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Dissolved Heavy Metals in the Rupsha River Near Khulna Shipyard, Bangladesh: Spatial and Seasonal Variation in the Surface Waters

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ABSTRACT: Shipyard activities can introduce dissolved metals to adjacent waterways through hull maintenance, painting, sanding, fuel handling, and waste discharge. This study assessed spatial and seasonal variation in dissolved heavy metals in surface water of the Rupsha River near Khulna Shipyard, Bangladesh. Twelve river-water samples were collected during the pre-monsoon and post-monsoon periods of 2023. Samples were collected at approximately 0.30-0.61 m depth, filtered through 0.45 µm membrane filters, acid-preserved, and analyzed for Cr, Mn, Ni, Cu, Zn, As, Hg, and Pb using EDXRF. Descriptive statistics, station-level exceedance analysis, contamination factor (CF), Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI), Metal Index (MI), and GIS-based IDW interpolation were used to evaluate contamination patterns. Mean pre-monsoon concentrations were Cr 3.67, Mn 26.84, Ni 16.03, Cu 22.96, Zn 13.96, As 1.22, Hg 6.86, and Pb 3.41 mg/L. Mean post-monsoon concentrations were Cr 1.32, Mn 1.99, Ni 0.56, Cu 3.25, Zn 5.76, As 1.99, Hg 9.67, and Pb 1.58 mg/L. Most metals decreased during the post-monsoon period, whereas As and Hg increased. CF and pollution-index results indicated severe station-level contamination, particularly for Hg, Pb, As, Cr, Mn, and Ni. Spatial patterns showed localized hotspots near shipyard-influenced sections of the river. The findings indicate substantial dissolved metal contamination in the Rupsha River near Khulna Shipyard and highlight the need for regular monitoring, source-control measures, and future sediment, biota, and human-exposure assessments.

Keywords: Heavy Metal Contamination; Rupsha River**;** Seasonal Variation**;** Industrial Pollution**;** Shipyard Discharge**;** Mercury Toxicity

INTRODUCTION

Heavy-metal contamination is a persistent environmental concern in industrial river systems because metals do not degrade and may remain dissolved in water, bind to suspended particles, accumulate in sediments, and enter aquatic food webs. Elevated concentrations of metals such as Cr, Mn, Ni, Cu, Zn, As, Hg, and Pb can affect aquatic organisms and may pose human-health risks through direct water contact, incidental ingestion, irrigation-related exposure, and consumption of contaminated fish and shellfish (Bose-O'Reilly et al., 2010; Syversen & Kaur, 2012; Tchounwou et al., 2012). Therefore, evaluating both spatial distribution and seasonal variation is necessary for identifying pollution hotspots and designing management interventions.

Bangladesh is a riverine country where many rivers receive mixed inputs from industrial discharge, municipal waste, urban runoff, agricultural drainage, and port-related activities. Previous studies have reported metal contamination in surface water and sediments of several Bangladeshi rivers, including urban and industrial reaches (Bashar et al., 2023; Bhuyan et al., 2019; Dey et al., 2021; Fardullah et al., 2025; Islam et al., 2018)the capital of Bangladesh. However, this river is severely polluted and is considered one of the most polluted in the world. Therefore, this study aimed to assess the concentrations of various metals in the Buriganga River. A study was conducted from August 2019 to February 2020 to determine the concentrations of 16 metals in water samples (n ¼ 210. Monsoonal hydrology can further modify metal distribution by changing river discharge, dilution, runoff input, suspended sediment concentration, and

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sediment-water exchange (Alam et al., 2023; Haque et al., 2020)health index and statistical techniques were incorporated to assess the heavy metal contamination. Two seasons, cool dry winter and pre-monsoon hot, were considered for sampling from 12 stations around the island. The Cool dry winter season has higher nutrient concentrations than the Pre-monsoon Hot season. The concentration of nutrients appeared as follows: Silicate > Nitrate > Ammonia > Phosphate > Nitrite. PCA and Pearson's Correlation showed that fresh water from nearby rivers, deep water upwelling, and, in some situations, modest anthropogenic sources are crucial. Hence, low DO and phosphate levels during the pre-monsoon hot season indicate there is a planktonic process like photosynthesis prevailing. The island's north-western and south-eastern regions have higher nutrient concentrations, which may be seasonal and due to wind action. Pb, Cu, As, Cr, Cd, and Zn were also considered to comprehend the island's geo-chemical perspectives and ecological and human health risks. The Pre-monsoon Heavy Metal Pollution Index (HPI. The Rupsha River is an economically and ecologically important waterway near Khulna city and the Sundarbans region. Shipbuilding and waterfront industrial activities along the river may release metals through paint residues, antifouling coatings, welding and sanding residues, oil and fuel handling, and solid-waste disposal (Chowdhury & Rasid, 2016). These inputs can create localized contamination near shipyard zones, while seasonal flow variation may either dilute contaminants or mobilize metals from banks, drainage channels, and contaminated sediments (Ali et al., 2024; Zhang et al., 2020)considering seasonal variations, and identify potential pollution sources using physicochemical parameters, multivariate statistical analysis, and the water quality index (WQI.

Although several studies have assessed river-water contamination in Bangladesh, dissolved metal data for the Rupsha River near the Khulna shipyard remain limited, particularly in relation to seasonal differences and spatial hotspots(Chowdhury & Rasid, 2016). This gap is important because dissolved metals are immediately available for transport and can provide a screening-level indication of exposure risk. This study investigates the surface waters shipbuilding areas of Rupsha river in order to : (i) quantify seasonal (pre- vs post-monsoon) and spatial variation of dissolved Cr, Mn, Fe, Ni, Cu, Zn, As, Hg, Pb, and Cd in surface waters; (ii) make comparisons with observed concentrations against World Health Organization (WHO) and national guideline values; (iii) visualize spatial patterns with GIS and detection of potential hotspots using interpolation; These analyses will provide a focused baseline for proper management actions in this intensively used industrial waterway.

