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ECOLOGICAL ASPECTS OF HEAVY METALS IN SEDIMENTS OF PADMA RIVER IN BANGLADESH

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ABSTRACT

The study was piloted to assess the ecological risk of heavy metals in sediments collected from the Padma River in Bangladesh during April to July 2022. The sediment samples were collected from five sampling sites and analyzed in the laboratory of the Soils Science, Dept. of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University using ICP-MS. The mean concentration of As, Cd, Cr, Cu, Pb and Zn in summer season were 0.59, 0.83, 7.10, 16.23, 5.53 and 44.60 mg/kg, respectively. In winter, the mean concentration of As, Cd, Cr, Cu, Pb and Zn are 1.59, 1.22, 10.37, 24.43, 8.07 and 66.97mg/kg, respectively. Metals concentrations were found below the recommended value set by different sediment quality guidelines except for Cd**.** Multivariate analysis demonstrated that the vast majority of the metals in agricultural sediments may originate from both anthropogenic and lithogenic activities. The contamination factor (CF), geo-accumulation index (Igeo) and potential ecological risk (PER) revealed that most of the soil samples were contaminated by Cd. The geo-accumulation index values showed that most of the samples were poorly contaminated by heavy metals. Sediment sampling sites showed low to moderate potential ecological risk (PER) in the context of PER. The results also described that the pollution load index (PLI) for all investigated samples were lower than the standard level but the growing number of industries may cause advanced declinations of sediments. However, regular monitoring is needed for the documentation of any alternation in the quality of sediments and minimizes the damage to the benthic ecosystem.

Key words: Heavy metal, Sediments, Spatial distribution, Ecological Risk, Padma River.

Introduction

The ecological risks of heavy metals are the major concern for modern world. Heavy metal residues from the contaminated habitat may lead to bioaccumulation as well as bio-magnification in microorganisms, aquatic vegetation, and fauna, which consequently may enter into the human food chain and create many problems related to human health (Kormoker *et al*., 2019; Kabir *et al*., 2020). Rajshahi is the largest city in Bangladesh which is situated on the bank of Padma River. A huge amount of domestic and municipal sewage is regularly mixed with its water and ultimately pollutes it. The domestic sewage contains fecal materials originated from human and other animals. There are roughly 5162 industries in Rajshahi district. These industries are dominated by hand looms, rice and oil mills, and other food industries. The industries are located throughout the district but around 32% are found within the Rajshahi City Corporation area. From these different industries and municipalities, contaminations of heavy metals are added with the Padma River. Although several studies have conducted for assessing ecological risk due to heavy metal in sediment in the urban and industrial regions of the world (Varol, 2011; Acharjee *et al*., 2021), but so far, to the best of our knowledge, no detailed scientific work has been performed on the distribution, potential sources and ecological implications of these pollutants in the Padma River sediments. Thus, the present study was conducted to address the following objectives: (i) to determine the spatio-temporal elemental distribution of heavy metals in Padma River sediment, (ii) to evaluate the possible sources of these metals and (iii) to assess the potential ecological risk of heavy metals using recommended indices.

Materials and Methods

Study area: Sediments samples were collected from different sites of the Padma Rivar at Rajshahi, Bangladesh. Geographically, Rajshahi is situated within Barind Tract, 23m (75ft) above sea level, and lies at 24°22′26″N latitude to 88°36′04″E longitude.

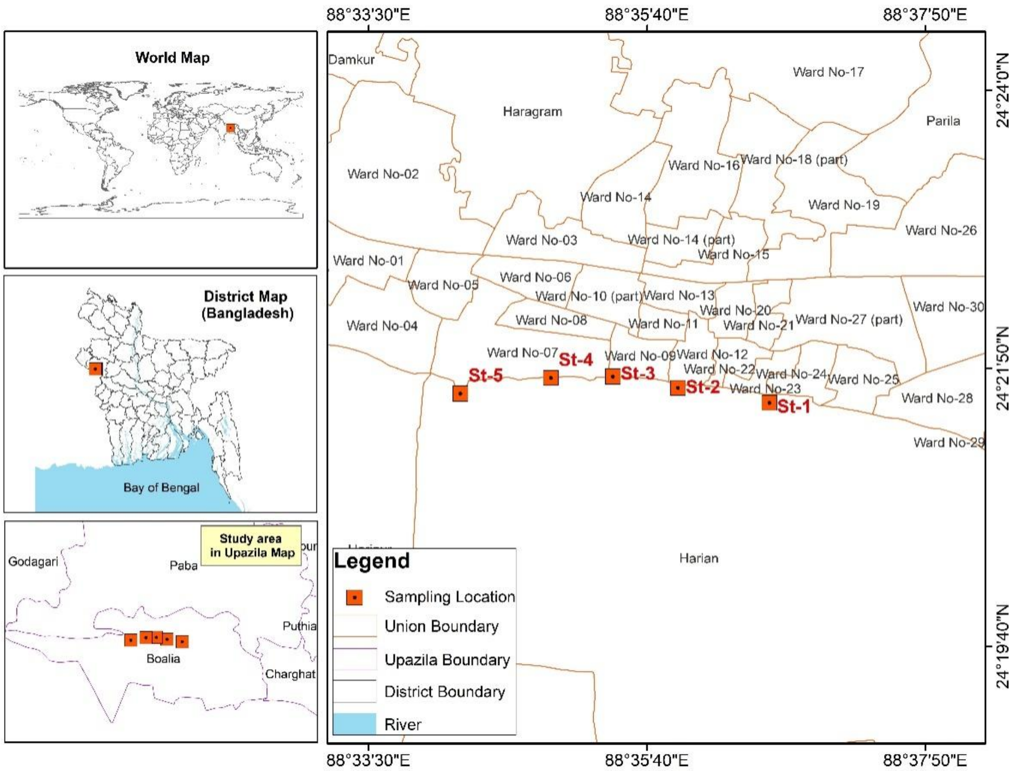

Fig. 1 Map showing the study area with sampling stations in the Padma River, Rajshahi, Bangladesh

