CONTAMINATION OF HEAVY METALS IN WATER AND SEDIMENT IN THE VICINITY OF INDUSTRIALIZED ZONES ALONG THE RUPSHA RIVER

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ABSTRACT

Heavy metals in aquatic environments significantly threaten ecosystems and human health. The Rupsha River, a vital water body in Khulna city, serves as a crucial source of water for various purposes, including agriculture and domestic use. It receives water from various industrial sources like shipyards, steel factories, cement industries, seafood industries, fertilizer industries and power companies. Due to rapid industrialization and urbanization, there are some possibilities for increasing heavy metals in the aquatic ecosystems. This research evaluates the contamination of heavy metals in water and sediment samples collected from the Rupsha River in the vicinity of industrial zones during the summer season. Analytical techniques, including Graphite Furnace- Atomic Absorption Spectrometry (GF-AAS) were employed to quantify the concentrations of selected heavy metals such as lead (Pb), Chromium (Cr), zinc (Zn), cadmium (Cd), iron (Fe), and copper (Cu). A spatial distribution of heavy metal concentration was mapped using geographic information system (GIS), providing insights into the extent of the affected areas. In addition, several pollution indices were used to assess the ecological risks. These were the pollution load index (PLI), the contamination factor (C_f), the potential ecological risk index (PER), and the heavy metal pollution index (HPI). Preliminary findings revealed the decreasing trend of heavy metals in water was Fe > Cu > Cr > Zn > Pb > Cd. The average concentrations of Cr, Pb, Cd, Fe, Zn, and Cu were 64.24, 49.2, 1.86, 360.9, 54.64, and 71.46 µg/L, respectively, with Cd, Fe, Zn, and Cu meeting the standard limits of Environmental Conservation Rules (ECR) 2023. Nevertheless, Cr and Pb exceeded the standard limit. In the sediment, the decreasing trend was Pb > Cr > Fe > Cu > Zn > Cd and the average concentrations of Cr, Pb, Cd, Fe, Zn, and Cu were 38.45, 40.26, 0.07, 20.5, 0.78, and 3.06 mg/kg, with Cr and Pb surpassing the toxicity reference value (TSV). Based on the spatial distribution map, stations RR2 and RR4 are more contaminated than other stations. The average HPI value was 159, surpassing the critical index threshold of 100. A maximum HPI value of 224.46 was found at station RR3. In all sediment samples, the PLI values are below 1, indicating negligible soil pollution from heavy metals. The PER ranges from 10.43 to 29.67, signifying low risks across all sampling stations. This investigation emphasizes the necessity for ongoing monitoring of the Rupsha River and the implementation of protective measures to address and mitigate pollution.

Keywords: *Rupsha River, Heavy Metal, Ecological Risk Index, Pollution Load Index, Heavy Metal Pollution Index.*

1. INTRODUCTION

Heavy metals are metallic elements that exhibit relatively high density and are known for their potential toxicity at low concentrations. The worldwide problem of water, sediment, vegetables and aquatic life's poses serious threat to both ecosystems and human well-being. Because of their inherent non-biodegradability, ability to accumulate in biological tissues, environmental stability, persistence, and biotoxicity, they impose a substantial environmental risk. Owing to the rapid expansion of industrial activities and the increasing consumption of industrial goods, a huge amount of industrial waste is consistently released into low-lying areas and water bodies without appropriate treatment (Rahman & Gagnon, 2014).

Surface water offers insight into the present state of a river or lake while sediments serve as a repository for contaminants (Varol, 2011). As sediment has a large residence time, sediments provide researchers with a valuable opportunity to investigate the origins and historical presence of anthropogenic pollutants (Nahar Jolly et al., 2019). Anthropogenic contributions have transformed sediments into the primary reservoir for heavy metals in aquatic ecosystems. Non-biodegradable heavy metals have the capacity to endure in surface sediments over a long period, facilitated by the amplification phenomenon within the food chain. This persistence can lead to various health issues and complexities within the human body.

Researchers have commonly utilized various pollution indices to assess heavy metals concentration and their associated ecological risks in water and sediment within the aquatic environment (Ahmad & Goni, 2010; Akbor et al., 2020; Dey et al., 2021a; Shil et al., 2017; Xie & Ren, 2022). Besides, (Hakanson, 1980) introduced an ecological risk index, widely accepted and utilized, that relies on the concentrations of heavy metals in sediment. This method is recognized as the simplest and most commonly used method for assessing ecological risks in sediment. Various approaches, such as the contamination factor (C_f), potential ecological risk index (PER), and pollution load index (PLI) have been implemented in evaluating the toxic effects of metals on sediment.

Khulna City stands as the third-largest city in the southwestern region of Bangladesh, serving as a central industrial hub. This city is next to the Rupsha River and 50 kilometres upstream of the Sundarbans mangrove forest (Adhikary et al., 2012). The Rupsha River bears the brunt of pollution from various industries, including food processing units, jute mills, paper mills, steel and cement factories, power plants, paint and dye manufacturing, soap and detergent production, and light industrial units. Unfortunately, these facilities discharge untreated hazardous effluents directly into the river, releasing heavy metals into the aquatic ecosystem. To the authors' awareness, there are limited scientific research regarding the presence of heavy metals and their allocated risk assessment in both the water and sediment of the Rupsha River, particularly in the vicinity of industrial areas. Therefore, the significant concern revolves around the pollution resulting from heavy metals, and it is essential to understand its potential threat to this particular ecosystem.

