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Research article

Ecological and public health risk assessment of potentially toxic elements in the surface sediments of the Pasur river estuary, Bangladesh

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ABSTRACT

Potentially toxic elements (PTEs) in the surface sediments of the Pasur river estuary was investigated to assess its distribution, potential sources, and current dangers to ecological and public health. The Pasur River is a tidal, meandering, perennial river in south-western Bangladesh with a considerable number of fisheries and industrial activities. Sediment samples were collected from seven sampling points from January to December 2022 to assess the contamination level of six potentially toxic elements (Pb, Cr, Cd, As, Cu and Zn). Flame Atomic Absorption Spectrophotometer was utilized to detect the concentration of PTEs by following some sequential analytical procedure. Concentration of PTEs followed the reducing trend of Zn > Cr > Pb > As > Cu > Cd with the mean value of 61.04 > 49.15 > 26.58 > 10.28 > 6.28 > 1.59 mg/kg, respectively. The principle component and cluster analyses justified the anthropogenic source of the studied PTEs. The mean values of contamination factor (CF), geo-accumulation index (I_{geo}) and enrichment factor (EFc) showed that Pb and Cd were highly responsible for sediment (uncontaminated to moderate) contamination. Pollution load index (PLI) indicated higher pollution of sediments near the port areas. Potential ecological risk index (PERI) indicated low to moderate risks due to the contaminated sediment. However, the contamination of sediment was not associated with the non-carcinogenic (HQ_{derm} and HI < 1) and carcinogenic ($CR_{derm} < 10^{-6}$) risks due to the dermal contact. Although the risks were within the tolerable limit, regular monitoring is suggested to reduce the risk of PTEs contamination.

1. Introduction

Potentially toxic elements (PTEs) are the most ubiquitous contaminants found in the river system [1]. The persistence toxicity and bioaccumulation of PTEs are pressing local, regional and global concerns [1–5]. Species availability and diversity of aquatic environment are severely affected by the existence of excessive level of PTEs [3,6,7]. In a riverine habitat, PTEs are carried down the water bottom, settles in the surface sediment and biomagnified in the aquatic food chain [5,8]. The major sources of these metals in aquatic

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ecosystem are anthropogenic activities, uncontrolled industrialization, and excessive usage of chemicals [9]. Moreover, excessive used of organic and inorganic fertilizers besides non-managed pesticide application aggravate the situation [10–12].

Sediment is an essential component of the riverine environment that can be polluted by a variety of PTEs. The existence of PTEs in sediment is recognized as an indicator for monitoring a riverine ecosystem's environmental conditions and pollution status [5,13–15]. River sediments tend to accumulate higher amount of PTEs compared to the water [16,17]. Chemical and physical properties of water and sediments are severally affected by the contamination of PTEs as they inhibit the activity of microbes [18,19]. Temperature, pH, and other physical or biological perturbations in the environment enhance the discharge of PTEs from the sediment into the water. Fish, crabs, and snails may also be infected with PTEs, which can subsequently be passed to people via the food chain [20,21]. As a result, it disrupts the normal food chain process and has both immediate and long-term consequences for public health [22]. Therefore, assessment of toxic metals is essential for the safety of ecology and the public health [23]. Several sediment value indicators are used to the evaluation of pollution in an aquatic habitat [24]. The enrichment factor (EF), contamination factor (CF), and geo-accumulation index (Igeo) quantify sediment pollution [23,25,26]. Furthermore, the pollutant load index (PLI) and potential ecological risk index (PERI) have been established to measure the combined hazard of a large number of PTEs in sediment [23,27]. Non-carcinogenic health risk of PTEs can also be assessed by estimated average daily doge (ADD), hazard quotient (HQ), and hazard index (HI), which together with cancer slop factor (CSF) are also used to estimate the potential cancer risk of the studied PTEs through the use of contaminated sediment [28–31].

The Pasur River is a major tidal river in southern Bangladesh that is home to the world's largest mangrove forest. The banks of this river are home to a sizable number of dockyards, shipyards, tanneries, textile mills, oil refineries, TSP, DDT, hazardous metals manufacture, and cement factories, among other enterprises. Therefore, the river receives a considerable amount of untreated industrial wastes, solid wastes, and hazardous pollutants [32]. Previous studies on metal contamination in the Pasur River did not assess the amount of ecological and public health risk [25,33]. Although a few studies have highlighted the river's ecological danger status [23,23], more extensive study is required to assess the current pollution level. Furthermore, several studies have been done to determine the levels of PTEs pollution in Bangladesh's rivers and estuaries [23,25,26,34]. However, the evidence on the harm caused by the river's polluted material is insufficient. Therefore, the study was carried out to assess the PTEs concentration in sediments samples of the Pasur River estuary. The study also evaluated the seasonal and geographical variability of PTEs in sediment, as well as the linked ecological and potential human health risk implications through the analysis of contaminated sediments.