Sample collection and preparation: The sediments samples were collected from 5 sampling stations denoted as St-1, St-2, St-3, St-4 and St-5 of the Padma River during dry (April-May), and wet (June to July) period of 2022, respectively. A total of 30 composite sediment samples were collected from the river according to the standard protocol (USEPA, 2001). The river bed sediment samples were taken at a depth of 0 to 10 cm using a portable Ekman Dredge grab sampler (20×20×20 cm). Three composite samples of mass approximately 200 g were collected at each station. All samples were immediately packed in acid-rinsed polyethylene plastic bags and stored at low temperature (4°C) before sample preparation at the laboratory (Islam *et al*., 2017b). The sediment samples were air-dried in a dry, dust-free place at room temperature. The dried samples were then pulverized into a small grain size and homogeneous mixture using a mortar and pestle and sieved through 2 mm aperture to remove organic materials, stones and lumps (Islam *et al*., 2017a). Then the homogenous powdered samples were stored in airtight clean zip lock bag in freezer condition at 8°C up to chemical analysis was carried out (Acharjee *et al*, 2021; Ali *et al*., 2018).

Sample analysis: Sediments samples were analyzed in the Laboratory of Soils Science, Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU). Sediments samples analyses were operated according to international standard analytical procedures. Experimental solutions were purchased from Merck Germ Merck with the maximum grade of purity (99.98%). Samples were digested using ultra-pure $HClO_4$ and HNO_3 (1:2.5). About 0.5 g powdered sediment samples were taken in a 100 mL beaker (Pyrex, Germany) then 15 ml of di-acid mixtures were added to it. The beaker with sample and acid mixture was heated on a hot plate for 5 hours at 130^{o}C until it stayed 2-3 mL in a beaker. Addition of 5 mL of di-acid mixture and boiling were repeated until the solution reached to clear or light colored. Volume was produced after cooling with deionized water. Then, digested materials were filtered using a filter paper (Whatman no. 41). The samples were then subjected to analysis for heavy metals using inductively coupled plasma mass spectrometer (ICP-MS, Agilent7500i, USA).

Sediment quality assessment

Sediment Quality Guidelines (SQGs): These synthesized guidelines consist of a threshold effect level (TEL) that identifies the contaminant concentration below, and the probable effect level (PEL) that indicates the concentration above in which possible adverse effects can be observed on sediment-dwelling organisms (Bai *et al*., 2015). The effect range low (ERL) represents that the chemical concentration below which adverse effects would be rarely observed, but above the effects range median (ERM) concentration, adverse effects would frequently occur (Long and Morgan, 1991). The lowest effect level (LEL) indicates that sediments are considered to be clean to marginally polluted. No effects on the majority of sediment-dwelling organisms are expected below this concentration (MacDonald *et al*., 2000).

Geo-accumulation Index (I_{geo}): The degree of contamination from the trace metals could be assessed by determining the geo-accumulation index (I_{geo}) proposed by Muller (1969). The I_{geo} is extensively used in the assessment of metal contamination in soils (Proshad *et al*., 2019) by comparing the presently obtained concentrations to pre-industrial background concentrations and can be calculated using the following formula defined by Muller (1969):

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

Where, C_n is the measured concentration of inspected metal (n), and B_n is the geochemical background concentration of that metal (n) in background sample (Turekian and Wedepohl, 1961; Rudnick and Gao, 2014). The factor 1.5 is applied for the probable deviations in background values because of lithological effect (Nikolaidis *et al*., 2010). The I_{geo} scale composed of seven classes varying from uncontaminated to extremely contaminated, i.e., class 0 ($I_{geo} \leq 0$): uncontaminated, class 1 ($0 \leq I_{geo} \leq 1$): uncontaminated to moderately contaminated, class 2 ($1 \leq I_{geo} \leq 2$): moderately contaminated, class 3 ($2 \leq I_{geo} \leq 3$): moderately to strongly contaminated, class 4 ($3 \leq I_{geo} \leq 4$): strongly contaminated, class 5 ($4 \leq I_{geo} \leq 5$): strongly to extremely contaminated, and class 6 ($5 < I_{geo}$): extremely contaminated.

Contamination Factor (CF) and Contamination Degree (CD): To investigate the contamination level of heavy metal in sediments, CF has been commonly employed by many authors previously (Varol, 2011). The CF is the ratio between the measured concentration of each metal in the sediment and the background concentration of that metal quantified by Rudnick and Gao (2014). The CF for each metal was calculated by the following formula stated by Håkanson (1980).

$$CF = \text{Measured metal concentration}(C_m) / \text{ Background concentration of the metal } (B_m) \quad \ldots\ldots\ldots(3)$$

The CD was determined by the sum of all the contamination factors for all of the elements to disclose the degree of potential toxic metal in sediments (Håkanson, 1980; Kabir *et al*., 2020). In this study, the CD was computed by the sum of the five/six heavy metals in the sediments of the Brahmaputra River. Håkanson (1980) categorized four ratings of sediments with respect to CF values e.g. CF<1: low, 1≤CF<3: moderate, 3≤CF<6: considerable, and CF≥6: very high contamination, and in contrast, Tomlinson et al. (1980) testified four grades of sediments based on the CD ranges, i.e., CD<6: low, 6≤CD<12: moderate, 12≤CD<24: considerable, and CD≥24: very high pollution.