Therefore, this current research, evaluated the distribution of heavy metals, including Cr, Cd, Pb, Fe, Zn, and Cu and their allocated ecological risk assessment in surface water and sediment. The environmental risks of these heavy metals were evaluated through comprehensive indices designed to quantify pollution levels. Furthermore, the aim of this research is to provide information that will facilitate the implementation of action plans concerning the immediate vicinity of the Rupsha River.

2. METHODOLOGY

2.1 Study Area and Sampling Stations

The Rupsha River, situated in the southwestern part of Bangladesh. It is a distributary of the Ganges-Padma River System and flows through Khulna Division. This river is very important for transportation, irrigation and supporting various ecosystem. Its formation occurs at the confluence of the Bhairab and Madhumati rivers and flow into the Pasur River. It changes its name to Pasur River at Mongla which ultimately flows into the Bay of Bengal. The average width of this river is 486 meters (Hossain Saran et al., 2017). It is 50 miles from Sundarban, the largest mangrove forest, and has many industries along the vicinity of this river. Over a period of March to May 2023, water and sediment samples were collected from five different stations during the summer season, shown in Figure 1.

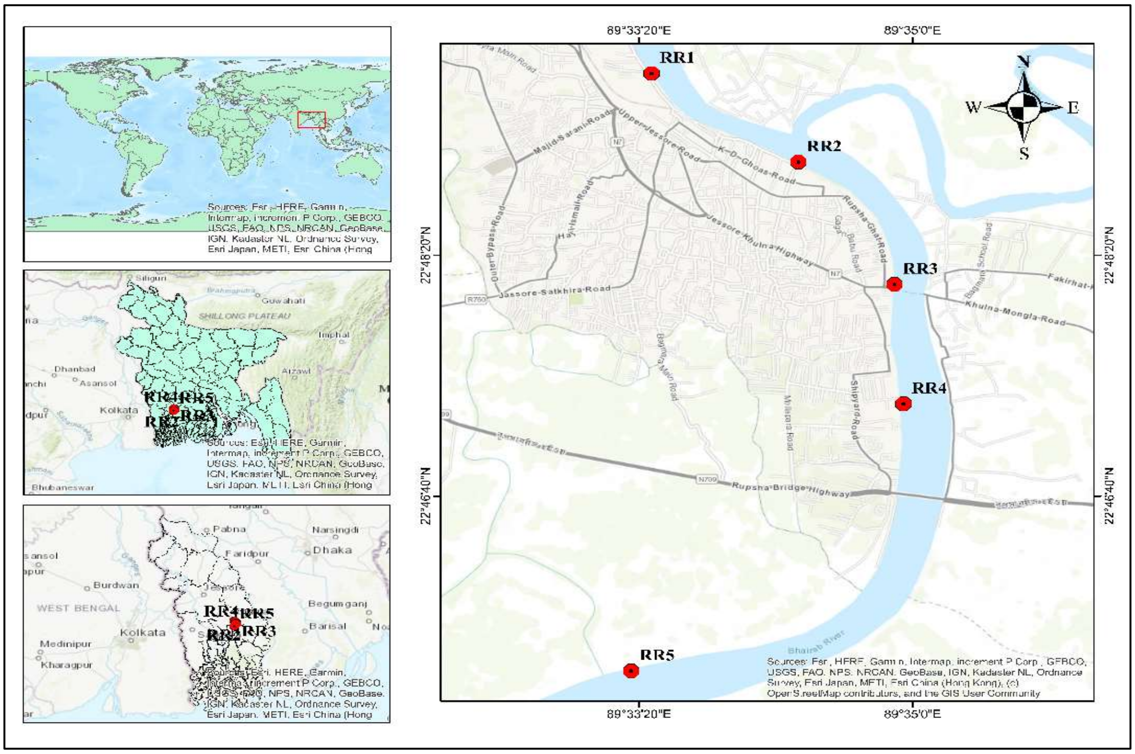

Figure 1: Map showing the sample collection point of the Rupsha River, Bangladesh

2.2 Sample Collection and Preservation

Water samples were collected from 0-10 cm depth, with precautions taken to minimize bubbles and suspended particles during the water collection process. Then the samples were carefully preserved in 500 ml high-density polyethylene (HDPE) bottles containing 0.4% ultra-pure HNO_3 (68-70% pure, Merck Germany) and stored in ice box for further analysis. The sediment sampling stations coincided with the water sample collection point. Sediment samples were collected from 0-5 cm depth following the standard method (APHA, 2005) and placed in a fresh air-tight plastic bag. Each sediment sample resulted from the random mixture of three collected samples.

2.3 Sample Preparation

After bringing the samples to the laboratory, filtration of the water samples were performed using Whatman no. 42 filter paper (Model: 934-AH, 1.5µm pore size). Then a 50 ml filtered sample was taken for digestion with 10 ml 0.4% ultra-pure HNO_3 at 80°C until the solution became transparent (Ahmad & Goni, 2010). The sediment digestion was carried out by following the standard procedure (EPA, method 3050B). After drying the sediment samples at room temperature, they were sieved with a USS #10 sieve. A 100 ml digestion vessel was used to digest 2 gm sediment sample and 20 ml HNO_3 solution. The solution was heated at 95 ± 5°C and left there for 2-3 hours until it evaporated to 5 ml. Finally, a 50 ml solution was prepared by adding distilled water and stored it for further analysis.

