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Comprehensive evaluation of heavy metals in surface water of the upper Banar River, Bangladesh

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A B S T R A C T

The main focus of the research was to examine the dispersion of elements and evaluate the possible ecological impact of heavy metals in the water of the Upper Banar River. To achieve this, water samples were obtained from ten different locations along the river, and the concentrations of Cr, Ni, Cu, Cd, Pb, and As were analyzed using an atomic absorption spectrophotometer (AAS). Results exhibited that the abundance of Cr, Ni, Cu, Cd, Pb, and As in water varied from 1.10 to 3.20, 0.11 to 1.30, 1.30 to 13.50, 1.14 to 1.91, 0.39 to 0.75 and 1.44 to 2.56 μgL^{-1}, respectively. Mean (±SD) concentrations of considered metals declined with the following downward direction: Cu (5.07±4.11) > As (1.94±1.15) > Cr (1.81±0.63) > Cd (1.42±0.23) Pb (0.55±0.12) > Ni (0.54±0.41), indicated that concentrations were reasonably assorted throughout the observed region. Moreover, the Upper Banar River water was contaminated with heavy metals, but the pollution level was not significant based on HPI analysis. Based on the computed HEI values, water quality is deemed low hazard and lower degrees of contamination. Overall, the river's water was still in good condition and had low levels of contamination, as per PI and CD ratings. Upper Banar River water's computed ERI ranged from 7.24 to 12.16, which showed a low-risk level. The study concluded that the Upper Banar River experienced some metallic pollution because of anthropogenic disturbances. Thus, responsible authorities should immediately implement appropriate management strategies and conduct routine water quality monitoring.

Keywords: Heavy metal, Surface water, Spatial distribution, Ecological risk

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Introduction

The presence of heavy metals in water bodies has become a global concern due to their toxic nature, resistance to biodegradation, long-lasting effects, ability to accumulate in living organisms, and potential for bio-magnification in food chains (Kafilat Adebola *et al.*, 2018; Hassimi *et al.*, 2019; Kumar *et al.*, 2019; Custodio *et al.*, 2021; Karaouzas *et al.*, 2021; Zhao *et al.*, 2021; Liu *et al.*, 2022). Heavy metals are characterized as metals with a density exceeding 5 g/cm3 and include various elements such as chromium (Cr), nickel (Ni), cadmium (Cd), arsenic (As), lead (Pb), zinc (Zn), copper (Cu), cobalt (Co), molybdenum (Mo), manganese (Mn), mercury (Hg), vanadium (V), iron (Fe), as well as rare metals, among others (Dey *et al.*, 2021). The increasing urbanization, population growth, urban runoff, agricultural activities, and discharge of domestic and industrial wastewater have significantly impacted the quality of aquatic ecosystems. These human activities have contributed to the introduction and accumulation of heavy metals in water bodies, posing serious threats to the environment and human health (Kabir *et al.*, 2020; Custodio *et al.*, 2021).

Rivers in Bangladesh are facing a serious issue of heavy metal pollution due to unplanned urbanization, industrialization, and the irresponsible use of agrochemicals (Dey *et al.*, 2021; Haque *et al.*, 2022). Heavy metals are released into the environment from various sources such as industries, agriculture, medicine, domestic activities, and atmospheric deposition, leading to significant alterations in the chemical and physical properties of water and sediment (Habib *et al.*, 2021; Huang *et al.*, 2021; Islam *et al.*, 2022). This pollution poses a significant threat to aquatic flora and fauna, including fish, crabs, and snails, and can be transmitted to humans through the food chain (Maurya *et al.*, 2019; Saha *et al.*, 2021; Haque *et al.*, 2022). The deposition of heavy metals in sediment can result in their bioaccumulation in benthic species, leading to disruptions in ecosystems and the natural balance (Karaouzas *et al.*, 2021). Microalgae, which serve as a primary food source for various aquatic organisms, are particularly impacted by the presence of heavy metals in water (Seshan *et al.*, 2010; Kabir *et al.*, 2020). As heavy metals move along the food chain, they can cause acute and chronic health effects on humans (He *et al.*, 2019; Briffa *et al.*, 2020; Haque *et al.*, 2022). Additionally, the accumulation of heavy metals in sediment can pose an ecological risk by being reactivated and released back into the surrounding water, further affecting aquatic organisms (Maina *et al.*, 2019; Wang *et al.*, 2019; Liu *et al.*, 2022). Consequently, it is crucial to assess the ecological risk of heavy metals to monitor and protect aquatic habitats (Saha *et al.*, 2021; Adams *et al.*, 2020; Liu *et al.*, 2022). A systematic study is needed to evaluate the distribution, potential sources, toxic load, and ecological risks of heavy metals in surface water (Huang *et al.*, 2021). The heavy metal pollution index can be a valuable tool for spatial assessments of contaminated rivers, aiding in identifying and predicting trends in water quality (Kumar *et al.*, 2018).