Modified degree of contamination (mCD): The modified degree of contamination (mCD) is Hakanson's modified degree of contamination index, which integrates single pollution index to evaluate each sediment sample (Hakanson, 1980). The mCD can be calculated by following equations:

$$mCD = \frac{1}{n} \sum_{i=n}^{1} CF_i \quad \ldots\ldots\ldots\ldots(4)$$

Where, mCD is the modified contamination degree; n is the total number of metal elements considered; i is the ith pollutant; CF_i is the contamination factor of ith heavy metals. The mCD is categorized as $mCD < 1.5$: Nil to very low; $1.5 \leq mCD < 2.0$: low; $2.0 \leq mCD < 4.0$: moderate; $4.0 \leq mCD < 8.0$: high; $8.0 \leq mCD < 16.0$: very high; $16.0 \leq mCD < 32.0$: extremely; $mCD > 32$: ultra-high contamination (Zhang *et al*., 2018).

Pollution load index (PLI): The PLI evaluates mutual pollution weight at dissimilar locations through the dissimilar metals in soils and sediments, and provided an evaluation of the inclusive toxicity grade of the each single sampling location (Proshad*et al.*, 2019). For all of the sampling stations, PLI was work out as the nth root of the product of the multiplications of the contents by the following equation suggested by the Tomlinson *et al.* (1980):

$$PLI = \sqrt[n]{(CF_1 \times CF_2 \times CF_3 \times \ldots . CF_n)} \ldots\ldots\ldots\ldots\ldots..(5)$$

The PLI value of 0, 1 and above 1 means perfection, existence of only baseline levels of pollutants and progressive deterioration of site quality, respectively (Tomlinson *et al.*, 1980). This empirical index delivers a simple and comparative means for weighing the level of heavy metal pollution, where, PLI>1 specifies pollution exists, conversely, if PLI<1 designates there are nonexistence metal pollution (Varol, 2011).

Ecological risk factor (E_r^i) and Potential ecological risk index (PER): The potential ecological risk coefficient E_r^i of a single metal and the potential ecological risk index PER of multi-metal can be calculated via the following equations:

$$E_r^i = T_f^i \times C_f^i \ldots\ldots\ldots\ldots..(8)$$

$$PER = \sum_{i=1}^{n} E_r^i \ldots\ldots\ldots\ldots\ldots.(9)$$

In these equations, C_f^i is the accumulating coefficient of metal (i) and T_f^i is the toxic-response factor of metal (i), which exposes its levels of toxicity and the sensitivity of bio-organism to it. The computing equation for accumulating coefficient C_f^i is as follows:

$$C_f^i = C_m^i / C_n^i \ldots\ldots\ldots\ldots..(10)$$

Where, C_m^i is the value of heavy metal concentration in the sediments samples, and C_n^i is the pre-industrial background values of respective metals. Chen and Zhou (1992) specified four ratings of ecological pollution degree of heavy metal in sediments like as E_r^i< 40 or PER < 150: low, 40 ≤ E_r^i< 80 or 150 ≤ PER < 300: moderate, 80 ≤ E_r^i< 600 or 300 ≤ PER <600: considerable and 160 ≤ E_r^i< 320 or 600 ≤ PER: very high ecological risk for the sediments.

Statistical Analysis: In this study, statistical tools including Pearson's correlation coefficient analysis was used using IBM SPSS Statistics 20.0 to reveal the relationships between studied heavy metals as well as to identify their plausible sources in the sediments. The spatial distribution maps were prepared using ArcGIS 14.1 software.

Results and Discussion

Elemental distribution of heavy metal concentration in sediments: The heavy metal contents of in sediments of the Padma River during the summer and winter seasons are presented in Table 1. The wide range of metal concentrations was witnessed among the sampling stations and seasons. The concentrations of As, Cd, Cr, Cu, Pb and Zn in sediments were ranged from 0.13 to 1.93, 0.66 to 1.67, 6.52 to 12.43, 12.17 to 29.12, 3.97 to 10.32 and 37.29 to 72.26 mg/kg (Table 1). By the result, the concentration of heavy metals increases in winter season. The mean concentration of As, Cd, Cr, Cu, Pb and Zn in summer season were 0.59, 0.83, 7.10, 16.23, 5.53 and 44.60 mg/kg, respectively. In winter the mean concentration of As, Cd, Cr, Cu, Pb and Zn are 1.59, 1.22, 10.37, 24.43, 8.07 and 66.97mg/kg, respectively (Table 1). Various influences such as geomorphological outfits, land runoff, and industrial discharge might have played a dynamic role on heavy metal concentrations (Kabir *et al.*, 2020).

