn (0.602) at the significance level of $p < 0.01$, which indicates that Cr, Pb, and Mn may have a common source of origin. It is also seen that the Ni-Mn pair has a moderate positive correla-

Table 4
Potential Ecological Risk Factor and Potential Ecological Risk Index of HMs in Shitalakshya river sediment.

Site	Season	Potential ecological risk factor (E^i_r)							Risk Index (RI) $= \Sigma E^i_r$
		Cr	Ni	Cu	Zn	Cd	Pb	As	
S-1	Dry	2.07	4.28	24.61	1.03	1.53	6.74	97.40	137.67
	Rainy	2.03	3.78	23.05	1.04	1.48	6.52	90.00	127.89
S-1	Dry	1.97	4.01	21.72	1.53	1.50	6.10	86.67	123.50
	Rainy	1.75	3.28	20.47	1.51	1.28	5.93	92.00	126.22
S-3	Dry	1.71	4.72	24.69	1.33	1.93	5.94	93.27	133.59
	Rainy	1.71	4.31	23.28	1.29	1.83	5.70	96.67	134.82
S-4	Dry	2.04	3.78	24.63	1.07	1.52	7.08	94.33	134.46
	Rainy	2.00	3.06	24.63	1.06	1.49	6.85	90.40	129.47
S-5	Dry	1.92	3.39	20.94	1.33	1.56	6.43	86.60	122.16
	Rainy	1.83	3.06	20.16	1.18	1.5	6.25	80.26	114.24
S-6	Dry	2.06	4.33	22.63	1.41	1.45	6.66	97.33	135.86
	Rainy	2.03	3.83	20.94	1.38	1.28	6.59	88.00	124.05
S-7	Dry	1.88	3.67	23.59	1.26	1.49	5.97	101.46	139.34
	Rainy	1.80	3.36	24.53	1.11	1.39	5.94	98.00	136.14
S-8	Dry	2.00	3.98	20.31	1.07	1.39	5.94	99.33	134.04
	Rainy	1.92	3.67	19.06	1.03	1.27	5.92	88.13	121.01
S-9	Dry	1.86	4.18	23.11	1.38	1.58	5.72	89.33	127.17
	Rainy	1.79	3.78	20.62	1.09	1.59	5.70	87.33	121.90
S-10	Dry	2.03	3.89	23.51	1.35	1.43	5.95	83.33	121.51
	Rainy	1.94	3.67	23.12	1.33	1.37	5.86	80.67	117.97

Table 5
Pearson's correlation coefficient between the determined HMs and the matrix of PCA lodgings.

	Cr	Mn	Ni	Cu	Zn	Cd	Pb	As	PC1	PC2	PC3
Cr	1								−0.160	**0.896**	−0.304
Mn	**0.602****	1							0.173	**0.863**	0.186
Ni	0.017	**0.457***	1						**0.636**	0.327	**0.625**
Cu	0.116	0.081	0.295	1					**0.759**	0.097	−0.246
Zn	−0.206	−0.156	0.207	−0.107	1				−0.193	−0.087	**0.712**
Cd	−0.460*	−0.009	**0.557***	**0.437**	0.037	1			**0.762**	−0.264	0.314
Pb	**0.695****	0.297	−0.149	0.288	−0.267	−0.156	1		0.073	**0.596**	−0.588
As	−0.017	0.151	**0.344**	**0.362**	−0.205	0.177	0.105	1	**0.666**	0.074	−0.191
Eigenvalues									2.370	2.177	1.223
Explained variance (%)									29.622	27.215	15.281
Cumulative variance (%)									29.622	56.838	72.119

** . Correlation is significant at the 0.01 level (2-tailed).
* . Correlation is significant at the 0.05 level (2-tailed).

tion of (0.457) at the significance level of $p < 0.05$, and Ni-As shows a moderate positive correlation of (0.344), whereas the Ni-Cd pair shows a strong positive correlation of (0.557) at the significance level of $p < 0.05$. Cu-Cd pair also has a moderate positive correlation of (0.437), and Cu-As has a correlation coefficient of (0.362). This indicates that Ni, Cu, Cd, and As may have originated from the same sources.