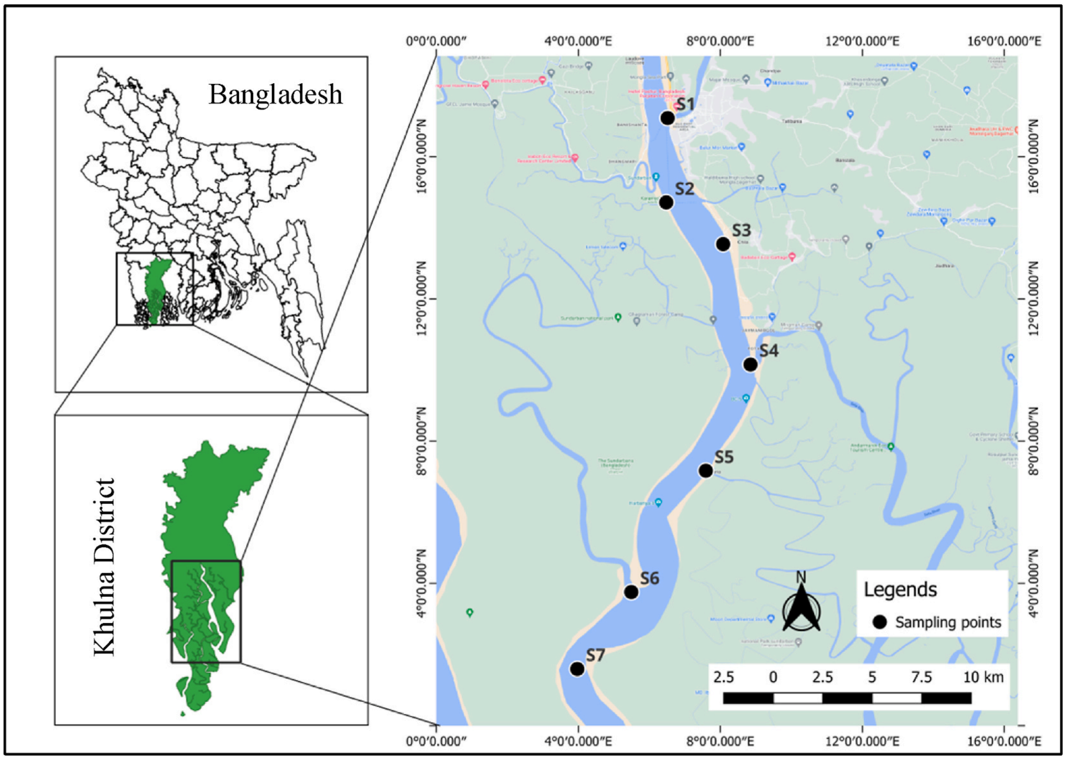

Fig. 1. Sampling locations in the Pasur river estuary, Bangladesh.

2. Materials and methods

2.1. Description of the studied river

The Pasur River Estuary (PRE) is a large tidal river in Bangladesh that flows through the Sundarbans mangrove environment and into the Bay of Bengal. Khulna city is situated on the bank of the PRE and it is one of the most noteworthy rivers in Bangladesh's southwestern coastal zone, where saltwater intrusion occurs upstream. After passing through the Bay of Bengal, the PRE divides into two branches near Akram Point: the Shibsa River and the Pasur River. Because the river is deep, perennial, and navigable, huge marine ships may readily approach Mongla Sea Port via it. The port area is mostly utilized for industrial, commercial, residential, and recreational purposes. As a result, the PRE is constantly inundated by untreated garbage and wastewater from industrial and household operations [25]. The river runs for around 142 km and has depths ranging from 3 to 15 m. All of its distributaries are tidal, with an approximate tidal area of 1.5–3 m.

2.2. Sample collection and preparation

Samples were collected seasonally in three respective seasons, Pre-monsoon, Monsoon and Post-monsoon from January to December 2022. Sediment samples were obtained from seven different sampling locations (Fig. 1) which were designated as S1 = Mongla Ferry Ghat (22° 27′ 57.24″ N, 89° 35′ 42″ E), S2 = Koromjol (22° 25′ 23.16″ N, 89° 35′ 40″ E), S3 = Chila (22° 24′ 6.48″ N, 89° 37′ 20.28″ E), S4 = Joymoni (22° 20′ 30.84″ N, 89° 38′ 9.60″ E), S5 = Harbaria (22° 17′ 20.04″ N, 89° 36′ 49.68″ E), S6 = Bhati Khal (22° 13′ 50.88″ N, 89° 34′ 40.44″ E) and S7 = Mazhar points (22° 11′ 38.40″ N, 89° 32′ 58.92″ E) of the Pasur River. A portable Ekman dredge sampler was employed to gather sediment samples at depths of 0–5 cm. The sediment samples were then packed in a polythene bag and sent to the Department of Fisheries, University of Rajshahi, Bangladesh. The samples were oven-dried at 80 °C for 24 h. The dried samples were mashed with a mortar and pestle, sieved with a 2 mm sieve, and kept in a sealed clean zip lock bag at 8 °C until the chemical analysis.

2.3. Digestion of sediment samples

About 2.0 g of dried sediment and 15 ml of concentrated HNO_3 were put into a 100 ml beaker in order to digest the samples. The contents were heated at 130 °C for 5 h. Following digestion, the samples were prepared in deionized water to a volume of 100 ml, prewashed with 0.1 M HNO_3, and filtered through filter paper (Whatman no. 41).

2.4. Metal analytical technique

The experimental process employed ultrapure deionized water. All glasses and containers were washed with 20 % nitric acid and oven-dried after being washed with deionized ultrapure water. The Pb, Cr, Cd, As, Cu, and Zn were detected using the Flame Atomic Absorption Spectrometer (AAS) (Shimadzu, AA-6800). Quality assurance (QA) and quality control (QC) verified the accuracy of the data for the study. Blank samples (no sediment), spiked samples (multi-standard spike), and repeat samples were all analyzed at the same time for QA/QC purposes. All tests were performed for the three replicates to eliminate any mistake, and only average data were used. To avoid contamination, all laboratory equipment was cleansed with distilled water and then immersed in 10 % HNO_3 for at least 24 h. To achieve quality assurance and control, analytical blank and spike samples were collected for each PTE. The AAS was calibrated based on regular laboratory measurements. Certified reference material DORM-4 Fish protein from National Research Council, Canada for PTEs was used for analytical procedure. The percentage recovery was between 90 and 99 %. Analytical conditions and procedure for the measurement of PTEs in sample using AAS are shown in Supplementary Tables 1 and 2

2.5. Risk assessment on ecology

2.5.1. Contamination factor (CF) and degree of contamination (C_d)

Contamination factor (CF) and degree of contamination (C_d) are considered to be a simple and essential tool to define the level of sediment contamination. CF is the ratio of the measured concentration to the PTEs background value. CF was measured according to Tomlinson et al. [35] as follows:

$$CF = C_{metal}/C_{background} \cdots \cdots \cdots \cdots \cdots \ldots. \tag{i}$$

CF values categorized the contamination scores for the metals as low-degree ($CF < 1$), moderate-degree ($1 \le CF \le 3$), considerable-degree ($3 \le CF \le 6$), and very high-degree ($CF \ge 6$) [36,37].

The degree of contamination (Cd) is an indicator used to quantify the metal element pollution range of sediment. C_d is the sum of the contamination factor (CF) and determined as:

$$C_d = \sum_{i=1}^{n} CF \tag{ii}$$

The degree of contamination is categorized as $C_d < 8$, $8 \le C_d < 16$, $16 \le C_d < 32$ and $C_d \ge 32$ designate low, moderate, considerable and very high degree of contamination accordingly [38].