In this study, the mean concentration of As was 0.59 (mg/kg) in summer and 1.59 (mg/kg) in winter, which is more than double in winter. The highest As was found in St-4 in summer and St-5 in winter. The highest and lowest mean concentrations of As is lower than TRV, average shale value, lowest effect level, threshold effect level, continental upper crust, severe effect level, probable effect level, effect range low, and effect range medium values (Table 2). Results of the study revealed that cadmium (Cd) concentrations in sediment from studied areas of the Padma River ranged from 0.66 to 0.98 mg/kg in summer, and 0.99 to 1.67 mg/kg in winter. The mean concentration of Cd is 0.83 mg/kg in summer and 1.17 mg/kg in winter. The mean is greater than TRV, average shale value, lowest effect level, toxicity reference values, threshold effect level, continental upper crust, effect range low values; but lower than severe effect level, probable effect level, effect range medium values (Table 2). The highest concentration of Cd was found in St-4 in summer and; St-5 in winter, while the lowest concentration of Cd was found in St-5 in summer and St-2 in winter. Higher Cd concentration in sediments might be come from industry, metal processing, atmospheric emission and Cd plated items, pesticides etc. The highest level of Cr was observed in sediment collected from St-5 in summer and St-5 in winter, while the lowest level was perceived at St-2 in summer and St-3 in winter. The mean concentration of Cd was 7.10 mg/kg in summer and 10.37 mg/kg in winter. The mean concentrations are lower than average shale value, lowest effect level, threshold effect level, continental upper crust, severe effect level, probable effect level, effect range low, and effect range medium values (Table 2). Anthropogenic sources include metal smelting and refining, fuel combustion in power generation and heating, pulp and paper production, metals processing, and wastewater treatment. Phosphate fertilizers can also have high cadmium levels. At the present investigation, lead (Pb) concentrations in sediments of the Padma River were ranged between 3.97(mg/kg) to 7.26(mg/kg) in summer; 4.19 (mg/kg) to 10.37 (mg/kg) in winter. The highest level of Pb was observed in sediment collected from St-5 in summer and St-5 in winter, while the lowest level was perceived at St-3 in summer and St-2 in winter. The mean concentration of Pb is 5.53 (mg/kg) in summer and 8.07(mg/kg) in winter.

The mean concentrations were lower than average shale value, lowest effect level, threshold effect level, continental upper crust, severe effect level, probable effect level, effect range low, and effect range medium values (Table 2). Lead-based paint, metal processing industries and lead-contaminated dust in older buildings are common sources of lead poisoning. The major sources of Cu are industries, electroplating, mining and agricultural activities. Cu can be toxic to human, animal and plants. The present result shows that, in the sample sites, the concentration of Cu ranged from 12.17 to 21.26 mg/kg in summer; 21.26 to 29.12 mg/kg in winter. The mean concentration of Cu is 16.23 mg/kg in summer; 24.43 mg/kg in winter. The highest concentration is 21.26 mg/kg in summer and 29.12 mg/kg in winter. The lowest concentration of Cu was 12.17 mg/kg in summer and 21.26 mg/kg in winter. The mean concentrations are lower than average shale value, toxicity reference values, threshold effect level, continental upper crust, severe effect level, probable effect level, effect range low, and effect range medium values (Table 2).

Table 1. Heavy metal concentration (mg/kg) in sediments of Padma River in two different seasons

Sampling sites	Arsenic (As)		Cadmium (Cd)		Chromium (Cr)		Copper (Cu)		Lead (Pb)		Zinc (Zn)	
	S	W	S	W	S	W	S	W	S	W	S	W
St-1	0.76	1.69	0.83	1.08	7.16	10.93	16.33	22.54	6.37	8.29	37.29	72.26
St-2	0.23	1.17	0.66	0.99	5.73	9.18	17.48	29.12	3.97	4.19	46.73	66.28
St-3	0.85	1.86	0.77	1.18	6.52	8.19	21.26	25.48	5.6	9.88	51.17	52.12
St-4	0.98	1.32	0.89	1.17	7.76	11.13	13.89	23.76	4.43	7.69	38.92	78.34
St-5	0.13	1.93	0.98	1.67	8.32	12.43	12.17	21.26	7.26	10.32	48.87	65.87
Mean	0.59	1.59	0.83	1.22	7.10	10.37	16.23	24.43	5.53	8.07	44.60	66.97
SD	0.38	0.33	0.12	0.26	1.02	1.68	3.49	3.05	1.36	2.43	6.16	9.74
CV (%)	65.08	20.99	14.64	21.69	14.33	16.21	21.53	12.48	24.53	30.08	13.81	14.54
Median	0.76	1.69	0.83	1.17	7.16	10.93	16.33	23.76	5.60	8.29	46.73	66.28
Minimum	0.13	1.17	0.66	0.99	5.73	8.19	12.17	21.26	3.97	4.19	37.29	52.12
Maximum	0.98	1.93	0.98	1.67	8.32	12.43	21.26	29.12	7.26	10.32	51.17	78.34
Skewness	-0.46	-0.44	-0.20	1.76	-0.25	-0.24	0.49	0.96	0.12	-1.21	-0.36	-0.75
Kurtosis	-2.82	-2.43	-0.13	3.51	-0.96	-1.26	-0.07	0.66	-1.76	1.48	-2.69	1.19