2.4 Sample Analysis

Primary Physicochemical characteristics of water including pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), Turbidity, Color, Hardness, and Chloride were measured using the standard procedures.

The levels of chromium (Cr), lead (Pb), cadmium (Cd), iron (Fe), copper (Cu) and zinc (Zn) were measured by Graphite Furnace- Atomic Absorption Spectrometry (GF-AAS). Heavy metal concentrations were calculated on dry weight basis. To assess the contamination level mean and standard deviation (SD) were performed using Microsoft Excel (v. 2021).

2.5 Risk Assessment of Heavy Metals

2.5.1 Heavy Metal Pollution Index (HPI)

The HPI is a qualitative tool used to quantify the level of heavy metal pollution in water. The formula for calculating the HPI varies, but it typically involves assigning weights for selected heavy metals based on their toxicity and then summing up the weighted concentrations. The resulting index provides a single value that represent the overall level of heavy metal pollution in the water. The resulting HPI values were divided into two groups: low (HPI < 100) and critical (HPI > 100). (Asim & Nageswara Rao, 2021). The following equation was used to calculate HPI:

$$\text{HPI} = \sum_{i=1}^{n} W_i Q_i / \sum_{i=1}^{n} W_i \quad (1)$$

$$W_i = k/C_s \quad (2)$$

$$Q_i = (C_a - C_i)/(C_s - C_i) \quad (3)$$

Where, Q_i is the subindex value and is W_i the unit weightage of i^{th} parameter. k is the proportionality constant (k = 1). W_i ranges from 0 and 1. C_a denotes the actual monitored value of heavy metals, C_i denotes the ideal value, and C_s is the standard value of i^{th} parameter.

2.5.2 Contamination Factor (C_f)

This parameter is utilized to evaluate the level of contamination of i^{th} heavy metals in water, sediment, and vegetables. It is the ratio of the measured concentration to the background concentration of each metal (Hakanson, 1980). This analysis, average shale value (ASV) is considered as the background concentration for each heavy metal (Turekian & Wedepohl, 1961).

$$C_f^i = C^i / C_n^i \quad (4)$$

Where, C^i is the concentration of heavy metal in sediment sample, while C_n^i is the ASV of i^{th} heavy metal. According to (Hakanson, 1980), C_f is categorized into four grades from 1 to 6:

- Low contamination level ($C_f < 1$)
- Medium contamination level ($1 \leq C_f < 3$)
- High contamination level ($3 \leq C_f < 6$) and
- Extremely high contamination level ($C_f \geq 6$)

2.5.3 Pollution Load Index (PLI)

The assessment of sediment quality involves the computation of PLI for the six heavy metals, as outlined in the study conducted by (Suresh et al., 2012). The PLI is frequently employed as a method for evaluating the influence of contaminants on aquatic ecosystems, particularly in the context of heavy metals.

$$PLI = \sqrt[n]{C_f^1 \times C_f^2 \times C_f^3 \times \ldots \ldots \times C_f^n} \quad (5)$$

PLI value of more than 1 signifies that the sediment is contaminated with heavy metals. In contrast, PLI value of less than 1 shows there is no evidence of heavy metal pollution.

2.5.4 Potential Ecological Risk Index (PER)

In order to evaluate the PER as proposed by (Hakanson, 1980), the potential risk factor (E_r) and potential ecological risk index were established in the following manner:

$$E_r^i = Tr^i \times C_f^i \tag{6}$$

$$\text{PER} = \sum_{i=1}^{n} E_r^i \tag{7}$$

Where, Tr^i represents the toxic response factor for a particular metal, and C_f^i denotes contamination factor and PER stands for the total of all risk factors in a particular sediment sample. The corresponding toxic-response factors for Cr, Pb, Cd, Zn, and Cu were 2, 5, 30, 5, and 1, respectively. The toxic response factor for Fe has yet to be established. However, E_r can be categorized as follows:

- Low ecological risk ($E_r < 40$)
- Medium ecological risk ($40 \leq E_r < 80$)
- Considerable ecological risk ($80 \leq E_r < 160$)
- High ecological risk ($160 \leq E_r < 320$) and
- Extremely high ecological risk ($E_r \geq 320$)

However, PER can be classified in four different categories:

- Low ecological risk (PER < 150)
- Medium ecological risk (150 ≤ PER < 300)
- High ecological risk (300 ≤ PER < 600) and
- Extremely high ecological risk (PER ≥ 600)

3. RESULTS AND DISCUSSION

3.1 Physicochemical Parameters of Water

A laboratory investigation assessed the physicochemical characteristics of the initial surface water quality. Table 1 presents the physicochemical properties of the water, including pH, DO, BOD, COD, TDS, TSS, color, turbidity, chloride, and hardness. Physicochemical parameters are essential since they significantly impact a river's water quality. Additionally, aquatic life is negatively affected by the deterioration of water quality.

Both pH and DO values are within the standard limit. However, BOD levels at stations RR2, RR3, and RR4 surpass the established limit of ECR (2023). The levels of TDS in the river water samples varied between 3570 to 4980 mg/L. At stations RR3 and RR5, the highest concentration of TDS was detected, whereas the lowest concentration was identified at station RR1. Excessive TDS can increase water temperatures, reduce water clarity, and hinder (Rahman & Gagnon, 2014).