2.5.2. Pollution load index (PLI)

PLI is defined as the nth root of the multiplications of the CF of metals and calculated based on the following formula of Tomlinson et al. [35]:

$$PLI = (CF1 \times CF2 \times CF3 \times \ldots \ldots \ldots \times CFn)1/n \quad \text{(iii)}$$

The PLI value of zero designates excellence, PLI = 1 indicates standard pollution level and PLI > 1 specifies the deterioration of the environment.

2.5.3. Geo accumulation index (I_{geo})

The I_{geo} index was analyzed according to Muller [39] as follows:

$$I_{geo} = \mathrm{Log}_2\,(C_n/1.5 \times B_n) \quad \text{(iv)}$$

In this equation, Cn denotes the value of the PTEs (n), Bn is the background value of the same element, and factor 1.5 denotes the background matrix. I_{geo} values are inferred as follows: $I_{geo} \leq 0$, uncontaminated; $0 \leq I_{geo} \leq 1$, uncontaminated to moderately contaminated; $1 \leq I_{geo} \leq 2$, moderately contaminated; $2 \leq I_{geo} \leq 3$, moderately to heavy contaminated; $3 \leq I_{geo} \leq 4$, heavy contaminated; $4 \leq I_{geo} \leq 5$, heavy to extremely contaminated; and $I_{geo} > 5$, extremely contaminated.

2.5.4. Enrichment factor (EFc)

The enrichment factor (*EFc*) is a helpful tool for measuring the degree of PTEs contamination, and computed as follows:

$$EFc = (C_M / C_X\ Sample) / (C_M / C_{X\ \mathrm{Earth\ crust}}) \quad \text{(v)}$$

Where, C_M is the value of metal studied and C_X is the value of reference element. In this study Mn was chosen as reference elements according to Liu et al. [40]. *EFc* results are inferred as EF = 1 means no enrichment, EF = 1–3 means minor enrichment, EF = 3–5 means moderate enrichment, 5–10 means moderately severe enrichment, and EF = 10–25 means severe enrichment [41,42].

2.5.5. Potential ecological risk factor (E_r^i) and risk index (PERI)

PERI was calculated according to Hakanson [43] using the following formula:

$$RI = \sum E_f^i \quad \text{(vi)}$$

Where RI is risk index; E_f^i is the potential ecological risk index for single HM pollution and analyzed using the following formula:

$$E_f^i = C_f^i \times T_f^i \quad \text{(vii)}$$

T_f^i is the toxicity response coefficient of a particular metal. C_f^i is the pollution index and calculated using the following formula:

$$C_f^i = C_s^l \Big/ C_n^l \quad \text{(viii)}$$

Where, C_s^i denotes the quantity of PTEs in the sediment and C_n^i denotes the amount of PTEs in the controlled sample. Risk factor (E_r^i) is classified into the following five groups: E_r^i <40; 40 ≤ E_r^i <80; 80 ≤ E_r^i <160; 160 ≤ E_r^i <320 and E_r^i ≥ 320; indicates low, moderate, considerable, high and very high risk, respectively [40]. PERI groups into the following levels: PERI <65 low; 65 ≤ PERI <130 moderate; 130 ≤ PERI <260 considerable and PERI ≥260 very high [43,44].

2.6. Risk assessment on human health

Non-cancer and cancer risks through the dermal contact of sediment were analyzed. Humans may be subjected to dermal contact of sediment through bathing, washing and recreational activities. According to Iqbal and Shah [45], the Average Daily Dose (ADD) was determined as:

$$ADD_{\mathrm{dermal}} = Cs \times SA \times Kp \times ET \times EF \times ED \times CF/BW \times AT \quad \text{(ix)}$$

where, Cs is the mean concentration of PTEs (mg/kg); SA is the contact area of skin (6600 cm^2 for the children and 18,000 cm^2 for the adults); Kp is the dermal permeability coefficient (0.0001, 0.002 cm/h for Pb and Cr, respectively, 0.001 for Cd, As and Cu and 0.0006 cm/h for Zn); ET is the exposure time (0.6 h/day); EF is the contact frequency (365 days/year); ED is the contact duration (6 years for the children and 30 years for the adult); AT is the ED × 365 for non-carcinogenic risk (2190 and 10950 for the children and the adult, respectively). AT is 70 × 365 = 25550 for both the child and the adult; CF is the unit conversion factor (0.001 L/cm^3).

Non-carcinogenic hazard quotient (HQ_{derm}) was calculated based on the following equation:

$$HQ_{\mathrm{dermal}} = ADD_{\mathrm{dermal}} / RfD_{\mathrm{dermal}} \quad \text{(x)}$$

where, RfD is the reference dose [46]. HQ > 1.0 designates an unacceptable risk of non-carcinogenic effects and HQ < 1.0 specifies a tolerable level of risk for public health [47]. Hazard index (HI_{dermal}) was calculated by Li et al. [48] using the following formula:

$$HI_{dermal} = \sum_{i=1}^{n} HQ_{dermal} \quad \text{(xi)}$$

where, HI_{dermal} is the possible risk through dermal absorption of PTEs, i is the routes of contact; n is the type of PTEs; HI > 1 unacceptable risk and HI < 1 tolerable value of non-carcinogenic risk on health.

Cancer slope factor (CSF) was used to estimate the carcinogenic risk. Cancer risk was measured according to the formula:

$$CR_{dermal} = ADD_{dermal} \times CSF \quad \text{(xii)}$$

where, CR_{dermal} is the cancer risk through dermal contact of PTEs. The permissible unit for lifetime CR exposure ranges from 10^{-6} to 10^{-4} [49]. A CR score more than 10^{-4} suggests the likelihood of a carcinogenic risk [50].