*S=Summer; *W=Wet

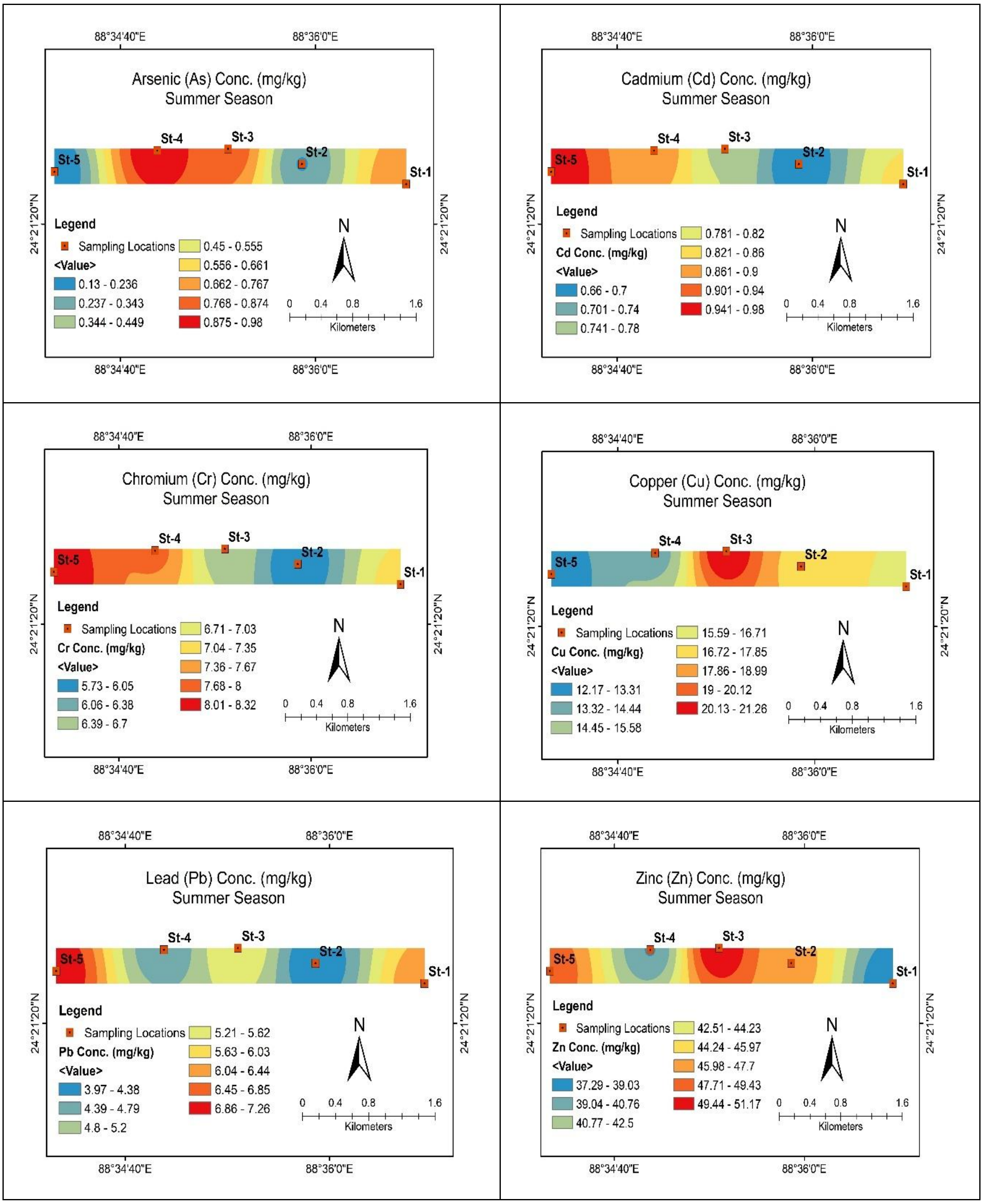

Fig. 2. Spatial distributions of heavy metals in sediments of the Padma River during summer season