3.6.2. Principal component analysis

The principal component analysis (PCA) results of the standardized dataset of the HMs have been shown in Table 5, suggesting that the PCA reduced the number of variables to three principal components (PCs) with Eigenvalues > 1. PC1 has an eigenvalue of 2.37 and explains 29.62% of the data variance and is highly loaded with Ni (0.636), Cu (0.759), Cd (0.762), and As (0.666), PC2 has an eigenvalue of 2.17, accounted for 27.21% of the data variance and has high positive loadings of Cr (0.896), Mn (0.863) and Pb (0.596), PC3 has eigenvalue 1.22, and it can explain 15.28% of the data variance with higher loading of Ni (0.625) and Zn (0.712). Fig. 4**(a)** represents the scree plot, and Fig. 4**(b)** shows the PCA correlation circle for metals based on the Pearson correlation matrix. The first PC (DIM-1, Horizontal axis) accounts for 29.6% of the data variation, and the second PC (DIM-2, vertical axis) describes 27.2% of the variation.

3.6.3. Cluster analysis

Cluster analysis was performed using the Wards method with square Euclidean distance metric to determine the group of analyzed variables. From the cluster dendrogram (Fig. 5), it can be elucidated that the studied elements have been divided into three statistically significant groups. Group-1 consists of Cr, Pb, and Mn; Group-2 consists of Ni, Cd, Cu, and As and Group-3 consists of only Zn, which builds up a cluster with the second group with a long distance. Narayanganj and Demra, as industrially prone areas situated on the bank of the Shitalakshya river, discharge a huge quantity of solid and liquid wastes, thus contributing HMs into the river. Similarly, the Shiddirganj area was also highly polluted by HMs as the power station and textile industries are located there. From field observation, three main sources of pollution are identified in all four reaches: Dhaka city domestic wastewater, industrial waste, and local waste. The oil industry and refinery are the main sources of Pb and Cd. Metal and waste dumping places contribute to the high Zn, Pb, and Mn concentrations. Boat and ship dockyard are probably the main sources of Mn, Pb, and Zn, whereas soap factory is the contributory source of Pb. Dye, textile, tannery factories, electroplating industries, highway, and railway stations mainly contribute to Pb, Cr, Co, Zn, and Cd. Thus, in Group 1, the contributory source for Mn and Pb was boats and ship dockyard and metal and waste dumping station, whereas, for Pb and Cr, the possible source may be dye, textile, and tannery factories. In Group 2, the contributory source for Cu, As was Glass and ferrous metal industries located near the bank of the Shitalakshya river and Cd, and Ni from the oil and refinery industry, untreated industrial effluents from the paint and textile industries. In Group 3, Zn can have been derived from multiple sources like dye factories, textiles, tanneries, electroplating, highway, rail station, etc.

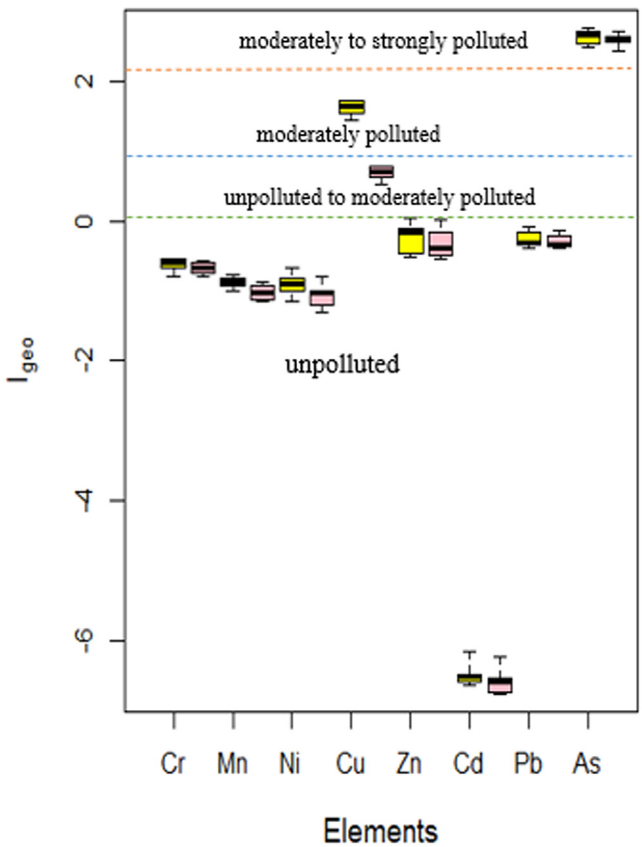

Fig. 3. Box-whisker plots showing the variation in of geo-accumulation index values of Shitalakshya river sediment in dry (yellow) and rainy (pink) season.