2.7. Statistical analysis

The collected PTEs concentrations were summarized by the mean and standard deviation (Mean ± SD). Normal distribution of the data was checked by the Kolmogorov-Smirnov and Shapiro-Wilk tests. Spatio-temporal variation of PTEs concentrations was analyzed by Two-way analysis of variance (ANOVA). Difference in the mean value of each PTEs was assessed using one-way analysis of variance. In both cases, the mean variation was evaluated at 5 % level of significance using Duncan multiple range test (DMRT) using SPSS (Statistical Package for Social Sciences, version 25.0, IBM Corporation, Armonk, NY, USA). The possible source and distribution of PTEs were analyzed by the principle component analysis (PCA) and cluster analysis using Origin (Pro), 2023 (Origin Lab Corporation, Northampton, MA, USA).

3. Results and discussion

3.1. Concentration of PTEs

The concentration of PTEs in the sediment of the Pasur River estuary at seasons and sites are shown in Table 1. Mean concentration of PTEs were significantly different among the seasons and sites (Supplementary Table 3). Zn concentration in sediment was significantly ($P < 0.05$) higher compared to the other PTEs during the study period. The highest value of Zn was noted at S1 (79.36 ± 8.09 mg/kg) in Post-monsoon season which was similar to the results of Hossain et al. [51] whereas these authors noted the Zn concentration of 88.97 ± 58.98 mg/kg from Sangu River estuary. The greatest concentration of Zn at S1 might be attributed to untreated waste discharge from residential and industrial sectors and runoff from agricultural land caused by pesticide misuse. During the investigation period, Cr was the second most prevalent metal in sediment. The concentrations of the PTEs were in the following decreasing order of Zn > Cr > Pb > As > Cu > Cd (Fig. 2). Cr concentration was 49.15 mg/kg, which was equivalent to the outcomes of

Table 1
Concentration of PTEs in the sediment (mg/kg) of the Pasur River estuary at different seasons and sites.

Season	Stations	Pb	Cr	Cd	As	Cu	Zn
Pre-monsoon	**S1**	35.95 ± 5.47	57.88 ± 5.83	2.40 ± 0.62	12.43 ± 4.67	9.16 ± 2.00	67.56 ± 9.31
	S2	32.68 ± 7.01	53.44 ± 5.68	2.15 ± 0.56	8.54 ± 1.99	6.43 ± 0.86	63.39 ± 8.26
	S3	27.33 ± 5.38	50.17 ± 8.11	1.73 ± 0.44	10.06 ± 1.87	7.27 ± 1.58	55.84 ± 10.02
	S4	19.59 ± 4.41	45.25 ± 7.48	1.17 ± 0.47	6.38 ± 1.95	3.82 ± 1.33	62.66 ± 9.63
	S5	25.77 ± 5.38	49.48 ± 7.52	0.96 ± 0.24	11.11 ± 2.00	8.34 ± 2.44	65.48 ± 5.50
	S6	21.22 ± 8.25	42.59 ± 5.52	0.53 ± 0.22	7.66 ± 1.86	2.91 ± 1.31	60.98 ± 4.69
	S7	14.87 ± 3.88	38.66 ± 5.70	0.79 ± 0.24	9.83 ± 1.82	4.35 ± 2.45	56.55 ± 8.10
Mean		**25.35 ± 8.57**	**48.21 ± 8.33**	**1.39 ± 0.77**	**9.43 ± 2.87**	**6.04 ± 2.72**	**61.78 ± 7.98**
Monsoon	**S1**	28.53 ± 6.25	48.58 ± 4.72	2.12 ± 0.38	11.26 ± 2.61	8.37 ± 1.89	56.694 ± 5.80
	S2	23.78 ± 8.08	44.33 ± 6.52	1.84 ± 0.33	7.52 ± 2.46	3.53 ± 1.41	52.37 ± 5.73
	S3	19.28 ± 3.92	40.47 ± 6.98	1.46 ± 0.47	8.35 ± 2.64	6.24 ± 1.92	49.44 ± 6.39
	S4	11.91 ± 2.89	36.19 ± 8.84	1.13 ± 0.36	5.69 ± 1.85	2.61 ± 0.68	44.25 ± 8.73
	S5	15.47 ± 5.80	32.73 ± 6.78	0.75 ± 0.29	10.46 ± 2.73	7.36 ± 2.29	48.09 ± 6.88
	S6	9.36 ± 2.86	23.22 ± 4.22	0.45 ± 0.11	4.25 ± 2.12	2.28 ± 0.89	41.43 ± 5.55
	S7	12.63 ± 4.86	29.63 ± 6.74	0.38 ± 0.03	6.93 ± 3.23	4.47 ± 2.39	37.79 ± 5.72
Mean		**17.28 ± 7.92**	**36.45 ± 9.96**	**1.16 ± 0.69**	**7.78 ± 3.19**	**4.98 ± 2.69**	**47.15 ± 8.21**
Post-monsoon	**S1**	47.39 ± 4.65	68.39 ± 7.76	3.24 ± 0.31	22.74 ± 7.99	12.51 ± 2.83	79.36 ± 8.09
	S2	43.84 ± 3.97	64.75 ± 8.49	3.06 ± 0.30	18.23 ± 5.45	8.33 ± 3.26	68.15 ± 3.93
	S3	38.46 ± 3.07	58.59 ± 10.58	2.82 ± 0.46	15.48 ± 3.13	7.651 ± 3.23	74.47 ± 6.44
	S4	41.64 ± 4.14	61.25 ± 9.94	2.53 ± 0.57	9.55 ± 2.17	9.36 ± 1.94	78.05 ± 8.70
	S5	34.18 ± 5.96	67.97 ± 5.78	1.95 ± 0.40	11.39 ± 2.58	5.82 ± 1.67	75.29 ± 6.50
	S6	25.73 ± 3.87	63.19 ± 3.22	1.21 ± 0.23	7.81 ± 2.16	6.45 ± 0.78	70.53 ± 5.84
	S7	28.59 ± 7.09	55.47 ± 6.24	0.67 ± 0.45	10.27 ± 1.89	4.63 ± 2.47	73.49 ± 6.43
Mean		**37.12 ± 8.61**	**62.80 ± 7.94**	**2.21 ± 0.98**	**13.64 ± 6.20**	**7.82 ± 3.22**	**74.19 ± 6.75**

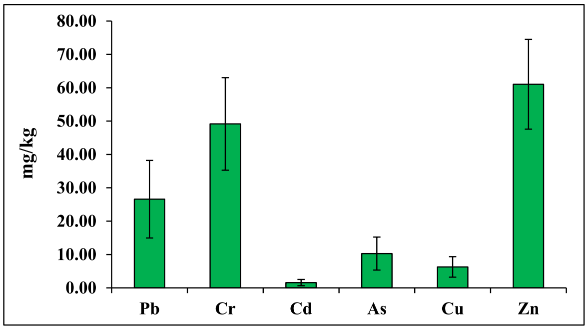

Fig. 2. Concentration of PETs in the sediment of the Pasur River estuary.