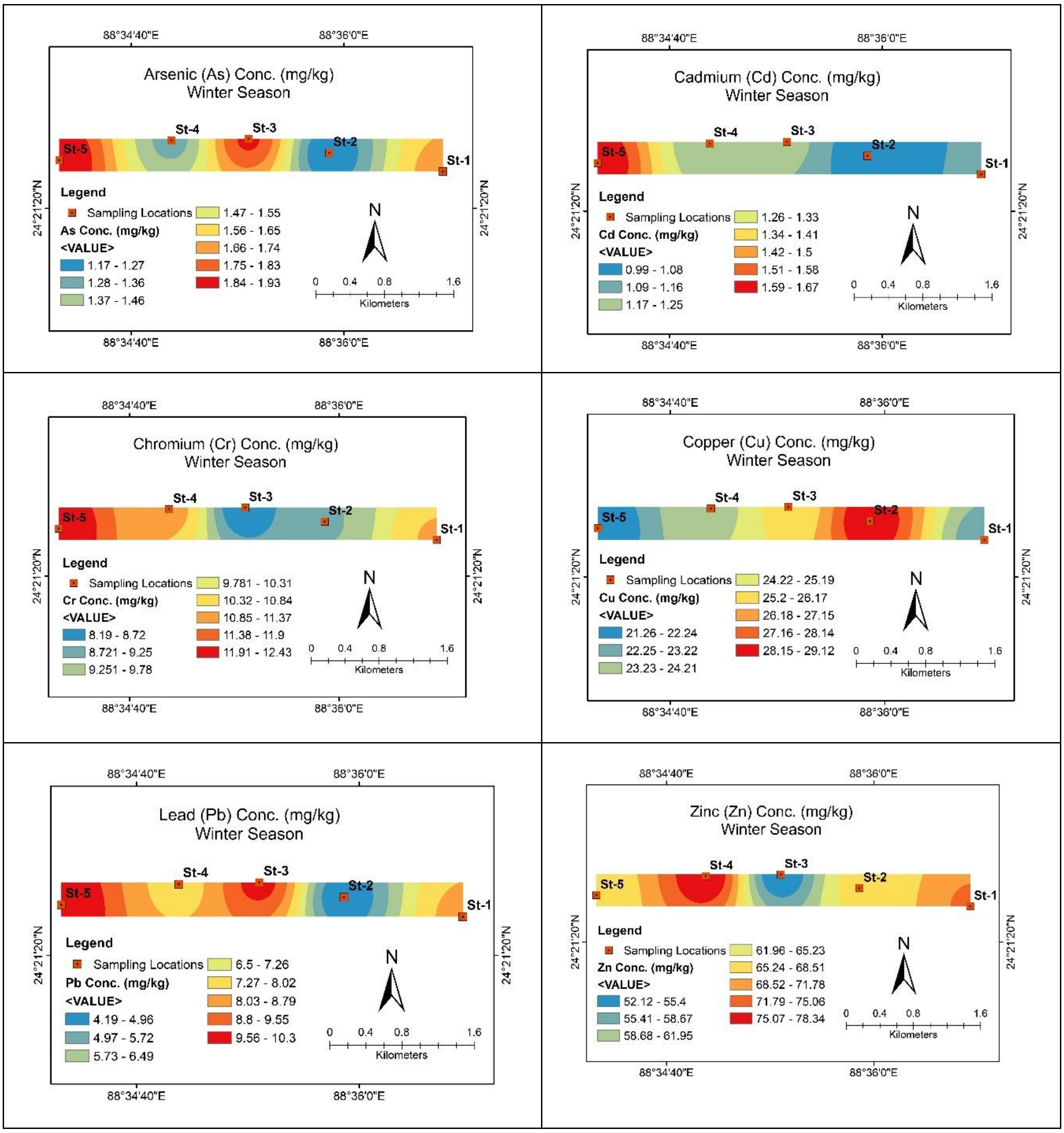

Fig. 3. Spatial distributions of heavy metals in sediments of the Padma River during winter season

Main sources of Zn are industries, electroplating and mining. At the present investigation, Zinc (Zn) concentrations in sediments of the Padma River were ranged between 37.29 (mg/kg) to 51.17(mg/kg) in summer; 52.12 (mg/kg) to 78.34 (mg/kg) in winter. The highest level of Zn was observed in sediment collected from St-3 in summer and S-4 in winter, while the lowest level was perceived at St-1 in summer and St-3 in winter. The mean concentration of Zn is 44.60 (mg/kg) in summer and 66.97 (mg/kg) in winter. The mean concentrations are lower than TRV and average shale value (Table 2). The concentrations of heavy metal in sediments of the Padma River were compared with other major rivers of Bangladesh and other countries (Table 2). The concentration of Cd is lower than Rupsa, Gomti, Ganges, Buriganga, Korotoa, Nanhe River, Kim Nguu River; while the concentration was higher than Dhaleshwari, Bangshi, Paira, Ganges, Louhajang, Old Brahmaputra and Meghna River (Table 2). The mean concentration of Cr is lower than Rupsa, Dhaleshwari, Bangshi, Padma, Paira, Ganges, Louhajang, Buriganga, Jamuna, Buriganga, Old Brahmaputra, Korotoa, Hooghly River, Nanhe River, Kim Nguu, Meghna River. But the concentration of Cr is higher than Ganges River. The mean concentration of Zn in present study is lower than Bangshi, Meghna River while higher than Dhaleshwari, and Ganges River. The mean concentration of Cu of present study was lower than Rupsa, Bangshi, Padma, Paira, Buriganga, Jamuna,Buriganga, Nanhe River; while higher than Dhaleshwari, Gomti, Ganges, andLouhajangRiver. The concentration of As in present study was higher than Ganges-Bangladesh; while lower than other studies. The mean concentration of Pb in present study is higher than Ganges, and Louhajang, River but lower than other studies.

Table 2. Comparison of heavy metals in sediments (mg/kg) with some reference values and some reported values

River	Cr	Zn	Cu	As	Cd	Pb	References
Padma	8.735	55.785	20.33	1.09	1.025	6.8	This study
Padma	9.31	16.14	9.33	0.65	1.90	6.43	Jewel *et al*. (2020)
Rupsa	25.26	NA	68.81	9.31	3.78	32.57	Proshad *et al*. (2019)
Dhaleshwari	64.7	7.29	6.8	NA	0.73	15.4	Haque *et al*. (2021)
Bangshi	98.10	117.15	31.01	1.93	0.61	59.99	Rahman *et al*. (2013)
Paira	45	NA	30	12	0.72	25	Islam *et al*. (2014)
Gomti	8.5	NA	5	NA	2.42	40.3	Singh *et al*. (2005)
Ganges	4.1	NA	2.69	NA	0.77	6.35	Gupta *et al*. (2009)
Louhajang	9.205	NA	17.72	8.999	0.083	4.597	Kormoker *et al*. (2019)
Buriganga	297	NA	280	21	7	732	Islam *et al*. (2018)
Jamuna	110	NA	28	NA	NA	19	Datta and Subramanian (1998)
Old Brahmaputra	30.25	NA	NA	3.74	0.03	14.29	Shorna *et al*. (2021))
Korotoa	109	NA	76	25	1.2	58	Islam *et al*. (2015)
Meghna	31.73	79.02	-	NA	0.23	9.47	Hassan *et al*. (2015)