MATERIALS AND METHODS

Study Area

The chosen study covers the region situated to the Khulna shipyard beneath the Khan Jahan Ali Bridge, Rupsha River. Twelve sampling stations were established for both seasons but due to difference in sampling vehicle difference the locations had few difference in post monsoon than pre-monsoon. Vertical variation of depth was also ensured. Khulna region is densely populated and has diverse ecosystems, situated in proximity to the Sundarbans, which is recognized as a highly ecologically vulnerable area and Rupsha river is more vulnerable due to the shipyard (Ahmed Shakik et al., 2025).

Sampling and Sample Design

Twelve sampling stations were selected to represent upstream, shipyard-adjacent, and downstream sections of the Rupsha River. Water samples were collected during the pre-monsoon period in March 2023 and the post-monsoon period in October 2023. Although the same general river sections were targeted in both seasons, the exact sampling coordinates differed between the pre- and post-monsoon surveys because of field-access limitations, boat movement, water-level variation, and safe positioning constraints near the shipyard area.

Therefore, the seasonal comparison was treated as a comparison between two spatial surveys within the same study reach rather than as a strictly paired station-by-station comparison. Samples were collected from surface water at approximately 0.30-0.61 m depth using acid-washed polyethylene bottles. The bottles were rinsed with site water before final collection, and field blanks and duplicate samples were included for quality control. Samples were filtered in the field using 0.45 μm membrane filters, acidified with ultrapure nitric acid to pH < 2, stored in clean cool boxes, and transported to the laboratory for analysis.