Nevertheless, the TDS concentration at each station surpassed the ECR standard limit (1000 mg/L). Extremely high chloride concentration was also detected, ranging from 4550 mg/L to 17400 mg/L. High chloride concentration enhances water's electrical conductivity, which increases water's corrosive properties (Abu & Siddique, 2018). Regarding industrial and household usage, the total hardness of water is an important parameter. The hardness values for all the samples exceeded the limit of the ECR standard (500 mg/L), with values ranging from 2546.5 mg/L to 4742.6 mg/L. The turbidity was between 139 and 476 NTU, surpassing the ECR standard limit of 10 NTU only. A substantial degree of turbidity prevents the penetration of sunlight into the river, consequently hindering photosynthesis and depletion of DO concentration in the water for plants and aquatic organisms. The remaining parameters, COD, TSS, and color, also exceed the standard limit in all locations. From the physicochemical parameter analysis, the water of the Rupsha River is not satisfactory for drinking, cooking, and irrigation purposes in terms of COD, TDS, TSS, Color, Turbidity, Chloride, and Hardness values.

Table 1: Physicochemical Parameters of Water in Rupsha River

Station	pH	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TDS (mg/L)	TSS (mg/L)	Color (Pt/Co)	Turbidity (NTU)	Chloride (mg/L)	Hardness (mg/L)
RR1	7.03	7.68	1.34	307.20	3570	125	576	139	4550	2546.5
RR2	7.40	7.47	5.82	463.40	5030	220	1068	257	10400	4954.1
RR3	7.62	7.53	2.10	373.10	4980	303	1272	419	16800	4742.6
RR4	7.23	6.65	4.12	592.74	4970	405	1616	476	17400	4368.9
RR5	7.53	7.41	1.93	441.43	4980	298	1372	390	12800	4676.3
Mean	7.36	7.35	3.06	435.57	4706.0	270.20	1180.80	336.20	12390.0	4257.68
ECR	6.5-8.5	≥6	≤2	10	1000	10	15	10	250-1000	500

3.2 Metal Concentrations in Water

The heavy metal concentrations in water samples are shown in Table 2 and illustrated in Figure 2. The mean concentration was found to decrease in the following manner: Fe > Cu > Cr > Zn > Pb > Cd.

Table 2: Concentration of Heavy Metals (µg/L) in Water at Different Sampling Stations

Station	Cr	Pb	Cd	Fe	Zn	Cu
RR1	25.1	40.6	1.1	321.2	93.2	182.3
RR2	72.6	50.7	2.9	683.0	50.3	70.9
RR3	91.9	77.3	1.9	412.7	20.5	51.1
RR4	81.4	41.2	1.8	156.1	88.7	33.2
RR5	50.2	36.2	1.6	231.5	20.5	19.8
Mean ± SD	64.24 ± 26.73	49.2 ± 16.57	1.86 ± 0.66	360.9 ± 204.14	54.64 ± 35.34	71.46 ± 64.87
ECR	50.0	10.0	3.0	300-1000	5000	1500
USEPA	16.0	65.0	1.8	*	120	*

*Not established yet

Iron (Fe) enters water through natural geological processes, industrial effluents, household sewage, and the discharge of steel by-products. The concentration of Fe in water ranges from 156.1 µg/L to 683.0 µg/L, having a mean concentration of 360.9 µg/L that was within the standard limit of ECR (2023). A previous study by (Hossain et al., 2021) identified higher Fe concentrations of 14,010 µg/L in the Buriganga River, surpassing the levels observed in the present study. The average concentration of copper (Cu) is 71.46 µg/L, with values ranging from 19.8 µg/L and 182.3 µg/L. Notably, the highest Cu value was recorded at the RR1 station (182.3 µg/L), potentially attributable to domestic effluent and discharge from extensively farmed lands. Chromium (Cr) concentration ranges from 25.1 µg/L to 121.4 µg/L with an average value of 72.24 µg/L, the metal concentrations significantly surpassing the drinking water limit of ECR (2023) and aquatic life criteria recommended by USEPA (1995). Recently, a study showed that the Buriganga River is heavily polluted with Cr (Hossain et al., 2021). In the industrial sector, Cr compounds are found in various processes such as leather tanning, the production of dyes and pigments, industrial welding, chrome plating, and the preservation of wood. The tanneries and shipping operations close to the Rupsha River might be connected to the higher chromium levels (Dey et al., 2021). The Zinc (Zn) concentration ranges from 20.5 µg/L to 93.2 µg/L with an average concentration of 54.44 µg/L, below the permissible limit of ECR (2023) for all stations. This concentration was much lower than the (Hossain et al., 2021) study on the Buriganga and Turag Rivers and almost similar to the (Nahar Jolly et al., 2019) survey on the Shitalakhya River. Lead (Pb) concentrations vary from 36.2 µg/L to 77.3 µg/L. The average Pb concentration was 49.2 µg/L, over 4 times the ECR standard limit. The maximum concentration was spotted in station RR3. (Nahar Jolly et al., 2019) conducted a similar investigation on the Shitalakhya River in Bangladesh and reported that the Pb concentration was 16 µg/L. (Hossain et al., 2021) found 300 µg/L and 385 µg/L of Pb levels in water samples collected from the Buriganga and Turag Rivers, respectively. Cadmium (Cd) concentration varied from 1.1 µg/L to 2.9 µg/L. The average value (1.86 µg/L) was within the standard limit. (Ali et al., 2016) reported 6.46 µg/L concentration of Cd in Karnaphuli River, Bangladesh. Recently, (Nahar Jolly et al., 2019) discovered 3 µg/L Cd content in Shitalakhya River water. The primary sources of Cd are thought to be the metal industry, coal burning, and disposal of domestic sewerage.