Evaluation of environmental and ecological risk of heavy metals

Geo-accumulation index (I_{geo}): The geo-accumulation index (I_{geo}) was developed by Muller (1969) to assess the level of heavy metal and metalloid elements in the sediment by comparing the status of the current concentration with the pre-industrial level. The mean I_{geo} Values of the considered six metals showed the decreasing order Cd> Zn> Cu> Pb> Cr> As in summer and Cd > Zn> Cu> Pb> As >Cr in winter. Based on Muller (1969) categorizations, I_{geo} values for Cd were determined as grade 3 (moderately to strongly contaminated) and for other metals such as As, Cr, Pb, Cu and Zn were determined as grade 0 (Unpolluted). The results also revealed that the highest I_{geo} value was found for Cd (3.63) in winter at St-5 and the lowest I_{geo} value was found for As (5.79) at St-5 in summer.

Contamination factor (CF): The contamination factor for all measured metals is presented in table 4.4. The mean CF value of all tested metals were found in following order: Cd (Very high) > Zn (low) > Cu (low)> Pb (low) > Cr (low)> As (low) in summer, and Cd (very high)> Zn(low) > Cu (low) > Pb (low) > As(low) >Cr (low) in winter. The maximum CF value was found for Cd 10.89 in summer and 13.56 in winter at St- 5. The lowest was found for As at St-5 in summer.

Contamination degree (CD): The contamination degree (CD) for all measured metals is presented in table 4.5. In summer, the mean CD values of all metals were found in following order: St-1 (Moderate degree contamination), St-2 (moderate degree contamination), St-3 (moderate degree contamination), St-4 (moderate degree contamination), and St-5 (considerable degree contamination). In winter, the mean CD values of all metals were found in following order: St-1 (considerable degree contamination), St-2 (considerable degree contamination), St-3 (considerable degree contamination), St-4 (considerable degree contamination), and St-5 (considerable degree contamination).

Modified Contamination Degree (mCD): The mean mCD values for all sampling sites showed evidently nil to very low extent of pollution (Table 4.4). Results of the study stated that for higher extent of mCD values along with spatial variations numerous anthropogenic causes in conjunction with the lithogenic factors are mainly responsible.

Pollution load index (PLI): A PLI mean to the number of times by which the heavy metal contents in the soil exceed the geochemical background concentrations and delivers a mass expression of the level of heavy metal toxicity in a specific sample (Barakat *et al*., 2012). PLI value zero means perfection; a value of one indicates progressive deterioration of sediment in terms of contamination of metals (Tomilson *et al*., 1980). The PLI values are not high but can grow in future for rapid industrialization.

Ecological Risk Factors (E_r^i) and potential ecological risk index (PER): The PER represents the sensitivity of the biological community to the toxic substances and illustrates the PER caused by the overall contamination (Proshad *et al*., 2019). The order of $\mathbf{E_r^i}$ in sediments was in the following descending order of Zn > Cu > Cr > Pb > As > Cd which indicates high to low ecological risk respectively.

Correlation Coefficient Analysis (CCA): Pearson's correlation analysis of all tested heavy metals in sediments from different sites of Padma River is summarized in (Table 7). In summer season, the study showed strong positive correlations between Cr with Cd, Pb with Cd, and Pb with Cr, whereas negative relation exists between Cu with Cd, and Cu with Cr. In winter season, the study showed strong positive correlations between Pb with As, As with Cd, Cd with Cr, Pb with Cd and, Zn with Cr whereas negative relation exists between Cu with As, and Cu with Cd. Considering the relationship between the combinations showed positive relationship which indicates the parameters were interrelated with each other and may be originated from the same source to study area. Other relationships among the constituents of sediments were not significant.

Table 3. Geo-accumulation index (Igeo) values of heavy metals in sediments

Sites	AS		Cd		Cr		Cu		Pb		Zn	
	S	W	S	W	S	W	S	W	S	W	S	W
St-1	-3.24	-2.09	2.62	3.00	-4.27	-3.66	-1.36	-0.90	-2.00	-1.62	-1.43	-0.48
St-2	-4.97	-2.62	2.29	2.87	-4.59	-3.91	-1.26	-0.53	-2.68	-2.61	-1.10	-0.60
St-3	-3.08	-1.95	2.51	3.13	-4.40	-4.07	-0.98	-0.72	-2.19	-1.37	-0.97	-0.95
St-4	-2.88	-2.45	2.72	3.12	-4.15	-3.63	-1.60	-0.82	-2.53	-1.73	-1.37	-0.36
St-5	-5.79	-1.90	2.86	3.63	-4.05	-3.47	-1.79	-0.98	-1.81	-1.31	-1.04	-0.61
Mean	-5.79	-2.62	2.29	2.87	-4.59	-4.07	-1.79	-0.98	-2.68	-2.61	-1.43	-0.95
Max.	-2.88	-1.90	2.86	3.63	-4.05	-3.47	-0.98	-0.53	-1.81	-1.31	-0.97	-0.36
Ave.	-3.99	-2.20	2.60	3.15	-4.29	-3.75	-1.40	-0.79	-2.24	-1.73	-1.18	-0.60
SD (±)	1.31	0.32	0.22	0.29	0.21	0.24	0.31	0.18	0.36	0.52	0.20	0.22