The Upper Banar River, located in Trishal Upazila, Mymensingh, holds significance as it provides fish and prawns to the local population, serving as a crucial protein source and livelihood for nearby fishermen (Sultana *et al.*, 2018). However, the river has recently drawn public concern due to severe pollution caused by untreated industrial waste discharged into the water from various industrial facilities. Given the lack of exhaustive research on contamination levels and ecological risks of heavy metals in the Upper Banar River's surface water, this study aimed to investigate heavy metal pollution in the river by collecting water samples from different locations along the river. The main objectives were to characterize the distribution of heavy metals (Cr, Cd, Pb, Ni, Cu, As) in the water bodies and assess the potential ecological risk posed by these metals in the river water. The study's findings are expected to provide fundamental data and scientific evidence for preventing and controlling metal pollution in drinking water sources, guiding the development of appropriate water quality management strategies in nearby areas, and benefiting other riverine systems in Bangladesh with similar challenges.

Materials and Methods

Study area

Water samples were collected from the Upper Banar River situated in Trishal upazila within the Mymensingh district of Bangladesh (Fig. 1). Trishal upazila covers an area of 338.98 km2 and is geographically positioned between latitudes 24°28' and 24°41'N, as well as longitudes 90°18' and 90°32'E (Banglapedia, 2021). The Upper Banar River holds significance as one of the primary rivers in the Madhupur tract. Numerous streams originating from the highlands to the north of Madhupur and Fulbaria upazilas converge in the southeastern region of Trishal, forming the Banar River. As it flows southward, the river splits into two arms: the eastern arm merges with the Old Brahmaputra, while the southeastern arm joins the Shitalakhya River. After the confluence with the Old Brahmaputra, the eastern arm continues its course and meets the Shitalakhya River. The length of the Upper Banar River is approximately 50 to 60 km, with an average width of 15.25 m. Rainfall serves as the primary source of water for the Upper Banar River, and its depth undergoes seasonal variations. During the rainy season, the depth ranges from 3.0 to 4.5 m, while in the winter season, it decreases to about 1.0 to 1.5 m (Sultana *et al.*, 2018).

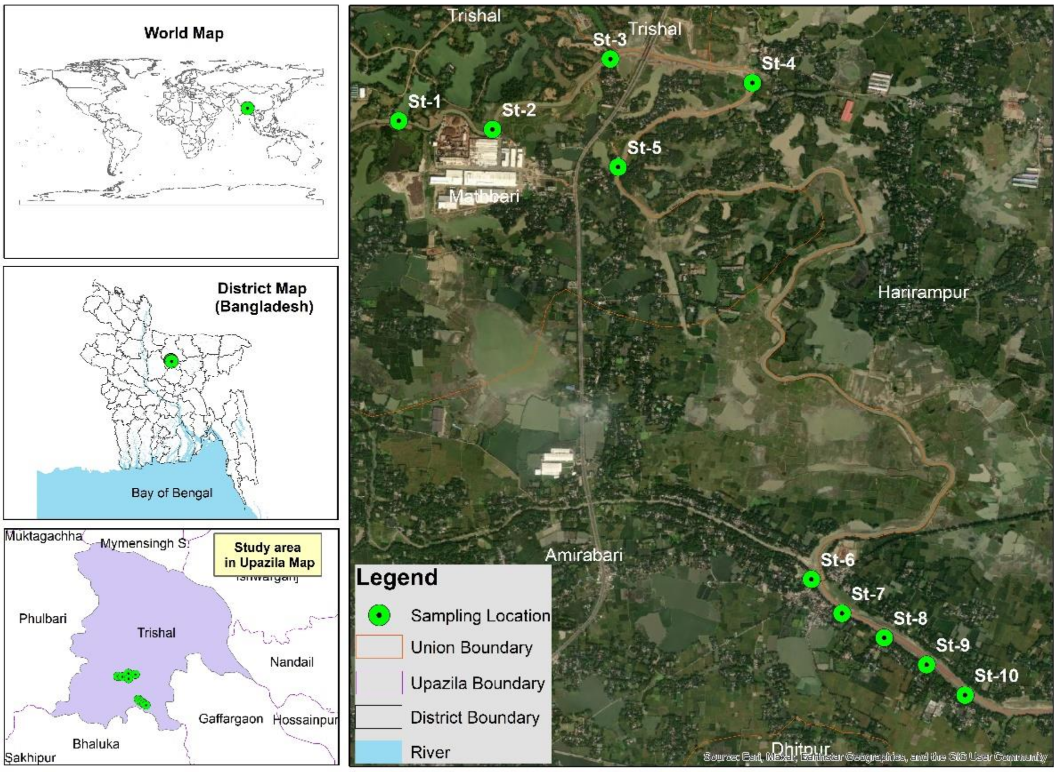

Fig. 1. Map of the study area showing all the sampling sites in the Upper Banar River.

Sample collection

To assess the water quality of the Upper Banar River, 500 ml water samples were collected from each sampling station using plastic bottles with double stoppers. Ten sampling locations were chosen based on the river's terrain and vegetation. Before sampling, the bottles were thoroughly cleaned, washed, and treated with 5% nitric acid (HNO3) overnight. Subsequently, the bottles were rinsed with deionized water and dried. Before sampling at each location, the sampling vials were washed at least three times. The pre-prepared sampling bottles were then carefully submerged about 10 cm below the water's surface (Tareq *et al.*, 2013). After collection, the bottles were securely sealed and labeled with the corresponding identification number. Upon arrival at the laboratory, the samples were acidified using 10% HNO3 and kept submerged in an ice bath. To prevent further contamination until analysis, the samples were filtered through a 0.45 m micropore membrane filter and stored in a freezer at 4°C.