Ali et al. [23], who found that the average Cr level in Pasur River varied from 44.9 to 57.7 mg/kg. Maximum concentrations of Cr for S1 (68.39 ± 7.76 mg/kg) in the present study specifies that household and industrial wastes are the main input of Cr in the Pasur river estuary. The mean concentration of Pb was 26.58 mg/kg, which was negligible than the toxicity reference value (31 mg/kg) proposed by USEPA [52]. When the mean Pb content in sediment was compared to other rivers' findings, the present value was found to be near to the Pb level (21.11–30.32 mg/kg) of Mongla port region, Bangladesh [25], but higher than the Pb concentration (19.58 mg/kg) of Sangu River estuary [51]. Point and non-point sources of Pb accumulation in sediment include leaded gasoline, petroleum, urban runoff, chemicals, lubricants, tyre and other industries, and steel operations adjacent to the river. As content in the sediment was 9.43 ± 2.87 mg/kg in the pre-monsoon, 7.78 ± 3.19 mg/kg in the monsoon, and 13.64 ± 6.20 mg/kg in the post-monsoon, which was close to the typical shale value (ASV) (13 mg/kg) [23]. Higher As content in the sediment is connected to the use of fertilizer and pesticides. Cu content of the sediment of the Pasur River estuary was the maximum at S1 (12.51 ± 2.83 mg/kg) in Post-monsoon and was lower at S6 (2.28 ± 0.89 mg/kg) in Monsoon season, respectively. The mean Cu concentration (6.28 mg/kg) during the study period was lower than that of the toxicity reference value of 16 mg/kg [52]. However, the recorded value of Cu during the present study was much lower than the Mongla port area, Bangladesh (35.70–41.00 mg/kg) as reported by Chakraborty et al. [25]. Cd concentrations were higher during the Post-monsoon season (2.21 ± 0.98 mg/kg), than during the Pre-monsoon (1.39 ± 0.77 mg/kg) and Monsoon (1.16 ± 0.69 mg/kg). Ali et al. [23] performed a similar study and revealed that the mean value of Cd was 1.33 mg/kg in summer and 2.10 mg/kg in winter. The mean Cd content in the Pasur River sediment was somewhat higher than the toxicity reference value of 0.6 mg/kg [52], representing that Cd may denote a concern to the contiguous ecosystems. The increasing concentration of Cd in the Pasur River sediment might be attributed to industrial operations. Comparisons with similar studies conducted around the world along with the reference values are presented in Table 2.

Table 2
Comparison of PTEs in sediment (mg/kg) with literature value and different international guidelines of the world.

Rivers (Locations)	PTEs concentrations (mg/kg)						References
	Pb	Cr	Cd	As	Cu	Zn	
Pasur River, Bangladesh	26.58 (17.28–37.12)	49.15 (36.45–62.80)	1.59 (1.16–2.21)	10.28 (7.78–13.64)	6.28 (4.98–7.82)	61.04 (47.15–74.19)	This study
Passur River, Bangladesh	6.92	19.37	–	–	15.83	–	[33]
Karnaphuli River, Bangladesh	43.69	20.30	2.01	81.09	–	–	[37]
Meghna River, Bangladesh	12.48	10.59	0.28	–	6.22	42.41	[53]
Rupsa River, Bangladesh	32.57	25.26	3.78	9.31	68.81		[54]
Shantou Bay, China	50.3	47.5	1.1	–	39.7	205.9	[55]
Estuaries, Black Sea	41.37	60.64	0.20	7.36	45.66	94.16	[56]
Danube River, Romania	19.03	42.28	0.36	–	38.56	98.37	[57]
Bahmanshir River, Iran	28.8	113	0.22	3.34	86.5	113	[58]
Terme River, Turkey	3.37	16.76	0.14	0.62	13.67	10.68	[59]
WASV	20	90	0.3	13	45	95	[60]
TRV	31	26	0.6	6	16	110	[52]
LEL	31	26	0.6	6	16	110	[61]
SEL	250	110	10	33	110	820	[62]

3.2. Source identification of PTEs

Principle component analysis (PCA) is the basic type of eigenvector-based multivariate analysis. According to the eigen-value of PCA analysis, PTEs investigated in this study might have come from the same source. Fig. 3A shows that the first principal component (PC 1) consisted of 80.40 % of the overall difference. Cluster analysis classified the PTEs into two groups and those including Pb, Cr, As, and Cu, and those having Cr and Zn (Fig. 3B). The examined metals in the study river might have come from the direct discharge of industrial waste water, which could have come from electrical, pigments and paints, varnish cosmetics, wood processing industries. Furthermore, surface runoff from agricultural regions might add to metal enrichment. As a result, anthropogenic activities were the main source of PTEs in the Pasur river estuary, which is comparable to the findings of Chakraborty et al. [25] and Prosad et al. [54].

3.3. Risk assessment on ecology

3.3.1. Contamination factor and degree of contamination

The contamination factor (CF) and degree of contamination (Cd) analyses revealed the current amount of metal pollution. The CF designated the individual calculation of metal contamination (Fig. 4). The average CF values ranged from 0.18 to 1.55, and decreased in the order of As > Zn > Cr > Cu > Cd > Pb. All metals, with the exception of Pb and Cd, had CF values less than 1, suggesting low contamination. However, the mean CF values of Pb (1.34) and Cd (1.55) exceed the reference value 1, indicating moderate contamination of sediment by Pb and Cd, through anthropogenic sources including the direct discharge of industrial and municipal wastewater, and waste materials. The C_d provides a comprehensive assessment of metal pollution (Fig. 4). The mean value of C_d was 5.04, which demonstrates low contamination of the river sediment. The calculated value of CF ($1 \leq CF < 3$) and C_d (ranges from 8.01 to 10.59 with average value 9.11) in the surface sediments of the Mongla port area (S1), representing a moderate degree of contamination which corresponds with the findings of Chakraborty et al. [25].