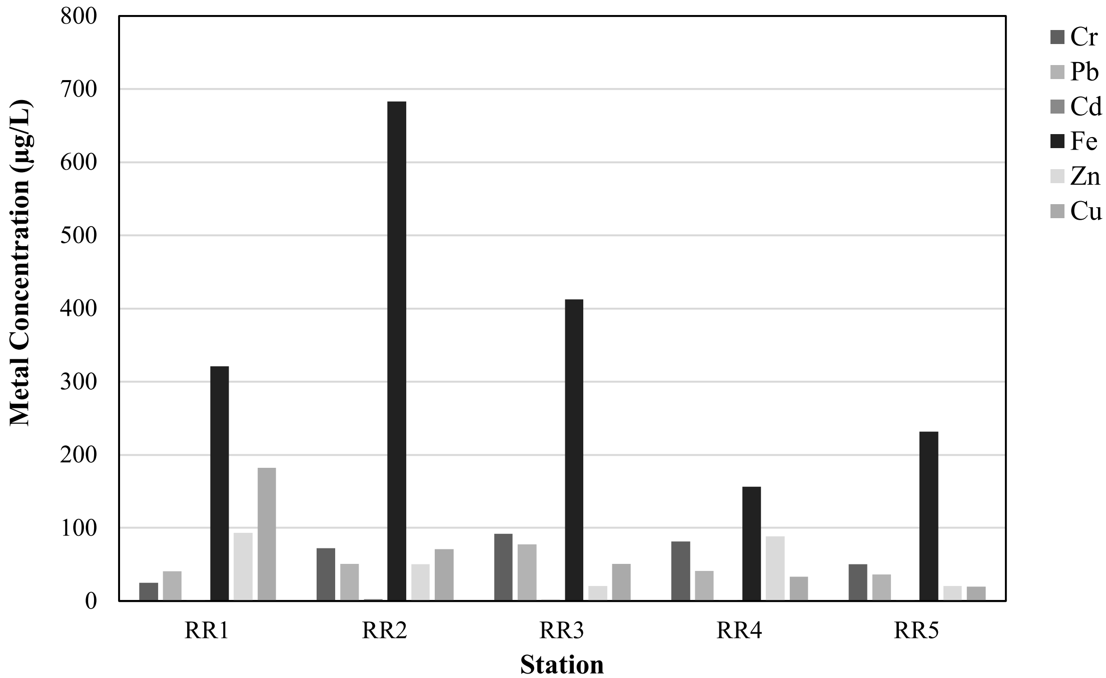

Figure 2: Heavy Metal Concentration (μg/L) in Water at different sampling stations

Taking into account the aquatic life ambient water quality criteria established by the U.S Environmental Protection Agency, USEPA (1995), the concentration of Cr and Cd significantly surpass the USEPA criterion maximum concentration (CMC) limits of 16 and 1.8 mg/L, respectively, indicating that this river water is unsuitable for drinking and cooking.

3.3 Metal Concentrations in Sediment

The concentrations of heavy metals in sediments are shown in Table 3 and illustrated in a spatial distribution using Arc GIS (v. 10.5) in Figure 3. Stations RR2 and RR4 stand out with significantly higher concentrations than other locations due to their direct exposure to untreated effluent from municipal wastewater, industrial discharges, household waste, and urban runoff from Khulna City. The study revealed that the average amount of heavy metals in sediment followed a decreasing order, with lead (Pb) having the highest concentration, followed by chromium (Cr), iron (Fe), copper (Cu), zinc (Zn), and cadmium (Cd).

In this study, Pb concentration ranges from 23.55 to 65.4 mg/kg. The mean Pb concentration was observed 40.26 mg/kg, twice the average shale value (ASV) (20 mg/kg) in the earth's crust (Turekian & Wedepohl, 1961). This might be due to influences from both point and non-point sources, such as petroleum, leaded gasoline, atmospheric deposition, municipal runoffs, activities associated with the production of electronics and chemicals, cables, oils, tire and cement factories, and steel works near the Rupsha River (Shikazono et al., 2012). Also, Pb concentration exceeded TRV and LEL, as presented in Table 4. A study conducted by (Islam et al., 2018) along the Buriganga River reported that the mean Pb concentration was considerably higher compared to both the present study and other relevant studies. The mean Cr concentration was 38.46 mg/kg, ranging from 15.4 to 82.28 mg/kg. The highest concentration of Cr was observed in station RR2 (82.28 mg/kg), while the average concentration (38.45 mg/kg) was within ASV but exceeded TRV and LEL, as shown in Table 4. Some researchers conducted similar studies (Ali et al., 2016; Hossain et al., 2021; Islam et al., 2018) and reported significant amounts of Cr in Karnaphuli, Turag and Buriganga River.