Sample preparation and analysis

For each water sample, 50 ml of water and 2 ml of pure HNO3 were carefully transferred into a beaker and placed on a hot plate for digestion. After the sample was adequately digested, it was transferred into a 50-ml volumetric flask, and the flask was filled up to the mark with distilled water. This process was repeated for each water sample, and the filtered residue was collected using Whatman Qualitative 1 filter paper and stored in a container following the guidelines of APHA (2012). At the laboratory of the Bangladesh Council of Scientific and Industrial Research (BCSIR), the concentrations of heavy metals in the water samples were analyzed using an atomic absorption spectrophotometer (AAS) following the methods specified by the American Public Health Association (APHA, 2012).

Heavy metal pollution index (HPI)

When determining the HPI (Health Pollution Index), Prasad and Bose (2001) adopted a unit weightage (Wi) that was inversely proportional to the recommended standard (Si) for the corresponding parameter, following the approach suggested by Reddy (1995). The HPI model, as proposed by Mohan *et al.* (1996), is represented by the equation:

$$HPI = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi}$$

In this equation, Qi represents the sub-index of the ith parameter, Wi denotes the unit weightage of the ith parameter, and n represents the number of parameters considered. The sub-index (Qi) of each parameter was calculated using the formula:

$$Qi = \sum_{i=1}^{n} \frac{\{Mi(-)Ii\}}{(Si - Ii)} \times 100$$

Where Mi represents the monitored value of the heavy metal for the ith parameter, and the sign

(−) denotes the numerical difference between the two values, disregarding the algebraic sign. In the current study, the HPI was calculated using the heavy metals Cr, Ni, Cd, Cu, Pb, and As. The weightage (Wi) was determined as the inverse of the MAC (Maximum Admissible Concentration), which is based on the WHO (World Health Organization) standard for drinking water in ppb (parts per billion), and Ii represents the guide value for the selected elements in ppb. The MAC serves as the upper permissible concentration, as shown in Table 1.

Table 1. Standard used for the indices computation (Brraich and Jangu, 2015; Kabir *et al.*, 2020).

Metals	Unit	Wi	Si	Ii
Cr	$\mu g\ L^{-1}$	0.02	50	0
Ni	$\mu g\ L^{-1}$	0.014	70	20
Cu	$\mu g\ L^{-1}$	0.00067	1500	50
Cd	$\mu g\ L^{-1}$	0.2	5	3
Pb	$\mu g\ L^{-1}$	0.1	10	0
As	$\mu g\ L^{-1}$	0.02	50	10

The heavy metal evaluation index (HEI) assesses the overall water quality concerning toxic metals. The calculation of the HEI follows the method described by Mokarram *et al.* (2020) and is represented by the formula:

$$HEI = \sum_{i=1}^{n} \frac{Hci}{Hmax}$$

In this equation, Hci represents the measured concentration of constituent i, and Hmax is the maximum allowed concentration of constituent i. According to the WHO (World Health Organization) standards from 2011, the maximum permissible concentrations of Cr, Ni, Cu, As, Cd, and Pb are 0.05, 0.02, 0.05, 0.04, 0.005, and 0.05 mgL^{-1}, respectively. The classification of HEI values is as follows: HEI < 10 indicates low risk; HEI between 10 and 20 indicates medium risk; HEI > 20 indicates high risk (Edet and Offiong, 2002; Proshad *et al.*, 2021).

Contamination Degree (CD)

The Contamination Index (CD) summarises the collective impact of multiple quality parameters detrimental to domestic water (Edet and Offiong, 2002; Kabir *et al.*, 2020). The calculation of the contamination index is derived from the following equation:

$$CD = \sum_{i=1}^{n} Cfi$$

$$Cfi = \frac{Cai}{Cni} - 1$$

In this equation, Cfi denotes the contamination factor of the ith component, Cai represents the analytical value of the ith component, and Cni stands for the upper permissible concentration of the ith component.

Pollution load index (PI)

To assess the pollution load in the study area, the researchers utilized the pollution load index (PI) to evaluate different pollutants. This index provides a comprehensive measure of the combined effect of various elements in the water sample (Bhattacharya *et al.*, 2015). The PI was calculated by summing up the ratio of metal concentration to the recommended standard guideline (Liu *et al.*, 2013), as expressed by the following equation:

$$PI = \sum_{i=1}^{n} \frac{Cn}{St}$$

In this equation, Cn represents the concentration level of a specific metal, and St denotes the standard guideline limit in Bangladesh, as proposed by the Department of Environment (ECR, 1997). The standard guideline limits for various metals are as follows: As: 0.05 mgL^{-1}, Cd: 0.005 mgL^{-1}, Cr: 0.05 mgL^{-1}, Pb: 0.05 mgL^{-1}, Cu: 1.00 mgL^{-1}, and Ni: 0.10 mgL^{-1} (ECR, 1997). The estimated PI values were classified into six categories, representing different degrees of anthropogenic influences of the studied elements on the water quality (Mitra *et al.*, 2018): PI < 0.3 indicates class 1 (very pure), 0.3 < PI < 1 indicates class 2 (pure), 1 < PI < 2 denotes class 3 (slightly affected), 2 < PI < 4 denotes class 4 (moderately affected), 4 < PI < 6 denotes class 5 (highly affected), and PI > 6 denotes class 6 (tremendously affected).