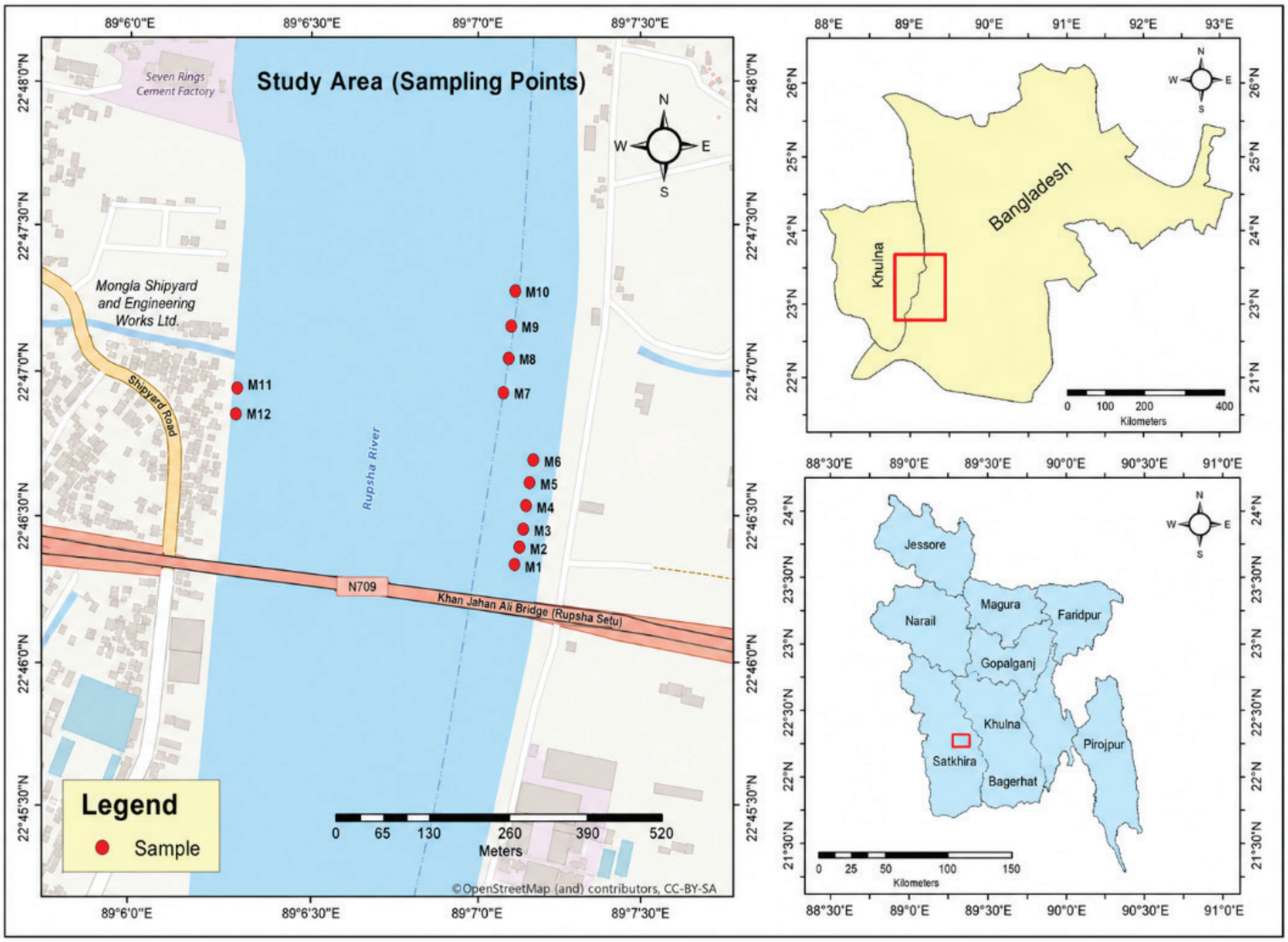

Figure 1: Study Location

Table 1: Sampling Station Coordinates

Station	Pre-monsoon latitude	Pre-monsoon longitude	Post-monsoon latitude	Post-monsoon longitude	Depth (m)
Water-M1	22.777643	89.586212	22.793877	89.582429	0.30-0.61
Water-M2	22.777629	89.586226	22.792551	89.582983	0.30-0.61
Water-M3	22.777843	89.586323	22.791392	89.583226	0.30-0.61
Water-M4	22.777858	89.586337	22.790297	89.583391	0.30-0.61
Water-M5	22.778100	89.586400	22.788930	89.583746	0.30-0.61
Water-M6	22.778100	89.586400	22.787698	89.583834	0.30-0.61
Water-M7	22.778743	89.586336	22.786358	89.583919	0.30-0.61
Water-M8	22.778729	89.586321	22.785055	89.584005	0.30-0.61
Water-M9	22.779259	89.586491	22.783640	89.584092	0.30-0.61
Water-M10	22.779231	89.586476	22.781955	89.584027	0.30-0.61
Water-M11	22.779918	89.582121	22.787745	89.582706	0.30-0.61
Water-M12	22.779918	89.582121	22.785875	89.582943	0.30-0.61

Laboratory Analysis and Quality Assurance

Dissolved metals were determined using energy-dispersive X-ray fluorescence spectrometry (EDXRF) after field filtration and acid preservation. In brief, water samples were filtered through 0.45 µm membrane filters, acidified with ultrapure nitric acid to pH < 2, and transported to the laboratory in clean cool boxes. Prior to EDXRF analysis, the dissolved metal fraction was prepared using an aqueous pre-concentration procedure suitable for trace-metal determination in water samples. A measured volume of each filtered and acidified sample was pre-concentrated onto a cellulose-based matrix and then analyzed by EDXRF. Spectra were processed using matrix-matched calibration standards, and spectral interference corrections were applied where necessary.

Calibration was performed using multi-element standards, and continuous calibration verification was carried out after every 10-15 samples. Accuracy was assessed using certified reference materials and/or matrix-spike recovery tests, with acceptable recoveries targeted within 75-125%. Analytical precision was evaluated using duplicate samples; relative percent difference values of ≤10% for moderate to high concentrations and ≤20% near the limit of quantification were considered acceptable. Method blanks were required to remain below the method detection limit; any blank exceedance required reanalysis or blank correction. Because unusually high Hg values were observed, Hg results were carefully checked using method-specific QA/QC results, including blank responses, duplicate precision, recovery performance, and spectral interference evaluation.

GIS Mapping and Interpolation

Sampling locations were mapped using GIS software, and station-level metal concentrations were joined with the corresponding sampling points. Spatial distribution maps were prepared using the inverse distance weighting (IDW) interpolation method to identify relative hotspots along the sampled river corridor. IDW was used because nearby sampling points are expected to have more similar concentrations than distant points. Interpolation was restricted to the river corridor and interpreted only as a visualization tool, not as a regulatory estimate for un-sampled locations. Map legends were prepared using rounded concentration classes to improve readability.

Statistical Analysis