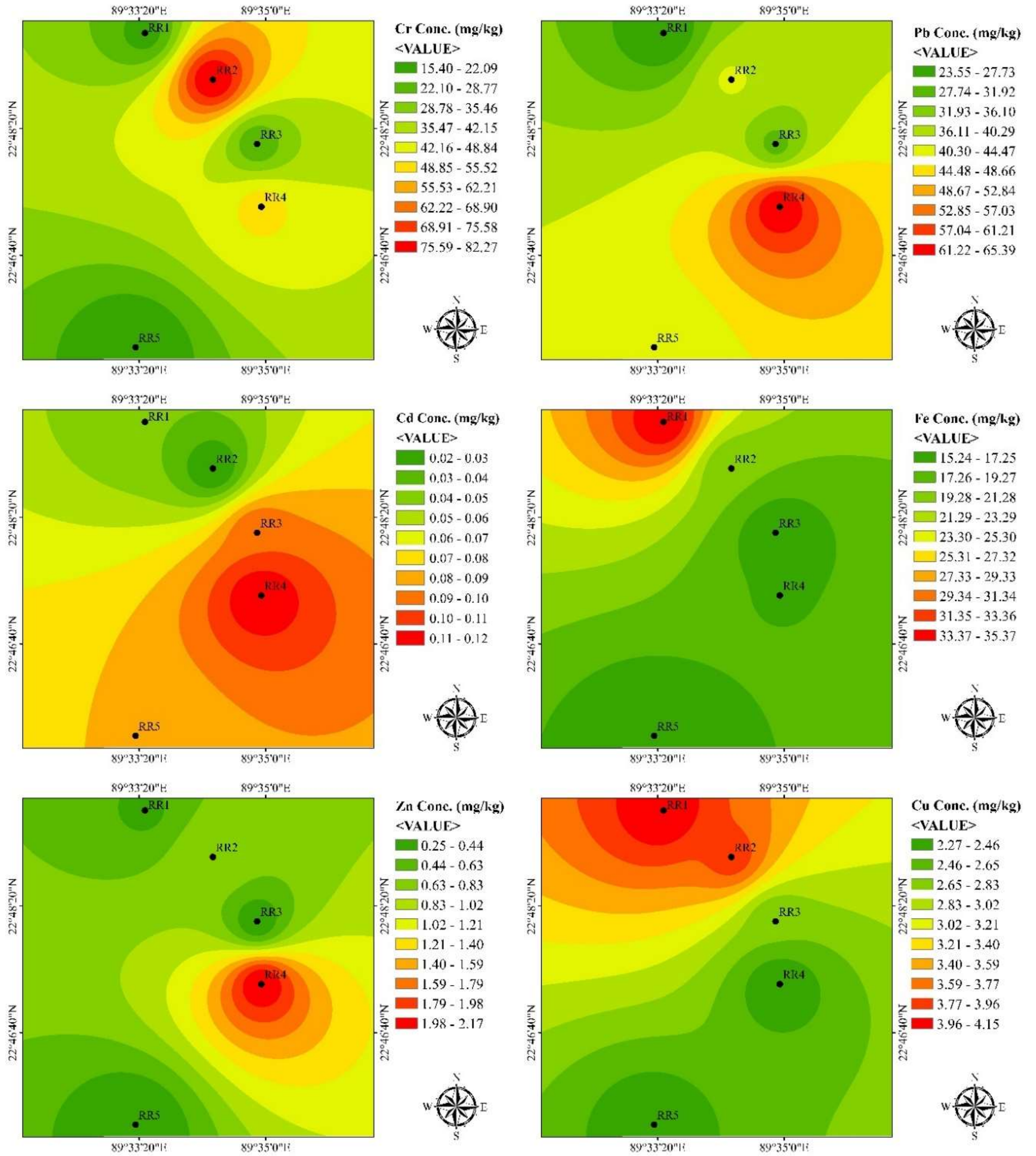

Figure 3: Spatial distribution of heavy metals (Cr, Pb, Cd, Fe, Zn and Cu) at different location

The Fe concentration in the sediment varies between 15.24 to 35.37 mg/kg, with a mean value of 20.50 mg/kg. The highest deposition of Fe is observed in station RR1. It is noteworthy that the recorded Fe concentrations are considerably below the ASV and LEL, suggesting that the Rupsha River is devoid of iron pollution. In contrast, (Hossain et al., 2021) reported an exceptionally higher Fe concentration (4233 mg/kg) in Turag River compared to this present study.

However, the findings of this research indicate that Cu, Zn, and Cd concentrations in sediment samples from all sampling locations were within acceptable limits, as they did not surpass the standard ASV and TRV values. A comparative analysis with various studies (Budianta, 2021; Hossain et al., 2021; Islam et al., 2018; Nahar Jolly et al., 2019) reveals that this study reports lower concentrations in comparison. In contrast, the Buriganga and Turag Rivers exhibit significant contamination with Cd and Cu, surpassing all toxicity reference values.

Table 3: Concentration (mg/kg) of Heavy Metals in Sediment at Different Sampling Stations

Station	Cr	Pb	Cd	Fe	Zn	Cu
RR1	19.15	23.55	0.04	35.37	0.4	4.15
RR2	82.28	40.82	0.02	19.34	0.8	3.89
RR3	23.65	30.5	0.1	15.44	0.28	2.66
RR4	51.8	65.4	0.12	17.13	2.17	2.27
RR5	15.4	41.05	0.08	15.24	0.25	2.32
Mean ± SD	38.46 ± 28.38	40.26 ± 15.87	0.07 ± 0.04	20.50 ± 8.47	0.78 ± 0.8	3.06± 0.89

Table 4: Comparative heavy metal concentration with other national and international rivers.