Ecological risk index (ERI)

The ecological risk index (ERI) for river water consumption was also calculated to evaluate the ecological impact using the following formulas (Egbueri, 2020a):

$$ERI = \sum RI = \sum Ti \times PI$$

$$PI = \frac{Cs}{Cb}$$

In this equation, RI represents the potential ecological risk factor of each metal, Ti denotes the toxic-response factor of heavy metals, PI represents the pollution index, Cs is the concentration of heavy metals in the water sample, and Cb is the corresponding background value. The toxic-response factors of the metals examined were reported as follows: 1, 5, 5, 10, 30, and 5 for Cr, Ni, Cu, As, Cd, and Pb, respectively (Ukah *et al.*, 2019; Egbueri, 2020b). The ERI values were classified as follows: ERI < 150 indicates low ecological risk, 150 < ERI < 300 indicates moderate ecological risk, 300 < ERI < 600 indicates considerable ecological risk, and ERI > 600 indicates very high ecological risk (Ukah *et al.*, 2019; Egbueri, 2020a).

Statistical analysis

In this research, Pearson's correlation coefficient and principal component analysis were employed using IBM SPSS Statistics 20.0 to uncover the connections between the investigated heavy metals and to pinpoint their plausible origins in the water. Spatial distribution maps were created using ArcGIS 14.1 software.

Results and Discussion

Table 2 summarizes the descriptive statistics of measured element concentrations (Cr, Ni, Cu, Cd, Pb, As) in water collected from various areas of the Upper Banar River in the Trishal region, Bangladesh. The abundance of Cr, Ni, Cu, Cd, Pb, and As were fluctuated within the ranges of 1.10 to 3.20; 0.11 to 1.30; 1.30 to 13.50; 1.14 to 1.91; 0.39 to 0.75; and 1.44 to 2.56 μgL^{-1}, respectively. The mean concentrations of elements exhibited the following descending order: Cu > As > Cr > Cd > Pb > Ni. The results indicated that the concentrations of these elements were relatively varied across the study area, showing spatial heterogeneity. Figure 2 presents the spatial distribution of heavy metal concentrations in the surface water of the Upper Banar River. Various urban activities in the Trishal area, such as the disposal of municipal wastes, domestic garbage, industrial wastes, and agricultural practices, are likely the primary causes of the wide range of metal concentrations. To assess the causes of toxic metal pollution and its variance, the coefficient of variation (CV) is a valuable tool. Higher CV values indicate that metal effluence is influenced by artificial factors, while lower CV values suggest natural influences (Li and Liao, 2018). In this study, the CV values for Cr, Ni, Cu, Cd, Pb, and As in the surface water samples were 34.81, 75.93, 81.06, 16.19, 21.81, and 59.27%, respectively (Table 2). The study's results showed that Cu, Ni, and As contamination levels were mainly influenced by anthropogenic activities throughout the surveyed areas.

Table 2. Heavy metal concentration in water of the Upper Banar River, Mymensingh.

Stations	Concentrations (μgL^{-1})					
	Cr	Ni	Cu	Cd	Pb	As
St-1	2.20	0.15	1.30	1.31	0.60	1.44
St-2	3.20	1. 30	10.40	1.61	0.71	1.83
St-3	1.60	0.95	8.30	1.32	0.59	1.92
St-4	1.20	0.12	1.60	1.15	0.47	2.14
St-5	2.60	0.83	6.20	1.61	0.56	2.45
St-6	1.70	0.22	13.50	1.91	0.75	2.56
St-7	1.50	0.69	3.40	1.52	0.44	2.07
St-8	1.10	0.82	1.90	1.14	0.41	1.44
St-9	1.30	0.11	2.60	1.28	0.39	1.93
St-10	1.70	0.23	1.50	1.31	0.56	1.62
Mean (n=10)	1.81	0.54	5.07	1.42	0.55	1.94
Minimum	1.10	0.11	1.30	1.14	0.39	1.44
Maximum	3.20	1.30	13.50	1.91	0.75	2.56
SD	0.63	0.41	4.11	0.23	0.12	1.15
CV (%)	34.81	75.93	81.06	16.19	21.81	59.27
Skewness	1.31	0.044	0.072	0.050	0.005	0.010
Kurtosis	3.38	0.18	0.23	0.26	0.19	0.54
Literature data						
BDWS	50	100	1000	5	50	50
WHO	50	20	50	5	50	40
TRV	11	52	9	2	3	150
ALWPL	2000	150,000	4000	1800	7000	50,000
ILWPL	100,000	200, 000	200,000	10,000	200,000	100,000

*Note: *BDWS-Bangladesh Drinking Water Standard (ECR, 1997); HBGV-health based guideline value (WHO, 2011); TRV-Toxicity Reference Value (USEPA, 1999); ALWPL-Aquatic Life Water Permissible Limits (CCME, 2007); ILWPL-Irrigation Life Water Permissible Limits (CCME, 2007).*

Chromium (Cr)

Chromium is discharged into rivers from leather, tanning, and chrome planting industries, leading to surface water pollution (Islam *et al.*, 2022). The highest concentration of Cr (3.20 μgL-1) was detected in St-2, while the lowest concentration (1.10 μgL-1) was observed in St-8, as depicted in Figure 2. The average Cr concentration in this study was measured at 1.81 μgL-1, which was below the HBGV and BDWS values. Moreover, the Cr concentration in this study was also lower than the respective ALWPL, TRV, and ILWPL limits. Comparatively, when assessing the Cr concentration in this study alongside other research conducted in Bangladesh and other countries (Table 3), all the examined rivers in Bangladesh exhibited higher Cr concentrations than the Upper Banar River.