3.3.2. Pollution load index

Pollution load index (PLI) of the PTEs is an essential tool to measure the quality of the sediments. The PLI varied in the following decreasing order of post-monsoon (PLI = 0.899) > pre-monsoon (PLI = 0.63) > monsoon (PLI = 0.45) and S1 (PLI = 0.98) > S2 (PLI = 0.77) > S3 (PLI = 0.71) > S5 (PLI = 0.67) > S4 (PLI = 0.57) > S7 (PLI = 0.49) > S6 (PLI = 0.43) (Fig. 5). The PLI values were akin to the findings of Kubra et al. [26] in the Rupsha River. The mean PLI value during the present study was recorded as 0.659 which was much lower compared to the results of Chakraborty et al. [25] as they recorded the mean PLI values of 1.26 and 1.97 during the rainy and dry season, respectively from the surface sediments of the Mongla port area, Bangladesh. The PLI value during the study period was higher (PLI >1) only in S1 in Pre-monsoon (1.02), Post-monsoon (1.23) and at S2 in Post-monsoon (1.12) which confirmed that the sediments were not polluted in other study sites except for S1 and S2. Port activities might be the reason for contamination of sediment at S1 and S2.

3.3.3. Geo accumulation index

Geo-accumulation index (I_{geo}) of the PTEs is shown in Fig. 6. I_{geo} value for Pb (0.1) and Cd (0.101) indicated that the sediment of the studied river was within the category of uncontaminated to moderately contaminate during Post-monsoon season [39] (Supplementary Table 4). However, the I_{geo} value of Cr, As, Cu and Zn indicated uncontamination ($I_{geo}< 0$) state of the sediments of all the studied sites except for S1 and S2. The present finding is similar to the findings of Kubra et al. [26] who reported the mean value of As and Cr was ($0< I_{geo}$) responsible for uncontamination and the mean value of Pb (winter) and Cd was ($I_{geo}>0$) responsible for moderately contamination of the Rupsha River. Consequently, Cd was responsible for the contamination of Mongla port area during wet season and major contributors for maximum Pb and Cd values might be atmospheric pollution, petroleum, municipal wastes, and discarded

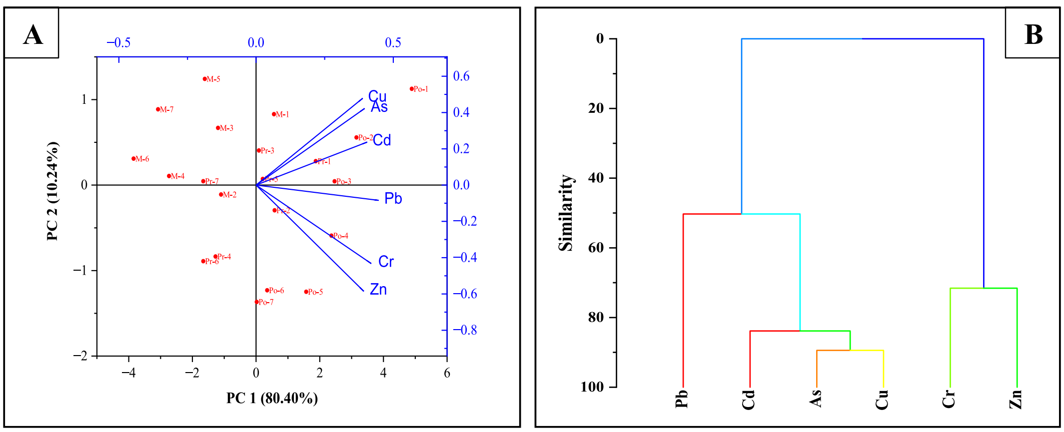

Fig. 3. Principal component analyses (A) and clustering (B) of PTEs in the Pasur River estuary.

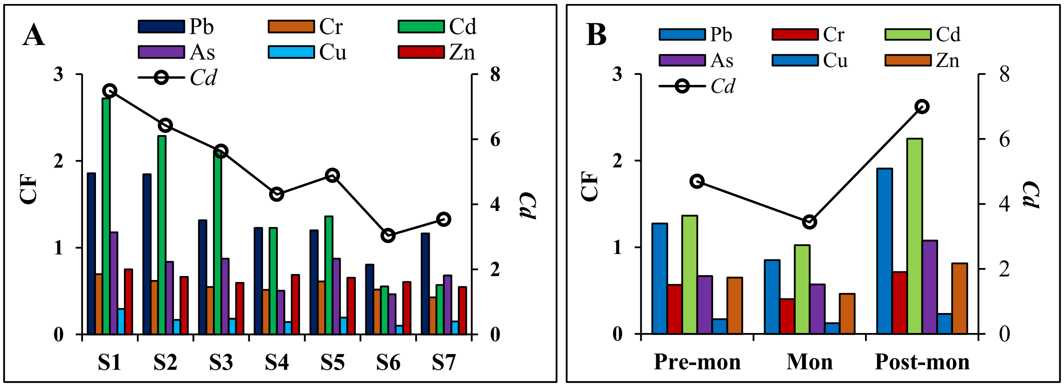

Fig. 4. Spatial (A) and temporal (B) variations of contamination factor (CF) and degree of contamination (*Cd*) of PTEs in the Pasur River estuary.

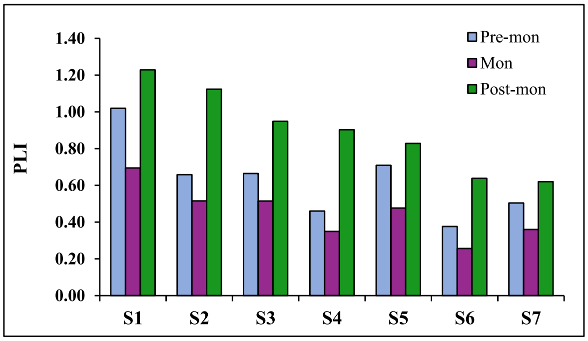

Fig. 5. Pollution load index of PTEs in the Pasur River estuary.