3.7. Associated human health risk assessment

In this study, non-carcinogenic risk HQ by the HMs Cr, Ni, Cu, Zn, Cd, Pb, and As in the sediment samples of Shitalakshya river has been calculated for dry and rainy seasons in both adult and children and computed in Table 6. The HQ value for individual pathway ingestion was found in the order Cd > As > Cr > Pb > Cu > Ni > Zn for adults in dry and rainy seasons, with a similar trend for children as well. Furthermore, the sequence wasAs > Cr > .Pb > Cd > Cu > Ni > Zn via inhalation and As>Cr>Cd>Pb>Cu>Ni>Zn via dermal contact for adults in both seasons, with similar findings in children as well. The calculated HQ value is higher in the dry season than the rainy season, possibly due to the estimated lower concentration of HMs in the rainy season; more children are found more vulnerable compared to adults. However, none of the calculated HQ values crosses the threshold limit (HQ > 1) for the individual path of exposure, thus posing no health risk. Hossain et al. (2021a) reported finding HQ < 1 for Fe, Cu, Zn, Sr, and Pb in males, females, and children. However, all three paths are considered in calculating health risks from direct soil exposure. Moreover, thus, non-carcinogenic health risk (HQ_{soil}) from the HMs contaminated sediment sample was measured at 1.40E-02 and 4.32E-02 for adults and children in dry season while 1.34E-02 and 4.11–02 for adults and children in rainy season, respectively, indicating an acceptable non-carcinogenic risk by HMs contaminated sediment collected from the Shitalakshya river. The human health hazard index (HI) was 9.80E-02 and 9.37E-02 for adults and 9.03E-01 and 8.63E-01 for children in dry and rainy seasons, respectively, which revealed HI < 1 for adults, but the value of HI for children is almost equal to unity and thus suspected, there might be a limited non-carcinogenic risk for the children with the sediment of Shitalakshya river. Hossain et al. (2021a) reported hazard index (HI) was 261, 20.6, and 20.6 for children, adult males, and adult females, respectively, due to the inhalation process, indicating elevated health risk from the sediment samples collected from Sundarban, mangrove forest of Bangladesh. Jewel et al. (2020) also reported HIs for dermal contact of sediment of the Ganges River (Northwestern Bangladesh) were 7.24E-05, 1.41E-05, and 6.60E-05 during summer, winter, and monsoon seasons, respectively.

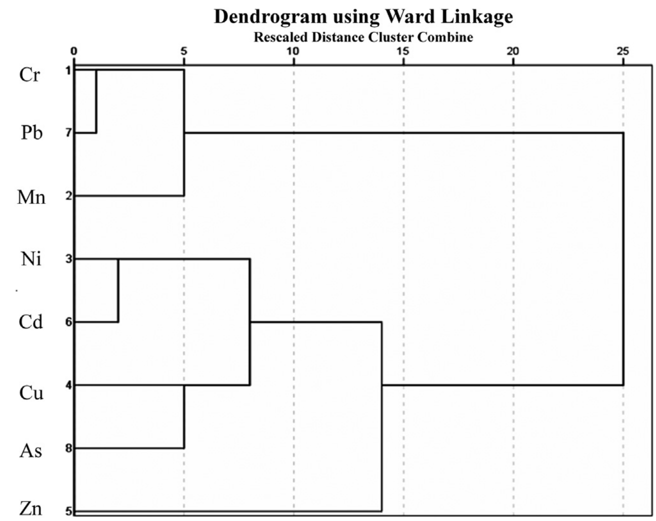

Fig. 5. Dendrogram showing clustering elements in the studied sediment of the Shitalakshya river.