Nickel (Ni)

The St-2 had the highest Ni concentration (1.30 μgL-1), while St-9 had the lowest concentration (0.11 μg L-1), according to Figure 2. The average Ni concentration in this study was 0.54 μgL-1, which was lower than the BDWS, HBGV, and TRV values. Moreover, the mean Ni concentrations were significantly below the ALWPL and ILWPL values specified for aquatic life and irrigation purposes. However, when comparing the Ni concentration in this study to other research conducted in Bangladesh and other countries (Table 3), all examined rivers in Bangladesh showed higher Ni concentrations than the Upper Banar River. The major sources of Ni contamination were reported to be mining activities, nickel metal refining, and sewage sludge incineration (Obasi and Akudinobi, 2020).

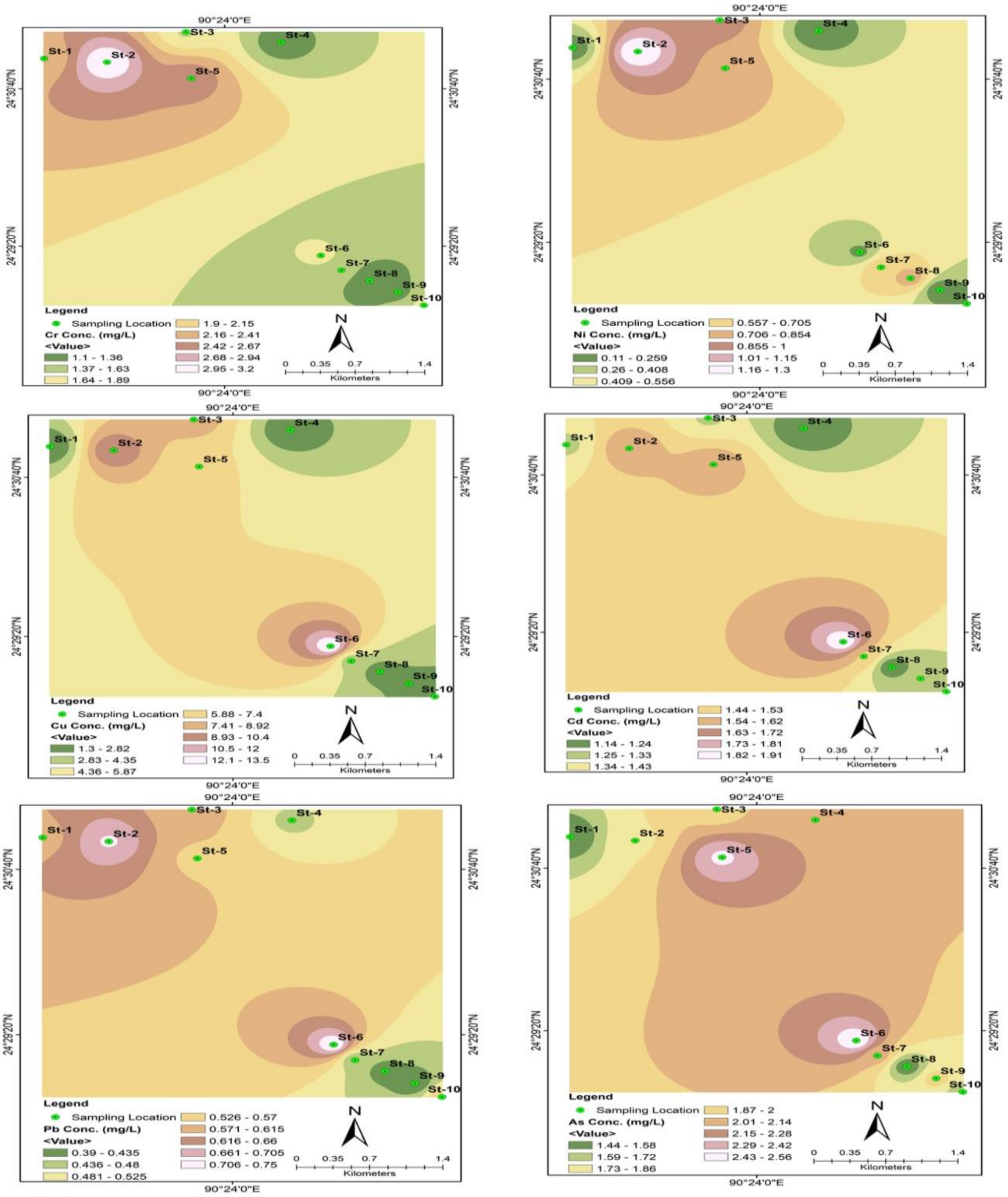

Fig. 2. Spatial distribution of heavy metal concentrations in surface water in the Upper Banar River, Mymensingh.