Table 4. Contamination Factor (CF) values of heavy metals in sediments

Sites	AS		Cd		Cr		Cu		Pb		Zn	
	S	W	S	W	S	W	S	W	S	W	S	W
St-1	0.16	0.35	9.22	12.00	0.08	0.12	0.58	0.81	0.37	0.49	0.56	1.08
St-2	0.05	0.24	7.33	11.00	0.06	0.10	0.62	1.04	0.23	0.25	0.70	0.99
St-3	0.18	0.39	8.56	13.11	0.07	0.09	0.76	0.91	0.33	0.58	0.76	0.78
St-4	0.20	0.28	9.89	13.00	0.08	0.12	0.50	0.85	0.26	0.45	0.58	1.17
St-5	0.03	0.40	10.89	18.56	0.09	0.14	0.43	0.76	0.43	0.61	0.73	0.98
Mean	0.03	0.24	7.33	11.00	0.06	0.09	0.43	0.76	0.23	0.25	0.56	0.78
Max.	0.20	0.40	10.89	18.56	0.09	0.14	0.76	1.04	0.43	0.61	0.76	1.17
Ave.	0.12	0.33	9.18	13.53	0.08	0.11	0.58	0.87	0.33	0.47	0.67	1.00
SD (±)	0.08	0.07	1.34	2.93	0.01	0.02	0.12	0.11	0.08	0.14	0.09	0.15

*S=summer; *W=Wet

Table 5. The CD, mCD and PLI of heavy metals in sediments

Sites	CD		mCD		PLI			
	Summer	Winter	Summer	Winter	Summer		Winter	
					Value	Status	Value	Status
St-1	10.97	14.84	1.83	2.47	0.49	nonsexist	0.77	nonsexist
St-2	9.00	13.62	1.50	2.27	0.36	nonsexist	0.64	nonsexist
St-3	10.66	15.86	1.78	2.64	0.52	nonsexist	0.76	nonsexist
St-4	11.51	15.87	1.92	2.64	0.48	nonsexist	0.76	nonsexist
St-5	12.60	21.44	2.10	3.57	0.39	nonsexist	0.88	nonsexist
Min.	9.00	13.62	1.50	2.27	0.36	nonsexist	0.64	nonsexist
Max.	12.60	21.44	2.10	3.57	0.52	nonsexist	0.88	nonsexist
Ave.	10.95	16.33	1.82	2.72	0.45	nonsexist	0.76	nonsexist

Table 6. Potential E_r^i and potential ecological risk indexes (PER) of heavy metals in sediments

Sites	Ecological risk factors (E_r^i)												PER	
	As		Cd		Cr		Cu		Pb		Zn			
	S	W	S	W	S	W	S	W	S	W	S	W	S	W
St-1	1.58	3.52	276.67	360.00	0.16	0.24	2.92	4.03	1.87	2.44	0.56	1.08	283.75	371.30
St-2	0.48	2.44	220.00	330.00	0.12	0.20	3.12	5.20	1.17	1.23	0.70	0.99	225.59	340.06
St-3	1.77	3.88	256.67	393.33	0.14	0.18	3.80	4.55	1.65	2.91	0.76	0.78	264.79	405.62
St-4	2.04	2.75	296.67	390.00	0.17	0.24	2.48	4.24	1.30	2.26	0.58	1.17	303.24	400.67
St-5	0.27	4.02	326.67	556.67	0.18	0.27	2.17	3.80	2.14	3.04	0.73	0.98	332.16	568.77
Min.	0.27	2.44	220.00	330.00	0.12	0.18	2.17	3.80	1.17	1.23	0.56	0.78	225.59	340.06
Max.	2.04	4.02	326.67	556.67	0.18	0.27	3.80	5.20	2.14	3.04	0.76	1.17	332.16	568.77
Ave.	1.23	3.32	275.33	406.00	0.15	0.23	2.90	4.36	1.63	2.37	0.67	1.00	281.91	417.28
SD (±)	0.80	0.70	40.32	88.05	0.02	0.04	0.62	0.54	0.40	0.71	0.09	0.15	40.15	88.66

Table 7. Pearson correlation matrix for heavy metals concentration in sediments

Elements	As	Cd	Cr	Cu	Pb	Zn
Summer Season						
As	1					
Cd	0.000	1				
Cr	0.031	0.996**	1			
Cu	0.341	-0.748	-0.782	1		
Pb	-0.241	0.693*	0.640*	-0.315	1	
Zn	-0.474	-0.153	-0.228	0.359	0.139	1
Winter Season						
As	1					
Cd	0.674*	1				
Cr	0.206	0.660*	1			
Cu	-0.680	-0.698	-0.779	1		
Pb	0.926**	0.710*	0.315	-0.797	1	
Zn	-0.509	-0.102	0.649*	-0.278	-0.315	1

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

Conclusion

Spatial distribution of heavy metals in different sampling sites showed low to moderate degree of concentration. So, appropriate preventive measures need to be adopted for maintaining the heavy metal contents in the sediments of the Padma River. The study also recommended that: (i) industries should strictly maintain the emission/discharge law in the agricultural area, (ii) public awareness and education about the sources and ecological effects of heavy metals should be improved, and (iii) updated technology of industrial emissions should be practiced.

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