Among the HMs studied in this project, only Cr, Ni, Cd, Pb, and As are considered carcinogens, according to IARC (International Agency for Research on Cancer, 2011). Hence, the present study focused only on those elements to measure carcinogenic risk for adults and children in both seasons (dry and rainy), and the estimated results are presented

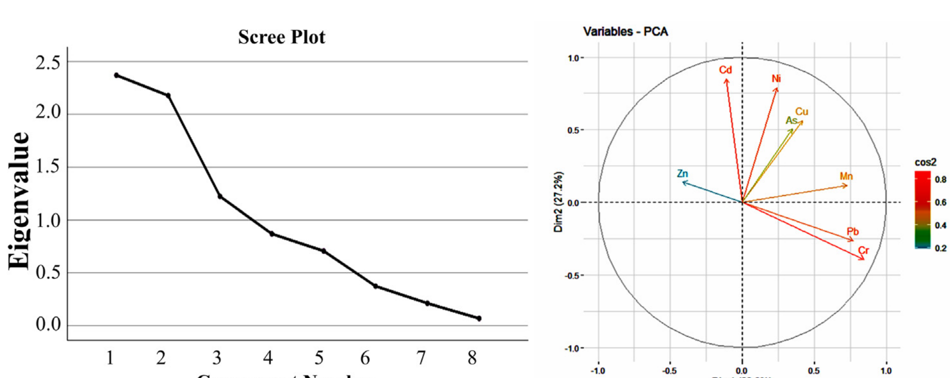

Fig. 4. Scree plot (a) and variable PCA plot (b) for HMs data set.

Table 6
Calculated values of health risk indices implicated by HMs contaminated sediment samples in Dry and Rainy seasons.

Metals	Non-carcinogenic health risk (HQ)				Carcinogenic health risk (CR)			
	Adult		Child		Adult		Child	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Ingestion								
Cr	1.63E-02	1.57E-02	1.52E-01	1.47E-01	–	–	–	–
Ni	1.39E-03	1.24E-03	1.30E-02	1.15E-02	–	–	–	–
Cu	2.65E-03	2.48E-03	2.42E-02	2.31E-02	–	–	–	–
Zn	3.82E-04	3.59E-04	3.57E-03	3.35E-03	–	–	–	–
Cd	3.52E-02	3.34E-02	3.29E-01	3.12E-01	–	–	–	–
Pb	4.03E-03	3.95E-03	3.76E-02	3.68E-02	5.44E-08	5.33E-08	1.01E-07	9.94E-08
As	3.27E-02	3.14E-02	3.06E-01	2.93E-01	6.31E-06	6.06E-06	1.18E-05	1.13E-05
Inhalation								
Cr	2.51E-06	2.42E-06	4.46E-06	4.29E-06	1.29E-07	1.25E-07	4.59E-08	4.42E-08
Ni	1.98E-07	1.76E-07	3.52E-07	3.13E-07	1.47E-09	1.31E-09	5.22E-10	4.64E-10
Cu	3.79E-07	2.63E-07	6.72E-07	6.43E-07	–	–	–	–
Zn	5.62E-08	5.28E-08	9.96E-08	9.37E-08	–	–	–	–
Cd	5.18E-07	4.91E-07	9.19E-07	8.71E-07	1.40E-09	1.33E-09	4.96E-10	4.70E-10
Pb	5.89E-07	5.77E-07	1.04E-06	1.02E-06	–	–	–	–
As	4.80E-06	4.60E-06	8.51E-06	8.16E-06	9.35E-09	8.96E-09	3.31E-09	3.18E-09
Dermal								
Cr	1.22E-03	1.18E-03	8.75E-03	8.42E-03	6.29E-07	6.06E-07	9.00E-07	8.67E-07
Ni	7.73E-06	6.87E-06	5.52E-05	4.91E-05	–	–	–	–
Cu	1.30E-05	1.24E-05	9.26E-05	8.87E-05	–	–	–	–
Zn	2.87E-06	2.70E-06	2.05E-05	1.93E-05	–	–	–	–
Cd	5.29E-04	5.01E-04	3.78E-03	3.58E-03	–	–	–	–
Pb	4.03E-05	3.95E-05	2.88E-04	2.82E-04	–	–	–	–
As	3.54E-03	3.39E-03	2.53E-02	2.43E-02	6.94E-07	6.66E-07	9.92E-07	9.51E-07
	Non-carcinogenic risk HQ_{soil}				**Carcinogenic risk CRs_{oil}**			
	1.40E-02	1.34E-02	4.32E-02	4.11E-02	3.88E-06	3.72E-06	6.94E-06	6.66E-06
	Hazard Index HI				**Total lifetime cancer risk TCR**			
	9.80E-02	9.37E-02	9.03E-01	8.63E-01	7.83E-06	7.52E-06	1.38E-05	1.33E-05