Copper (Cu)

The St-6 exhibited the highest Cu concentration (13.50 μgL^{-1}), while St-1 had the lowest concentration (1.30 μgL^{-1}), according to Figure 2. The average Cu concentration in this study was 5.07 μgL^{-1}, which was below the HBGV, BDWS, TRV, ALWPL, and ILWPL values. However, it was higher than the concentrations observed in the Turag and Khiru Rivers and comparable to the Rupsha River. On the other hand, when compared to the Shitalakhya, Pasur, Old Brahmaputra, and Karnaphuli Rivers (Table 3), the mean Cu concentration in this study was lower. According to White and Brown (2010), Cu-enriched liquid dairy waste can harm plants, and an excess of it can be toxic to certain microbes (Hasnine *et al.*, 2017).

Cadmium (Cd)

The St-6 exhibited the highest Cd concentration (1.91 μgL^{-1}), whereas St-8 had the lowest concentration (1.14 μgL^{-1}), according to Figure 2. The average Cd concentration measured in this study was 1.42 μgL^{-1}, lower than the BDWS, HBGV, TRV, ALWPL, and ILWPL values. On the other hand, it was higher than the concentrations observed in Rupsha, Dakatia, and Bangshi River, but comparable to Bhairab, Old Brahmaputra, and Louhajang Rivers (Table 3). However, the mean Cd concentration in this study was lower compared to Meghna, Shitalakhya, Padma, Karnaphuli, and Turag Rivers (Table 3). The primary sources of Cu were reported to be the production of batteries, dyes, and alloys (Hanfi *et al.*, 2020).

Lead (Pb)

Exposure to Pb can have adverse effects on the gastrointestinal tract, liver, and CNS, with the potential to breach the blood-brain barrier, leading to interference in the brain development of infants (Rajeswari and Sailaja, 2014). According to Figure 2, St-6 exhibited the highest Pb concentration (0.75 μgL^{-1}), while St-9 showed the lowest (0.39 μgL^{-1}). The average Pb concentration was 0.55 µgL-1, below the values of BDWS, HBGV, TRV, ALWPL, and ILWPL. Moreover, this study's Pb concentration was also lower than that observed in other studies like the Meghna, Shitalakhya, and Karnaphuli Rivers (Table 3). Sources of Pb in urban areas encompass manufacturing, fossil fuel, weathering, agricultural and domestic applications (Hanfi *et al.*, 2020).

Arsenic (As)

The St-6 had the highest As concentration (2.56 μgL^{-1}), while St-1 and St-8 had the lowest concentration (1.44 μgL^{-1}) (Figure 2). Average As concentration was 1.94 μgL^{-1}, below the values of BDWS, HBGV, TRV, ALWPL, and ILWPL. Compared to other studies, such as those conducted on the Meghna, Rupsha, and Louhajang Rivers (Table 3), the As concentration in this study was lower. Possible sources of As were identified as the fertilizer and pesticide industry, the wood industry's use of copper arsenate, and tanning involving certain chemicals like arsenic sulfide, as reported by Bhuiyan *et al.* (2011) and Fu *et al.* (2014). Arsenic is also referred to as "death metal" due to its gradual toxicity to the human body (Nawab *et al.*, 2018).

Table 3. Comparison of metal concentration in surface water of the Upper Banar River with other studies.

Name of river	Metal concentrations ($\mu g\ L^{-1}$)						References
	Cr	Ni	Cu	Cd	Pb	As	
Upper Banar	1.81	0.54	5.07	1.42	0.55	1.94	Present study
Meghna	45.0	NF	NF	29.0	10.0	24.0	Rahman *et al.* (2021)
Shitalakhya	6.90	NF	24.0	4.40	6.50	NF	Kabir *et al.* (2020)
Pasur	20.0	NF	20.0	NF	NF	NF	Shil *et al.* (2017)
Bhairab	13.0	NF	NF	10.0	14.0	NF	Sarkar *et al.* (2016)
Old Brahmaputra	10.0	440	120	1.00	110	NF	Bhuyan *et al.* (2019)
Padma	3.00	NF	20.0	2.00	1.50	NF	Jolly *et al.* (2013)
Karnaphuli	250	NF	50.0	10.0	140	NF	Islam *et al.* (2013)
Rupsha	7.20	3.85	5.36	0.98	7.09	5.45	Proshad *et al.* (2020)
Dhaleshwari	440	7.00	150	6.00	50.0	NF	Ahmed *et al.* (2012)
Turag	NF	NF	4.00	10.0	2.00	NF	Mokaddes *et al.* (2013)
Buriganga	590	8.00	163	9.00	70.0	NF	Ahmad *et al.* (2010)
Dakatia	3.00	NF	32.6	1.30	6.30	NF	Hasan *et al.* (2015)
Bangshi	NF	NF	70.0	1.20	13.5	NF	Rehnuma *et al.* (2016)
Khiru	NF	NF	4.00	130	200	NF	Rashid *et al.* (2012)
Balu	NF	NF	10.0	8.00	1.00	NF	Mokaddes *et al.* (2013)
Louhajang	6.70	9.00	8.00	1.00	8.00	7.00	Proshad *et al.* (2021)