River	Location	Cr	Pb	Cd	Fe	Zn	Cu	References
Water (µg/L)								
Rupsha River	Bangladesh	64.24	49.2	1.86	360.9	54.64	71.46	Present Study
Buriganga River	Bangladesh	2850	300		14010	1250	800	(Hossain et al., 2021)
Turag River	Bangladesh	690	385		8410	1840	950	(Hossain et al., 2021)
Shitalakhya River	Bangladesh	18	16	3		56	22	(Nahar Jolly et al., 2019)
Posur River	Bangladesh	20			270	10	20	(Shil et al., 2017)
Karnaphuli River	Bangladesh	69.56	9.85	6.46				(Ali et al., 2016)
Hanoi River	Vietnam	5.74	6.43			15.9	7.38	(Kikuchi et al., 2009)
Ganga River	India	33	5		1476	289		(Prasad et al., 2020)
ECR (2023)		20	30					
TRV[b]		11	2.5	2.2		118	9	USEPA (1999)
Sediment (mg/kg)								
Rupsha River	Bangladesh	38.45	40.26	0.07	20.5	0.78	3.06	Present Study
Buriganga River	Bangladesh	297	731	7.7			280	(Islam et al., 2018)
Turag River	Bangladesh	70	31		4233	163	48	(Hossain et al., 2021)
Karnaphuli River	Bangladesh	81.09	43.69	2.01				(Ali et al., 2016)
Shitalakhya River	Bangladesh	74.2	71.42	1.46		132.2	12.72	(Nahar Jolly et al., 2019)
Tajum River	Indonesia		71.83	4.46		286.5	128.75	(Budianta, 2021)
Lijiang River	China	43.62	42.80	0.97		129.33	31.72	(Xiao et al., 2021)
ASV[a]		90	20	0.3	47200	95	45	(Turekian & Wedepohl, 1961)
TRV[b]		26	31	0.6		110	16	(Ali et al., 2022)
LEL[c]		26	31	0.6	2%	110	16	(Persaud, 1993)
SEL[d]		110	250	10	4%	820	110	(Persaud, 1993)

[a]Average Shale Value (ASV); [b]Toxicity Reference Value (TRV); [c]Lower Effect Level (LEL); [d]Severe Effect Level (SEL)

3.4 Assessment of Metal Pollution in Water

The HPI values for five water samples were computed and illustrated in the Figure 4. The HPI value serves as a crucial indicator for evaluating the overall quality of river water. The mean HPI value for the Rupsha River water was determined159, surpassing the established critical index value of 100. All the water samples collected exhibited HPI values exceeding the critical index value, indicating the river water is contaminated and is not suitable for consumption. The max HPI (224.46) was observed in station RR3 as this station is highly contaminated by Cr, Pb, and Cd. Among these heavy metals Cd and Pb carry the highest unit weightage, which could be the reason for higher HPI value in station RR3. Other stations RR1, RR2, RR4, and RR5 have HPI values of 118.64, 189.9, 141.27 and 123.03, respectively.

3.5 Assessment of Metal Pollution in Sediment

The C_f for each metal were assessed by utilizing the ASV of the earth's crust (Cr = 90, Ni = 68, Cu = 45, Pb = 20, Fe = 47,200, Zn = 95), shown in Table 5. The values indicate low level of contamination ($C_f < 1$), except for lead (Pb) which exhibits higher contamination ($C_f > 1$), shown in Figure 5. The descending order of C_f values for the sediment samples is Pb > Cr > Cd > Cu > Zn > Fe. C_f values range from a maximum of 3.27 for Pb to a minimum of 0.00032 for Fe. The C_f values for Pb indicates moderate degree of contamination in all station, except for station RR4, which shows a considerable degree of contamination. Other heavy metals exhibit low degree of contamination.

Table 5: Contamination Factor (C_f) of heavy metals in sediment samples

Station	Cr	Pb	Cd	Fe	Zn	Cu
RR1	0.21	1.18	0.13	7.49E-04	4.21E-03	0.09
RR2	0.91	2.04	0.07	4.10E-04	8.42E-03	0.09
RR3	0.26	1.53	0.33	3.27E-04	2.95E-03	0.06
RR4	0.58	3.27	0.40	3.63E-04	2.28E-02	0.05
RR5	0.17	2.05	0.27	3.23E-04	2.63E-03	0.05

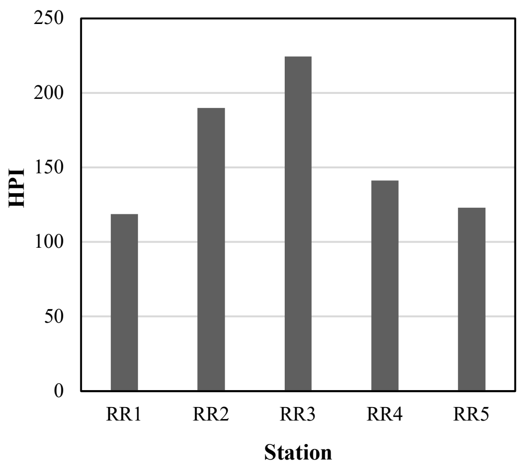

Figure 4: Heavy Metal Pollution Index (HPI)