Descriptive statistics were calculated for each metal and season, including minimum, maximum, mean, standard deviation, and median. Because reviewers noted that pre-monsoon and post-monsoon sampling points may not be exactly identical, seasonal differences were treated as independent groups in this draft and evaluated using Welch's t-test and Mann-Whitney U tests. If the final GPS table confirms that stations were identical across seasons, the analysis should be changed to paired t-tests or Wilcoxon signed-rank tests. Statistical significance was interpreted at $p < 0.05$, while results were also evaluated cautiously because of the small sample size ($n = 12$ per season).

Pollution Indices

Contamination factor (CF) was calculated to assess station-level metal contamination relative to the Bangladesh drinking-water standard (BDS). CF was calculated as:(Chowdhury & Rasid, 2016)

$$CF_i = \frac{C_i}{S_i}$$

where C_i is the measured concentration of metal i, and S_i is the BDS value for that metal. A *CF* value greater than 1 indicates that the concentration exceeded the selected standard. *CF* values were calculated separately for each metal, station, and season, and are presented in Tables 5 and 6.

Heavy metal pollution index was calculated following the formula below:

$$HPI = \frac{\sum W_i Q_i}{\sum W_i}$$

where W_i is the unit weight of metal i and is the sub-index value. The unit weight was calculated as: $W_i = \frac{1}{S_i}$; and the sub-index was calculated as: $Q_i = \frac{C_i}{S_i} \times 100$; where C_i is the measured concentration of metal i, and S_i is the Bangladesh drinking-water standard for that metal (Haque et al., 2020).

The Heavy Metal Evaluation Index (HEI) was calculated as:

$$HEI = \sum_{i=1}^{n} \frac{C_i}{S_i}$$

The Metal Index (MI) was calculated as:

$$MI = \sum_{i=1}^{n} \frac{C_i}{MAC_i}$$

where MAC_i is the maximum allowable concentration of metal i. In this study, the Bangladesh drinking-water standard was used as the reference value for both C_i and MAC_i. Therefore, HEI and MI produced the same numerical values but were both reported to allow comparison with previous water-quality studies. All indices were calculated at the station level to avoid relying only on seasonal average concentrations.

Ecological and Human Health Risk Assessment

Ecological risk was evaluated using the ecological risk index (ERI). The single-metal ecological risk factor was calculated as: $E_r^i = T_r^i \times CF_i$; The total ecological risk index was calculated as:(Fardullah et al., 2025)

$$ERI = \sum_{i=1}^{n} E_r^i$$

where E_r^i is the ecological risk factor for metal i; T_r^i is the toxic-response factor, and CF_i is the contamination factor. Toxic-response factors of 2, 1, 5, 5, 1, 10, 40, and 5 were used for Cr, Mn, Ni, Cu, Zn, As, Hg, and Pb, respectively. Human health risk was assessed for non-carcinogenic ingestion exposure using chronic daily intake (CDI) and hazard quotient (HQ). CDI was calculated as:

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

where (C) is the metal concentration in water, (IR) is the ingestion rate, (EF) is the exposure frequency, (ED) is the exposure duration, (BW) is body weight, and (AT) is the averaging time. For non-carcinogenic risk, (AT = ED 365). Therefore, CDI was simplified as:(Rahman et al., 2019)

$$CDI = \frac{C \times IR}{BW}$$

The hazard quotient was calculated as:

$$HQ = \frac{CDI}{RFD}$$

where (RFD) is the oral reference dose for each metal. An HQ value greater than 1 indicates potential non-carcinogenic health concern. CDI and HQ values were calculated using seasonal mean concentrations and standard adult and child ingestion assumptions(Dey et al., 2021).