*Note: *NF = Not Found*

According to Prasad and Bose (2001), heavy metal pollution can be categorized as follows: low pollution (HPI < 100), pollution at the threshold risk level (HPI = 100), and high pollution (i.e., critical pollution index) (HPI > 100). The water is not potable if the samples have an HPI greater than 100. The overall findings indicated that the water of the Upper Banar River was contaminated with heavy metals, but the pollution level was not significant based on the HPI analysis. The analysis of HEI values for the Upper Banar River water showed that the lowest value was 0.35 (St-4), and the highest value was 0.78 (St-6) (Table 4), indicating low heavy metal contamination for all sampling stations across the study area. The HEI values are classified as follows: < 10 indicates low risk, 10 to 20 indicates medium risk, and > 20 indicates high risk (Proshad *et al*., 2020). Therefore, the computed HEI values suggested that the water quality fell under the lower level of pollution and represented a low risk. To estimate the extent of metal pollution, CD was used as a reference, and it can be grouped into three categories: low (CD < 1), medium (CD = 1 to 3), and high (CD > 3) (Brraich and Jangu, 2015). The range of CD was from -5.65 (in St-4) to -5.22 (in St-6) (Table 4), indicating that the CD values fell into the low pollution category. The assessment of PI helps identify the pollution status in the study area. The cumulative PI values ranged from 0.28 (in St-8) to 0.49 (in St-6) (Table 2). Mitra et al. (2018) categorized PI values as follows: PI < 0.3 denotes class 1 (very pure), and 0.3 < PI < 1 denotes class 2 (pure). In the study area, except for Site-8 (falling into class 1 category), all other sites were categorized as class 2 (Table 4).

Table 4. Heavy metal pollution indices (HPI, HEI, CD and PI) of surface water of the Banar River.

Stations	HPI	HEI	CD	PI
St-1	52.56	0.39	-5.61	0.35
St-2	44.18	0.72	-5.28	0.46
St-3	51.87	0.57	-5.43	0.36
St-4	56.25	0.35	-5.65	0.31
St-5	43.65	0.62	-5.39	0.45
St-6	35.65	0.78	-5.22	0.49
St-7	45.79	0.49	-5.50	0.39
St-8	56.45	0.37	-5.63	0.28
St-9	52.46	0.39	-5.60	0.33
St-10	52.19	0.38	-5.61	0.34

Understanding individual risk factors and cumulative potential ecological risk (ERI) is essential for gaining advanced insights into river water pollution and its associated ecological risks (Kabir *et al*., 2020; Islam *et al*., 2018). The mean ERI values for individual toxic metals, such as Cr, Ni, Cu, Cd, Pb, and As, ranged from 0.022 to 0.064, 0.0055 to 0.065, 0.0065 to 0.0675, 6.84 to 11.46, 0.039 to 0.075, and 0.288 to 0.512, respectively (Table 5). Among these metals, Cd emerged as the primary contributor to ecological hazards in the river water, owing to its pronounced effect on the toxicity state. Conversely, the risks posed by Cr, Ni, Cu, Pb, and As were relatively low at all stations along the Upper Banar River. In general, the ERI value of Cd far surpassed that of all the other metals studied, emphasizing Cd as a significant potential threat to the environment.

Moreover, the study indicated that anthropogenic activities were projected to be the major sources of Cr, Ni, Cu, Cd, Pb, and As in the study areas. The calculated ERI values for the water of the Upper Banar River ranged from 7.24 at St-8 to 12.16 at St-6 (Table 5). Due to sufficient water flow, the ERI values for the Upper Banar River water samples generally demonstrated a low-risk level. Proshad *et al.* (2021) revealed ERI values ranging from 47.32 to 293.58 for the Louhajang River in Tangail City, indicating a low to moderate ecological risk. Similarly, Latif *et al.* (2021) reported an ERI range of 1.79 to 7.27 for the Bangshi River, indicating low potential ecological risk from heavy metal contamination. As for the Rupsha River, its mean ERI ranged from 79.53 to 298.90, indicating low to moderate potential ecological risks from heavy metal pollution (Proshad *et al*., 2020). When comparing these results with earlier studies conducted on various rivers in Bangladesh, it can be inferred that the water quality of the Upper Banar River remains in good condition and is suitable for both human utilization and aquatic life.

Table 5. Ecological risk index (ERI) of studied metals in Upper Banar River of Bangladesh.