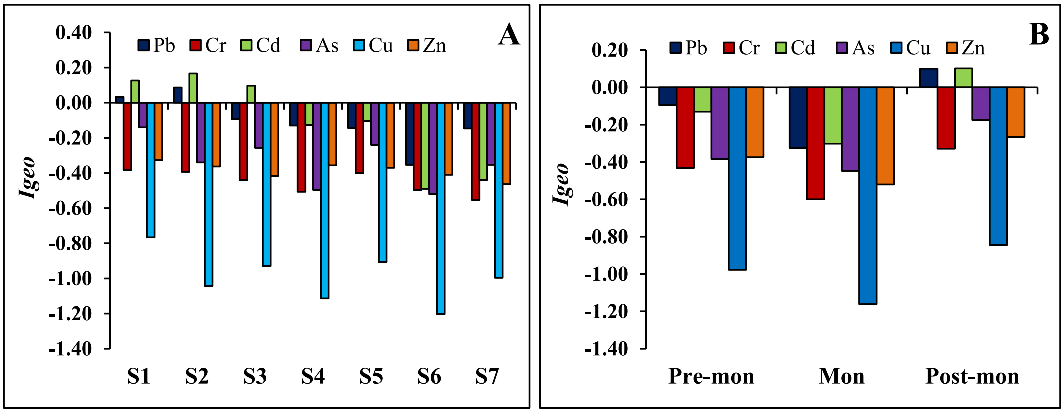

Fig. 6. Spatial (A) and temporal (B) variations of geo-accumulation index of PTEs in the Pasur River estuary.

materials from the port region which supports the findings Chakraborty et al. [25].

3.3.4. Enrichment factor

The enrichment factor (EFc) is a measure of environmental pollution that distinguishes between natural and artificial causes. The *EFc* of the studied metals in the sediments of the Pasur River estuary is shown in Fig. 7. The mean EFc values of the PTEs investigated increased in the following order: Cu (0.06) > Cr (0.19) > Zn (0.22) > As (0.26) > Pb (0.45) > Cd (0.52). (Supplementary Table 5). The *EFc* of sediment ranged from 0.28 to 2.60 in the Bengal Basin river system of Bangladesh, which was greater than the current findings [29]. The *EFc* of the PTEs (except Cd) presented no enrichment ($EFc < 1$) in all the sites during the studied seasons. However, Cd showed no enrichment in all the studied sites except for S1 (1.18), S2 (1.05) and S3 (1.08) during Post-monsoon season, whereas minor enrichment (*EFc* value ranged from 1 to 3) of Cd was observed. The present finding is alike to that of Chakraborty et al. [25] who stated

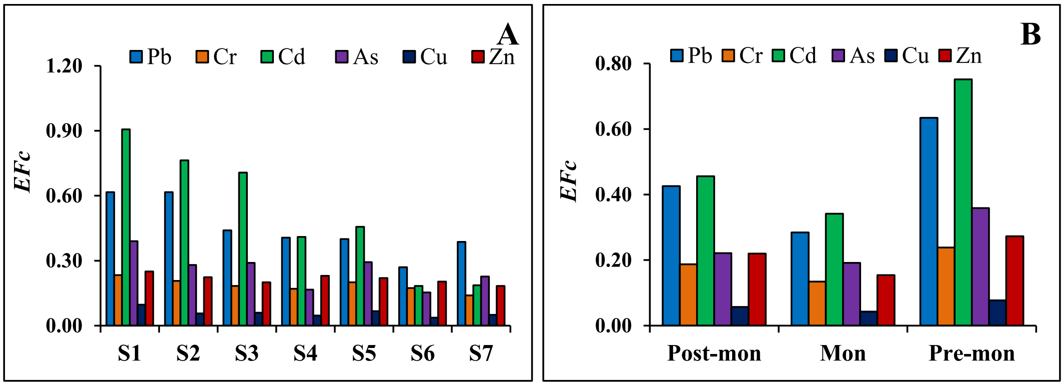

Fig. 7. Spatial (A) and temporal (B) variations of enrichment factor of PTEs in the Pasur River estuary.

higher enrichment of Cd during dry and wet seasons in the sediment. The *EFc* values represent the causes of metal deposition in sediments. The *EFc* values greater than 1.5 suggest that human activity was most likely the cause of enrichment. Conversely, metals with an EFc of 0.05–1.50 are considered lithogenic [63]. [63].

3.3.5. Potential ecological risk factor and risk index

The potential ecological risk factor (E_r^i) and risk index (PERI) are critical for a comprehensive knowledge of sediment pollution and the associated biological threat [64]. The mean E_r^i scores of PTEs in the sediments of Pasur River Estuary dropped gradually to the direction of Cd (46.42) > As (7.72) > Pb (6.72) > Cr (1.12) > Cu (0.87) > Zn (0.64) (Supplementary Table 6). Cd posed a moderate to significant ecological danger during the study period with E_r^i values in the range of 9.84–105.96 (with a mean value 46.42). The dumping of oily discharges and industrial wastes in the port region, as well as land-based runoff into the river, might be the reason of Cd in the sediments. E_r^i value of Cd was in the range of 46.51–170.00 with a mean value of 94.57 in Mongla port area and might be responsible for moderate to considerable ecological risk in this area [25]. Among all the PTEs analyzed, Cd posed the greatest risk to the surface sediment of the Old Brahmaputra River since its eco-toxicological impact was higher than that of all the other metals computed [65]. However, the E_r^i scores of all the studied metals (except Cd) in sediments in all the season and sites were lower than E_r^i <40, which designated low ecological risk by these metals [43]. Furthermore, during the study period, the mean value of PERI was 56.59, 42.60 and 91.3 during the three studied seasons (Fig. 8). A range of PERI (41.0–223) in the sampling sites was recorded by Ali et al. [23] which was greater compared to the present study. However, the PERI values indicated low to moderate risk by the PTEs in the Pasur River estuary.