RESULTS

Pre-monsoon Concentrations

During the pre-monsoon period, dissolved metal concentrations varied among the 12 sampling stations, indicating spatial variation within the sampled river reach. Mn, Cu, Ni, Zn, Hg, and Pb showed high concentrations across several stations. The maximum Cr and Zn concentrations were recorded at Water-M12, maximum Mn and Hg at Water-M9, maximum Ni at Water-M6, maximum As at Water-M5, and maximum Pb at Water-M1.

Post-monsoon Metal Concentrations

Post-monsoon concentrations also showed clear spatial variation among stations. In general, Cr, Mn, Ni, Cu, Zn, and Pb were lower than pre-monsoon values, while As and Hg remained high. Most post-monsoon maximum concentrations were recorded at Water-M11, indicating a localized hotspot in the post-monsoon survey.

Descriptive Statistics

Descriptive statistics were calculated to summarize the overall concentration pattern of each metal during the pre- and post-monsoon periods. Since the exact sampling coordinates differed between seasons, the datasets were treated as independent spatial surveys rather than paired station-wise observations. Minimum, maximum, mean ± SD, and median values are presented in (Table 2).

Figure 2: Concentration of Major Heavy Metal During Pre-monsoon

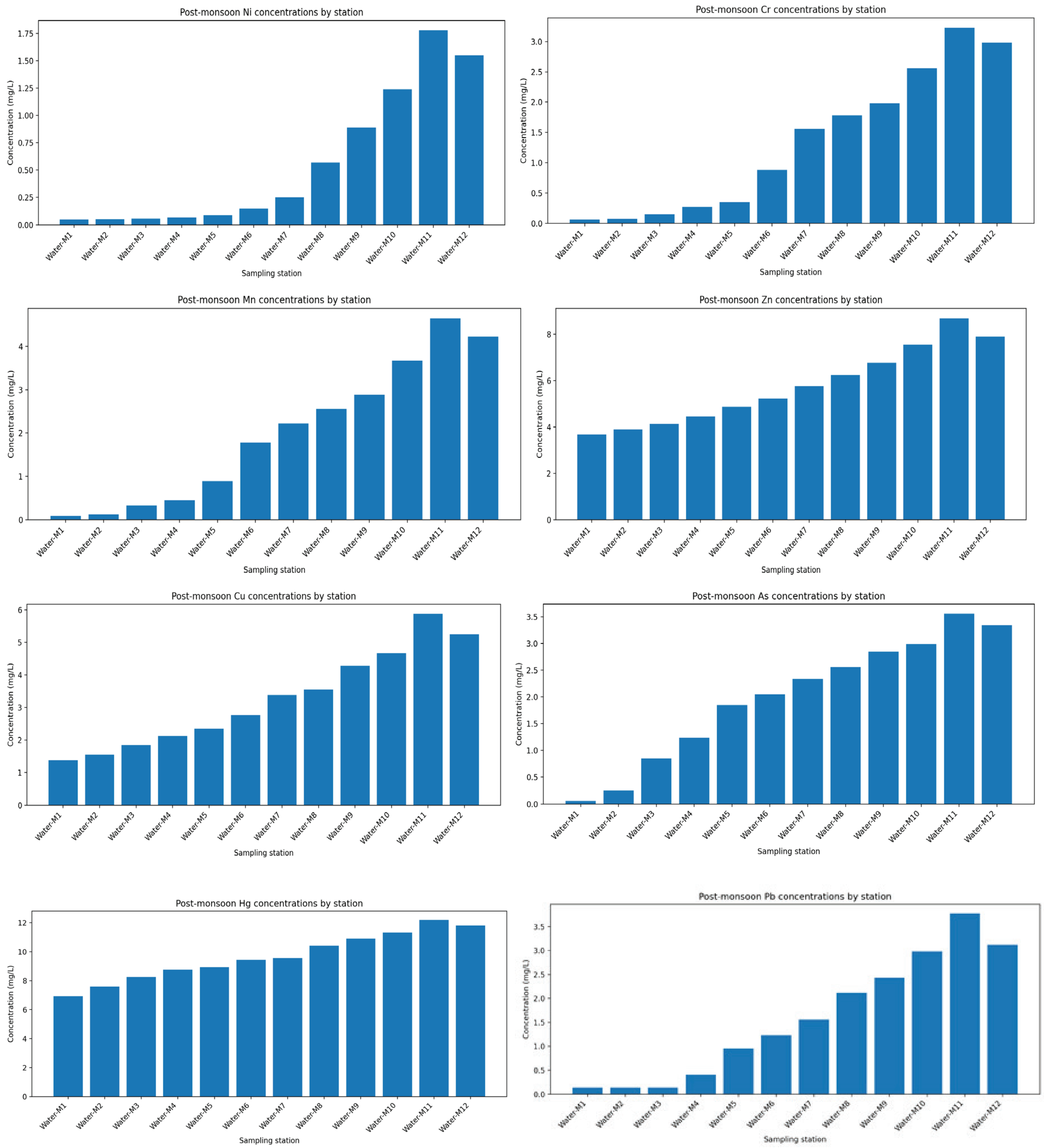

Figure 3: Concentration of Major Heavy Metal During Post-monsoon

Table 2: Descriptive Statistics of the Seasonal Concentration of Heavy Metals

Metal	Season	Minimum	Maximum	Mean	SD	Median
Cr	Pre-monsoon	1.03	7.97	3.671	2.41	2.94
Mn	Pre-monsoon	5.94	32.5	26.828	8.595	29.95
Ni	Pre-monsoon	15.0	17.7	16.05	0.837	16.05
Cu	Pre-monsoon	19.7	24.2	22.967	1.594	23.6
Zn	Pre-monsoon	9.77	18.1	13.956	2.689	13.45
As	Pre-monsoon	0.39	2.55	1.219	0.754	1.01
Hg	Pre-monsoon	3.44	9.54	6.86	2.001	6.74
Pb	Pre-monsoon	1.65	5.39	3.407	1.117	3.705
Cr	Post-monsoon	0.058	3.23	1.323	1.183	1.22
Mn	Post-monsoon	0.088	4.65	1.989	1.64	2.0
Ni	Post-monsoon	0.048	1.78	0.562	0.643	0.2
Cu	Post-monsoon	1.38	5.88	3.253	1.5	3.075
Zn	Post-monsoon	3.68	8.68	5.758	1.674	5.49
As	Post-monsoon	0.057	3.56	1.995	1.173	2.195
Hg	Post-monsoon	6.93	12.2	9.668	1.68	9.495
Pb	Post-monsoon	0.136	3.78	1.583	1.29	1.395

The descriptive statistics were used to understand the overall seasonal variation of dissolved metal concentrations across the sampled river reach. During the pre-monsoon period, higher mean concentrations were found for Cr, Mn, Ni, Cu, Zn, and Pb, while during the post-monsoon period, higher mean concentrations were observed for As and Hg. This result suggests that the concentrations of most metals decreased after the monsoon, whereas As and Hg showed a persistent or increasing trend. Therefore, to clearly represent these seasonal differences, the mean ± SD values of each metal are presented in (Fig. 4).

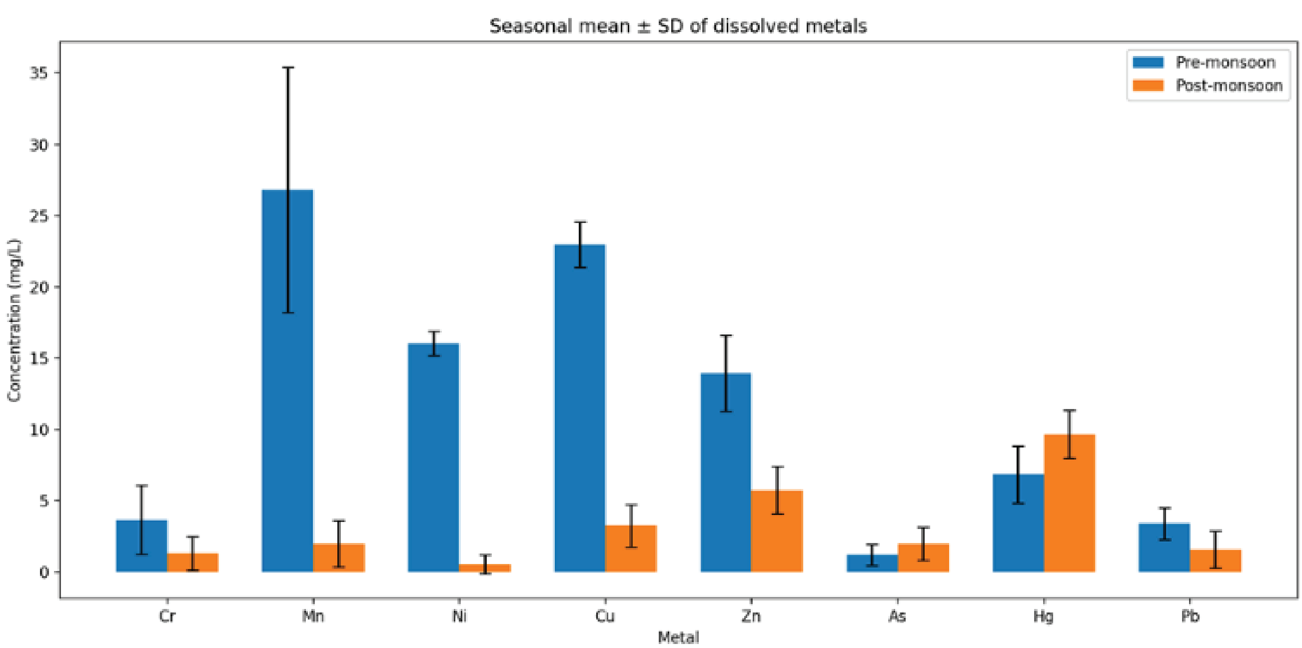

Figure 4: Statistical Representation of Heavy Metals During 2 Seasons

Spatial Distribution Maps

The IDW interpolation maps should be inserted after the concentration and CF results because they visually support the station-level patterns described above. The maps should show only the sampled river corridor, the Khulna Shipyard location, and the sampling points.