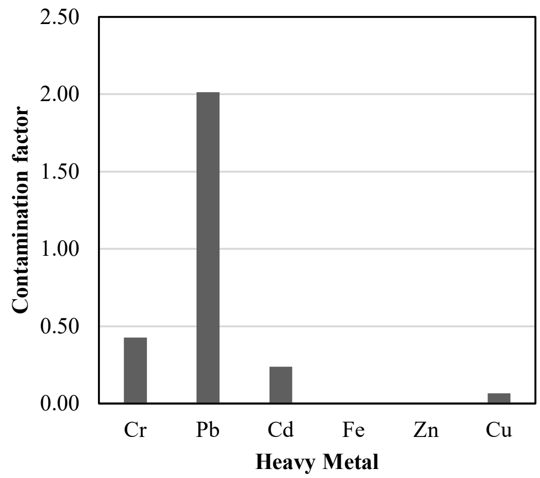

Figure 5: Contamination Factor(C_f) of Heavy Metals

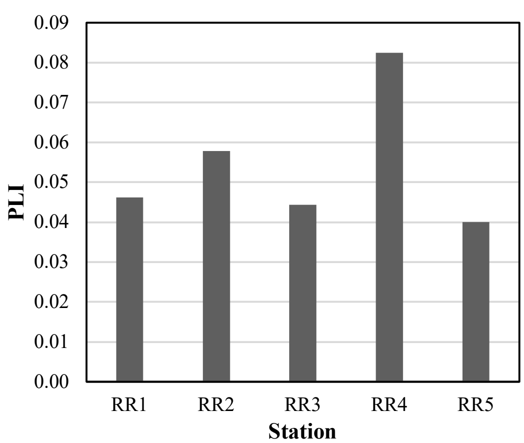

Figure 6: Pollution Load Index (PLI)

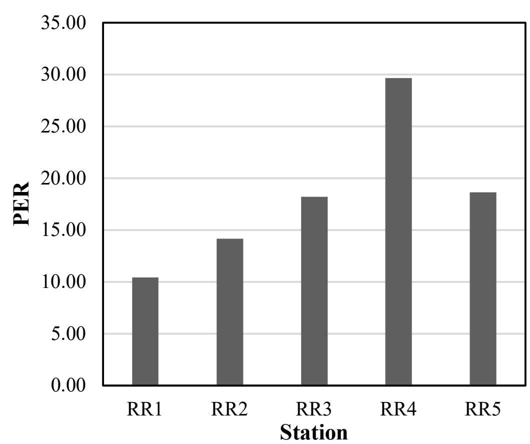

Figure 7: Potential Ecological Risk (PER)

An ideal pollution load index (PLI) value would be zero, whereas a value of one would signify the existence of a baseline level of pollutants. According to (Suresh et al., 2012), when values are greater than 1, it means that the site and estuary are gradually deteriorating. Figure 6 illustrates the PLI values for heavy metals in sediment. The average PLI exhibits a consistent decrease across all metals, providing evidence that the river sediment had no sign of contamination (PLI < 1). In contrast, the PLI values were RR1 (0.05), RR2 (0.06), RR3 (0.04), RR4 (0.08) and RR5 (0.04), suggesting an excellent sediment quality at these specific sites.

Table 6: Ecological Risk Factor (E_r) and Potential Ecological Risk Index (PER) of heavy metals

	Ecological Risk Factor (E_r)						PER	Pollution Status
Station	Cr	Pb	Cd	Fe	Zn	Cu		
RR1	0.43	5.89	4.00	-	0.02	0.09	10.43	Low
RR2	1.83	10.21	2.00	-	0.04	0.09	14.16	Low
RR3	0.53	7.63	10.00	-	0.01	0.06	18.22	Low
RR4	1.15	16.35	12.00	-	0.11	0.05	29.67	Low
RR5	0.34	10.26	8.00	-	0.01	0.05	18.67	Low

The consequences of an ecological risk factor (E_r) and its corresponding potential ecological risk index (PER) are presented in Table 6. The recorded E_r values for Cr, Pb, Cd, Fe, Zn, and Cu were below 40, indicating a low ecological risk. However, Pb and Cd exhibit the highest risk factors at station RR4 due to significant influences by several sources such as heavy traffic, shipyard, food processing industry, cement industry, the use of fertilisers and pesticides in agriculture, atmospheric deposition, and more. Despite this, all stations showed a low ecological risk, with station RR4 having the highest PER (29.67) value (Figure 7). The assessment of PER for each particular heavy metal and its corresponding grade classification indicates that all metals provide a low potential ecological threat.

4. CONCLUSIONS

These research findings revealed that the physicochemical parameters of water samples were above the acceptable thresholds for drinking, cooking and irrigation purposes. The presence of harmful toxic heavy metals, specifically Chromium (Cr) and Lead (Pb), surpasses the safety limit (for drinking water) suggested by ECR (2023). The heavy metal pollution index (HPI) was also beyond its critical limit. Assessing ecological risk through indicators such as contamination factor (C_f), potential ecological risk (PER), and pollution load index (PLI) demonstrated that the heavy metals exhibit low level of contamination in sediment. However, this study strongly suggests that before releasing industrial wastewater and household sewage into rivers, it's essential to remove heavy metals to maintain a healthy aquatic environment. Failing to do so could lead to significant contamination of heavy metals in the Rupsha River systems in the near future. Therefore, this study also provides valuable insights to the scientific community and governmental entities developing more effective policies and methodologies to enhance the environmental state of water bodies in Bangladesh.

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