3.4. Human health risk of the contaminated sediment

The cancer and non-cancer risk of PTEs of the Pasur River's surface sediment owing to dermal contact was considered in adults and children (Table 3). ADD_{derm} of Zn was the highest in both adult and child during the Post-monsoon (2.91E-07, 1.65E-06) season. Moreover, ADD_{derm} of Zn was the highest for child compared to the adult. According to the HQ_{derm} values PTEs of the Pasur River estuary showed non-carcinogenic risk for both adults and children. Maximum HI value was recorded from both adult and child during the Post-monsoon (8.86E-03, 5.02E-02) compared to the Pre-monsoon (6.05E-03, 3.43E-02) and Monsoon (4.65E-03, 2.63E-02). Furthermore, HQ_{derm}, and HI values of the PTEs were below 1.0, indicating no potential hazard for both adult and child health due to the contact of sediment. The HQ and HI values in the sediment of Miliç Wetland were <1.0, suggesting non-carcinogenic hazards for adults and children, which is consistent with our current findings [66]. Consequently, Cr displayed the highest CR_{derm} value whereas; Pb showed the lowest CR_{derm} value during the studied seasons whereas maximum value was recorded for child compared to adult. The CR_{derm} value for all the PTEs in both adult and child found much lower than 10^{-6} during the present study. Therefore, dermal contact of sediment of the Pasur river is assumed to be non-carcinogenic for both adult and child. Topaldemir et al. [66] also reported that the calculated cancer risk values are under the target risk limit (1.00E-04), showing no-carcinogenic risk for adults irrespective of whether the sediment is inadvertently ingested or dermally contacted [67,68], which supports the current findings.

4. Conclusion

The contamination of PTEs in the surface sediment of the Pasur River estuary was evaluated, with Zn exhibiting the greatest concentration, followed by Cr, Pb, As, Cu, and Cd. PCA and CA analyses indicated the common anthropogenic origin (largely from industries and municipal origin) of the PTEs in sediment. The mean CF and I_{geo} value outlined that the surface sediment of Pasur River estuary was uncontaminated to moderately contaminated with Pb and Cd. Both PLI and *EFc* (only Cd) confirmed that the sediments of S1 and S2 were polluted compared to other sites and sea port activities might be responsible for this pollution. However, E_r^i (except Cd) and PERI values of the present study specified that there was low to moderate potential ecological risk posed by PTEs. Furthermore, the dermal contact of the surface sediment of Pasur River estuary did not pose any non-carcinogenic risk (HQ_{derm} and HI < 1) and

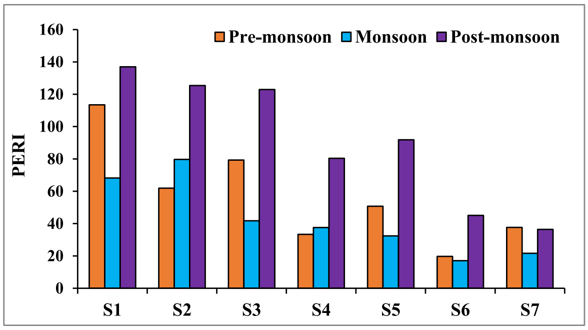

Fig. 8. Potential ecological risk index posed by PTEs in the Pasur River estuary.

Table 3
Health risk of contaminated sediments by PTEs in the Pasur River estuary.

	Non-carcinogenic risk of adult		Non-carcinogenic risk of child		Carcinogenic risk of adult	Carcinogenic risk of child
	ADD_{derm}	HQ_{derm}	ADD_{derm}	HQ_{derm}	CR_{derm}	CR_{derm}
Pre-monsoon						
Pb	2.88E-09	2.29E-04	5.44E-07	1.30E-03	8.17E-10	4.62E-09
Cr	1.27E-08	2.56E-03	1.09E-06	1.45E-02	9.61E-08	5.44E-07
Cd	6.40E-08	1.03E-03	2.91E-08	5.82E-03	3.24E-08	1.83E-07
As	3.82E-08	2.22E-03	2.14E-07	1.26E-02	5.67E-08	3.21E-07
Cu	6.19E-08	2.13E-06	1.45E-07	1.21E-05		
Zn	1.12E-07	3.88E-06	1.32E-06	2.19E-05		
HI		6.05E-03		3.43E-02		
Monsoon						
Pb	6.42E-08	1.53E-04	3.63E-07	8.65E-04	5.46E-10	3.09E-09
Cr	1.36E-07	1.82E-03	7.71E-07	1.03E-02	6.81E-08	3.85E-07
Cd	3.87E-09	7.73E-04	2.19E-08	4.37E-03	2.44E-08	1.38E-07
As	3.22E-08	1.90E-03	1.82E-07	1.07E-02	4.84E-08	2.74E-07
Cu	1.88E-08	1.56E-06	1.06E-07	8.85E-06		
Zn	1.67E-07	2.78E-06	9.42E-07	1.57E-05		
HI		4.65E-03		2.63E-02		
Post-monsoon						
Pb	1.44E-07	3.43E-04	8.14E-07	1.94E-03	1.22E-09	6.92E-09
Cr	2.42E-07	3.23E-03	1.37E-06	1.83E-02	1.21E-07	6.85E-07
Cd	8.49E-09	1.70E-03	4.81E-08	9.61E-03	5.35E-08	3.03E-07
As	6.09E-08	3.58E-03	3.45E-07	2.03E-02	9.13E-08	5.17E-07
Cu	3.47E-08	2.89E-06	1.97E-07	1.64E-05		
Zn	2.91E-07	4.86E-06	1.65E-06	2.75E-05		
HI		8.86E-03		5.02E-02		

carcinogenic risk ($CR_{derm} < 10^{-6}$) for both child and adult. Although the river's sediment was not sufficiently polluted to pose a significant risk to ecological and public health, frequent monitoring is suggested to ensure that the river's quality does not deteriorate in the coming years. The experiment was only run once a year, which was the primary flaw in the current study. Long-term research is thus advised. The report also suggests looking into how PTEs affect the river's aquatic life.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Md. Abu Sayed Jewel: Supervision. **Afia Zinat:** Investigation. **Bithy Khatun:** Writing – original draft. **Sumaiya Akter:** Writing – review & editing. **Arun Chandra Barman:** Writing – review & editing. **Abdus Satter:** Writing – review & editing. **Md. Ayenuddin Haque:** Writing – review & editing, Writing – original draft, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e29278.

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