Sampling stations	Risk index of single metal						ERI	
	Cr	Ni	Cu	Cd	Pb	As	Value	Level
St-1	0.044	0.0075	0.0065	7.86	0.060	0.288	8.27	low
St-2	0.064	0.0650	0.0520	9.66	0.071	0.366	10.28	low
St-3	0.032	0.0475	0.0415	7.92	0.059	0.384	8.49	low
St-4	0.024	0.0060	0.0080	6.90	0.047	0.428	7.41	low
St-5	0.052	0.0415	0.0310	9.66	0.056	0.490	10.33	low
St-6	0.034	0.0110	0.0675	11.46	0.075	0.512	12.16	low
St-7	0.030	0.0345	0.0170	9.12	0.044	0.414	9.66	low
St-8	0.022	0.0410	0.0095	6.84	0.041	0.288	7.24	low
St-9	0.026	0.0055	0.0130	7.68	0.039	0.386	8.15	low
St-10	0.034	0.0115	0.0075	7.86	0.056	0.324	8.29	low

Proshad *et al.* (2020) and Kabir *et al.* (2020) employed both Pearson's correlation and principal component analysis to explore the connections among heavy metals present in water and to identify key factors influencing the transport and distribution of metal contaminants. The Pearson's correlation matrix revealed interrelationships among the analyzed heavy metal concentrations in water, as shown in Table 6. The study observed robust positive correlations between As and Cd, Pb and Cd, Cr and Cd, Cr and Pb, as well as Ni and Cr. These significant positive correlations between different metal combinations indicated that these parameters were interconnected and likely originated from the same source in the study area (Proshad *et al.*, 2021). However, no other significant relationships were found among the constituents of the water.

Table 6. Pearson correlation matrix for heavy metals concentration in water.

Elements	As	Cd	Pb	Cr	Ni	Cu
As	1					
Cd	0.687*	1				
Pb	0.295	0.723**	1			
Cr	0.098	0.519*	0.659*	1		
Ni	-0.033	0.203	0.216	0.525*	1	
Cu	0.595*	0.831**	0.790**	0.452	0.418	1

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

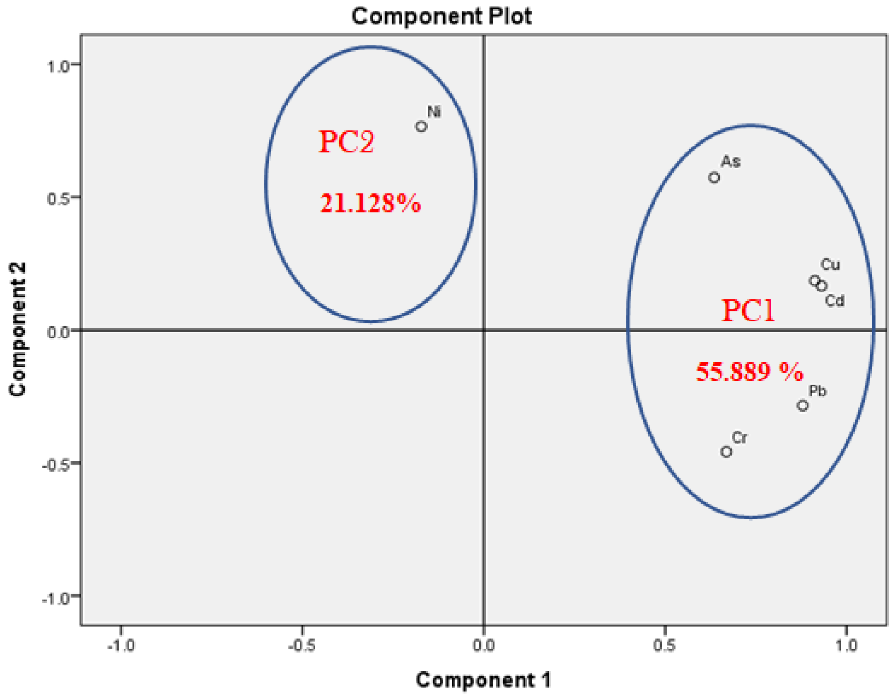

Fig. 3. Principal component analysis (PCA) of toxic metals in water samples.

The PCA analysis yielded significant findings regarding the representation of toxic metals studied through two principal components (PCs), which collectively accounted for 77.017% of the total variance (Fig. 3). The first principal component (PC1) predominantly reflected the presence of five metals (As, Pb, Cu, Cr, and Cd) and explained 55.889% of the total variance. On the other hand, the second principal component (PC2) was mainly influenced by one metal (Ni) and accounted for 21.128% of the total variance. These PCA results aligned with the outcomes of Pearson's correlation analysis, indicating that the toxic metals in the river water likely originated from anthropogenic sources (Proshad *et al.*, 2021). Specifically, PC1 effectively characterized the impact of industrial activities on the contamination of water samples with toxic elements, while PC2 revealed the influence of industrial practices on Ni contamination in the water. Furthermore, it was noted that Ni can be directly or indirectly released from industries involved in metal processing, smelting, and manufacturing electronic components (Proshad *et al.*, 2020; Kabir *et al.*, 2020).

Conclusion

The research focused on examining the presence of six toxic metals (Cr, Ni, Cu, Cd, Pb, As) in the surface water of the Upper Banar River, which is situated close to industrial areas in Mymensingh district, Bangladesh. Through the use of elemental abundances, index-based calculations, and statistical analyses, the study provided various insights into pollution status, source evaluation, and ecological risk assessment. The results indicated that the average concentration of the metals studied followed the order of Cu > As > Cr > Cd > Pb > Ni. Moreover, after assessing the HPI, HEI, CD, and PI values of all the examined metals, it was determined that the river water maintained a satisfactory level of contamination. Although the ERI indicated a minimal risk, Cd's ERI was far higher than any other metals examined. Thus, it is crucial to set up appropriate monitoring procedures even when the risk is below the allowable level to lessen surface water pollution.

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