The pre-monsoon spatial distribution maps indicate localized heavy-metal hotspots that are co-located with the shipbuilding zones along the Rupsha River. The maps further demonstrate a clear dilution/attenuation trend, where metal concentrations generally decrease with increasing distance from these facilities along the river's flow path. This spatial pattern is quiteconsistent across the studied metals (Cu, Mn, Ni, Pb, Zn, Hg, As, and Cr) and is also supported by the station-wise maximum concentrations reported in (Table 1)

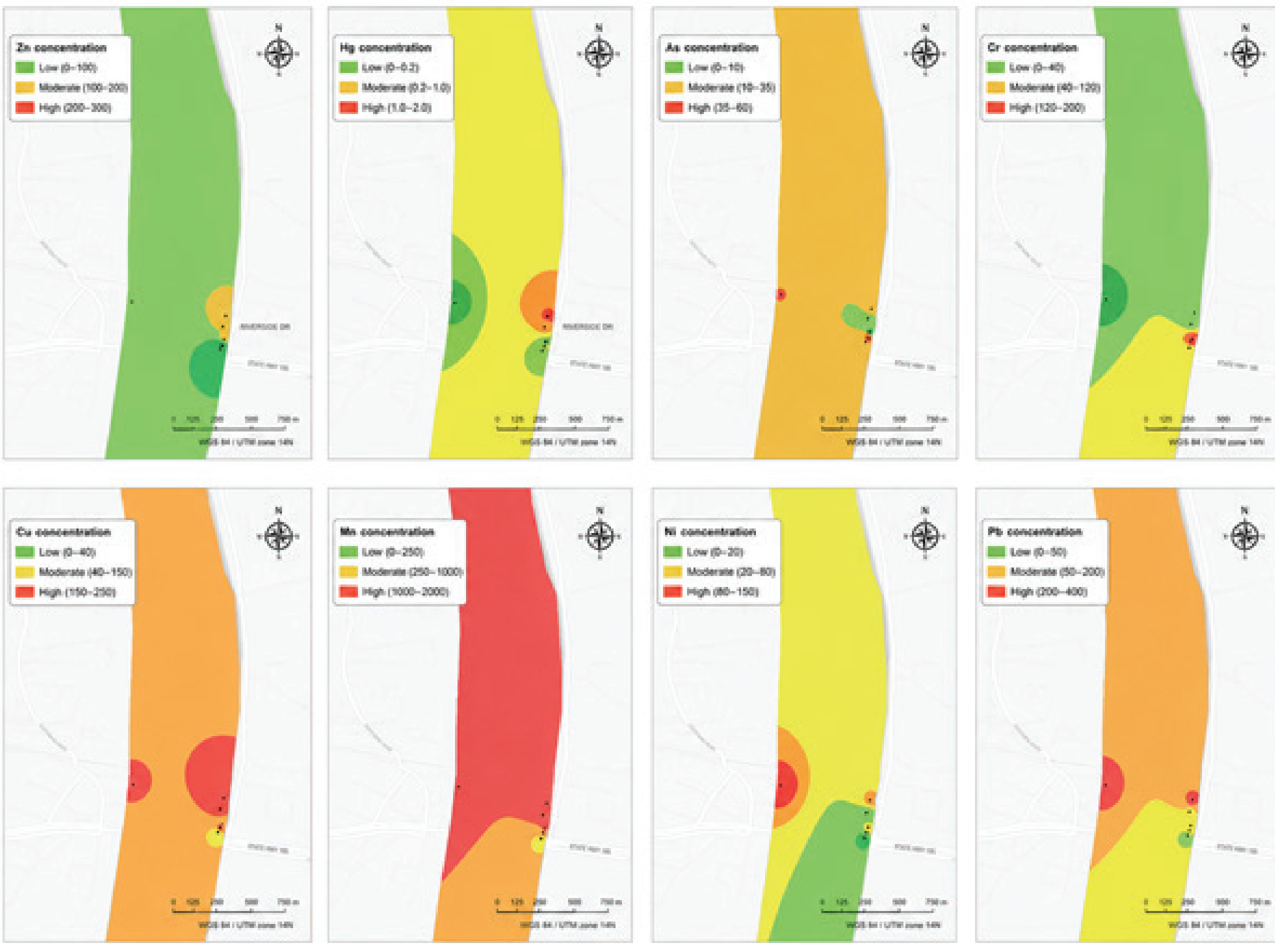

Figure 5: Concentration of Major Heavy Metals in Pre-Monsoon

Contamination Factor Analysis

To evaluate station-level contamination intensity, CF values were calculated for each metal using Bangladesh drinking-water standards as reference values. The pre-monsoon CF values are shown in (Table 3), and the post-monsoon CF values are shown in (Table 4). A CF value greater than 1 indicates that the measured concentration exceeded the selected national standard.