in Table 6. The result revealed that carcinogenic risk for Cr, Ni, Cd, Pb, and As for all the exposure pathways for adults and children in both seasons lay within the threshold limit of 1E-06 to 1 E-04, except for As through ingestion pathway for both the population group. As (arsenic) is the only element that showed a risk value higher than 1E-06 (Table 6), and the level of carcinogenic health risk by As in ingestion pathway was found at 6.31E-06, 6.06E-06 and1.18E-05, 1.13E-05, for adult and child in dry and rainy seasons, respectively, which lied in level II category and suggested low risk for adult for both the season, while for children the value lied in level III category and suggested low-medium risk in both the season (Li et al., 2017). However, the overall sediment impact for carcinogenic risk is 3.88E-06, and 3.72E-06 for adults in dry and rainy seasons, while 6.94E-06 and 6.66E-06 for children in dry and rainy seasons, respectively, which are level II category risk, but the health risk is low or negligible, and will not cause obvious carcinogenic health effect to the population (Li et al., 2017). Calculated total carcinogenic risk factors (TCR) were7.83E-06 and 7.52E-06 for adults in dry and rainy seasons, respectively, whereas 1.38E-05 and 1.33E-05 for children in dry and rainy seasons, respectively (Table 6), indicating, low risk for adults but low to medium risk for children.

4. Conclusion

The present study dispenses beneficial information about the surface sediments of an industrially affected river, namely the Shitalakshya river of Bangladesh. Results divulged that Shitalakshya river sediment is highly contaminated by arsenic (As) and considerably contaminated by Cu, whereas moderately contaminated by Pb and Zn. Moreover, Cr, Mn, Ni, Zn, and Cd appeared in less contaminant status. The HMs analyzed for the study area offered a minimum to significant enrichment. The estimated contamination factor (CF) results from low to very high contamination. I_{geo} value indicates moderate to strong pollution by As in both seasons, whereas Cu showed moderate pollution in the dry season but unpolluted to moderate pollution in the rainy season, while Cr, Ni, Zn, Cd, and Pb indicated unpolluted status. The quality of sediments in the study area showed a progressive depletion as PLI > 1 for all the sampling sites. Among the HMs studied, arsenic (As) was found to dominate the single factor pollution (E^i_r) for all the sampling sites compared to the other elements. RI indicates a moderate ecological risk by the HMs in the whole sampling area. A noticeable correlation was detected from Pearson's correlation coefficient, delineating that most HMs originated from human activities. This study illuminated that HQ and HI values for both population groups are within the safe limit range (HI < 1). Carcinogenic risk assessment also stipulated no risk through the three individual paths for adults and children, except for As for children (1E-05 to 5E-05) through the ingestion pathway. However, TCR for children showed a value in the risk category of III; thus, particular attention should be given, and regular monitoring is suggested. Seasonal variations for the studied parameters are noticeable, and the dry season dominates over the rainy season.

Author contributions

Y.N. Jolly: Conception and design, writing, and final approval of the manuscript; **Md. Refat J. Rakib:** Writing-original draft, reviewing and editing; **Rakesh Kumar:** Validation, Formal analysis, Writing- reviewing and editing; **Abu Reza Md. Towfiqul Islam**: Writing- reviewing and editing**; Atahar Rabby:** Sample collection and analysis; **S. Akter, K.M. Mamun** and **J. Kabir**: Sample irradiation and data acquisition; **TaseenJubair Bhuiyan**: Data calculation; **A.M.Sarwaruddin Chowdhury**: Visualization, Writing-reviewing and editing; **Abubakr M. Idris**: Writing- reviewing and editing.

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Consent for publication

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Consent to participate

Not applicable.

Declaration of Competing Interest

The authors declared no known competing financial interests or personal relationships regarding the work reported in this paper.

Data Availability

All data and materials required to understand the study are presented in the manuscript.

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