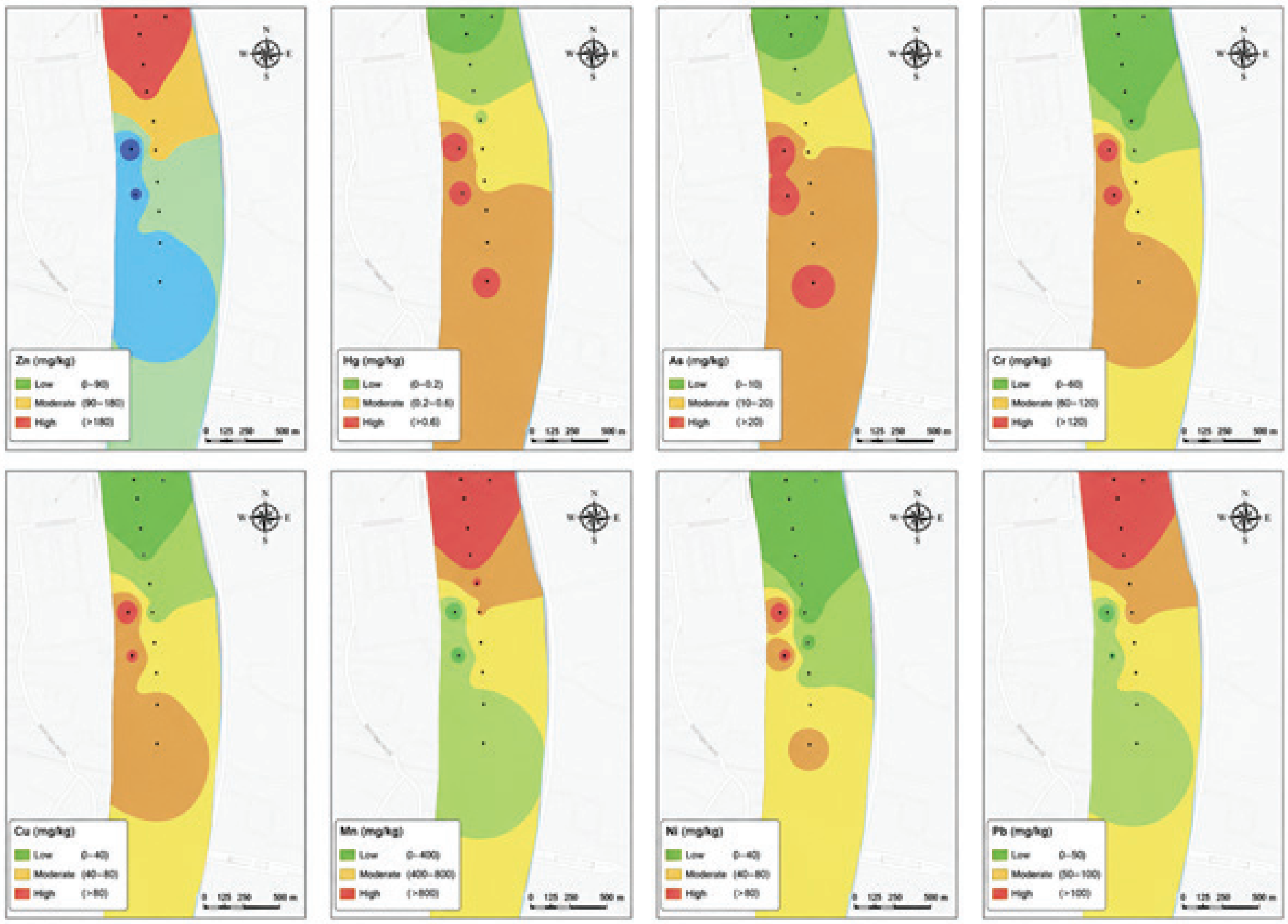

Figure 6: Post Monsoon Concentrations of Major Heavy Metals

Table 3: Pre-monsoon Contamination Factor Values of Dissolved Metals Based on Bangladesh Drinking-Water Standards

Station	Cr	Mn	Ni	Cu	Zn	As	Hg	Pb
Water-M1	27.0	323.3	150.1	19.7	3.0	14.6	6930.0	107.8
Water-M2	77.8	59.4	150.5	22.5	3.3	28.8	6550.0	67.8
Water-M3	111.0	252.0	156.1	24.2	3.2	8.2	4510.0	80.4
Water-M4	134.4	300.4	160.7	24.2	3.5	9.4	9200.0	54.2
Water-M5	126.6	295.8	162.1	22.0	2.0	51.0	5240.0	83.0
Water-M6	58.8	279.5	176.7	24.2	2.5	7.8	3440.0	83.8
Water-M7	52.4	314.5	155.5	23.8	2.2	27.8	6930.0	53.4
Water-M8	33.4	321.8	150.5	24.2	2.7	39.6	9470.0	83.0
Water-M9	20.8	325.4	166.7	23.0	2.2	19.6	9540.0	49.2
Water-M10	58.8	298.7	163.5	24.2	2.6	20.8	8480.0	33.0
Water-M11	20.6	324.3	170.5	23.4	2.7	16.6	5480.0	39.0
Water-M12	159.4	125.8	160.3	20.2	3.6	48.4	6550.0	83.0

Table 4: Post-monsoon Contamination Factor Values of Dissolved Metals Based on Bangladesh Drinking-Water Standards

Station	Cr	Mn	Ni	Cu	Zn	As	Hg	Pb
Water-M1	1.2	0.9	0.5	1.4	0.7	1.1	6930.0	2.7
Water-M2	1.5	1.2	0.5	1.6	0.8	5.0	7570.0	2.7
Water-M3	3.0	3.3	0.6	1.9	0.8	17.0	8250.0	2.7
Water-M4	5.4	4.5	0.7	2.1	0.9	24.8	8750.0	8.2
Water-M5	7.0	8.9	0.9	2.4	1.0	37.0	8930.0	19.2
Water-M6	17.6	17.8	1.5	2.8	1.0	41.0	9430.0	24.6
Water-M7	31.2	22.2	2.5	3.4	1.1	46.8	9560.0	31.2
Water-M8	35.6	25.6	5.7	3.5	1.2	51.2	10450.0	42.4
Water-M9	39.6	28.8	8.9	4.3	1.4	57.0	10880.0	48.6
Water-M10	51.2	36.7	12.4	4.7	1.5	59.8	11340.0	59.6
Water-M11	64.6	46.5	17.8	5.9	1.7	71.2	12250.0	75.6
Water-M12	59.6	42.3	15.5	5.2	1.6	66.8	11750.0	62.4

The CF values indicate that contamination was widespread across the sampled river reach. Hg showed the highest CF values in both seasons, followed by Pb, Mn, Ni, As, Cr, and Cu. Although some metals decreased during the post-monsoon period, several remained above the selected standard at multiple stations. These results show that station-level assessment is more informative than relying only on seasonal average concentrations.

To further evaluate the overall metal pollution status at each sampling station, HPI, HEI, and MI were calculated using Bangladesh drinking-water standards as reference values. The pre-monsoon and post-monsoon results of these indices are shown in Tables 6 and 7, respectively. These indices provide a station-wise summary of combined metal contamination and help to identify the pollution condition of groundwater in the study area.

Table 5: Pre-monsoon and Post-monsoon HPI, HEI, and MI Values

Station	Pre-monsoon HPI	Pre-monsoon HEI	Pre-monsoon MI	Post-monsoon HPI	Post-monsoon HEI	Post-monsoon MI
Water-M1	641671.0	7575.5	7575.5	640965.0	6938.5	6938.5
Water-M2	606327.0	6960.1	6960.1	700167.0	7583.3	7583.3
Water-M3	417878.0	5145.1	5145.1	763087.0	8279.3	8279.3
Water-M4	851701.0	9886.8	9886.8	809362.0	8796.6	8796.6
Water-M5	485554.0	5982.4	5982.4	826060.0	9006.3	9006.3
Water-M6	318867.0	4073.3	4073.3	872351.0	9536.3	9536.3
Water-M7	641639.0	7559.7	7559.7	884428.0	9698.4	9698.4
Water-M8	876606.0	10125.2	10125.2	966787.0	10615.3	10615.3
Water-M9	882976.0	10146.9	10146.9	1006590.0	11068.5	11068.5
Water-M10	784952.0	9081.6	9081.6	1049200.0	11565.9	11565.9
Water-M11	507445.0	6077.0	6077.0	1133450.0	12533.3	12533.3
Water-M12	606613.0	7150.7	7150.7	1087160.0	12003.4	12003.4

Heavy-metal Pollution Index Assessment

(Table 5) presents the station-wise HPI, HEI, and MI values for both pre-monsoon and post-monsoon periods. These indices were calculated using Bangladesh drinking-water standards as reference values to understand the combined metal pollution level at each sampling station. From the descriptive comparison, it was observed that metal pollution during the pre-monsoon period was highest at Water-M9 and Water-M8, whereas during the post-monsoon period, the highest pollution was found at Water-M11 and Water-M12. However, the sampling coordinates of pre-monsoon and post-monsoon periods were not exactly the same. Therefore, the index values were not considered as paired observations. For this reason, the seasonal variation of HPI, HEI, and MI should be interpreted as reach-scale differences between two independent spatial surveys. In addition, Mann-Whitney U test or Welch's t-test can be applied to examine the seasonal differences of these indices, while Spearman correlation can be used to determine whether stations with high HPI values also show high HEI and MI values.

Ecological and Human Health Risk Assessment

Ecological and human health risk values were calculated using seasonal mean concentrations because the pre-monsoon and post-monsoon sampling coordinates were not identical. Therefore, the results represent seasonal reach-scale risk estimates rather than paired station-level

Ecological Risk Assessment

Table 6: Ecological Risk Factor of Dissolved Metals Based on Seasonal Mean Concentrations

Metal	Pre-monsoon (ERI)	Risk class	Post-monsoon (ERI)	Risk class
Cr	146.8	Considerable	52.9	Moderate
Mn	268.3	High	19.9	Low
Ni	802.5	Very high	28.1	Low
Cu	114.8	Considerable	16.3	Low
Zn	2.8	Low	1.2	Low
As	243.8	High	399.0	Very high
Hg	274400.0	Very high	386720.0	Very high
Pb	340.7	Very high	158.3	Considerable

The ecological risk factor values showed that Hg was the dominant contributor to ecological risk in both seasons. In the pre-monsoon period, Hg, Ni, Pb, Mn, As, Cr, and Cu showed elevated ecological risk values, while Zn showed low risk. In the post-monsoon period, Hg and As remained the major ecological-risk contributors.

Human Health Risk Assessment

Table 7: Chronic Daily Intake Values for Adult and Child Ingestion Exposure

Metal	Adult CDI Pre	Adult CDI Post	Child CDI Pre	Child CDI Post
Cr	0.1049	0.0378	0.2447	0.0882
Mn	0.7665	0.0568	1.7890	0.1326
Ni	0.4586	0.0161	1.0700	0.0375
Cu	0.6562	0.0929	1.5310	0.2169
Zn	0.3987	0.1645	0.9304	0.3839
As	0.0348	0.0570	0.0813	0.1330
Hg	0.1960	0.2762	0.4573	0.6445
Pb	0.0973	0.0452	0.2271	0.1055

Table 8: Hazard Quotient Values for Adult and Child Ingestion Exposure

Metal	Adult HQ Pre	Adult HQ Post	Child HQ Pre	Child HQ Post
Cr	116.5	42.0	271.9	98.0
Mn	5.48	0.41	12.78	0.95
Ni	22.93	0.80	53.50	1.87
Cu	16.41	2.32	38.28	5.42
Zn	1.33	0.55	3.10	1.28
As	580.5	950.0	1354.0	2217.0
Hg	653.3	920.8	1524.0	2148.0
Pb	N/A	N/A	N/A	N/A

CDI values were higher for children than adults because of the lower assumed body weight. HQ values greater than 1 indicate potential non-carcinogenic health concern. The HQ results showed that As and Hg were the dominant contributors to potential non-carcinogenic risk in both seasons. Pb HQ was not calculated because no oral reference dose was used for Pb in this assessment.

DISCUSSIONS

The elevated amounts of major heavy metals detected in the surface waters of Rupsha river, particularly close to the Khulna shipyard area, definitely indicate serious pollution primarily originating from various industrial activities. The spatial patterns eventually reveal localized hotspots close to shipbuilding facility locations (Chowdhury & Rasid, 2016). These findings are very consistent with similar studies linking shipyard operation zones and heavy metal contamination(Ali et al., 2024; Singh et al., 2015). Monsoonal variations between pre- and post-monsoon concentrations severely reflect hydrological dynamics and pollutant mobilization systems. The marked rise in metals like arsenic (As), mercury (Hg) in post-monsoon suggests that surface runoff, resuspension of sediments, and reduced dilution effects after flood recession might have played a major role in transporting contaminants from land-based contaminant sources into the rupsha river(Chowdhury & Rasid, 2016; Md Saiful Islam et al., 2015) . Conversely, falling concentrations observed in chromium (Cr), manganese (Mn), nickel (Ni), copper (Cu), zinc (Zn), and lead (Pb) may be a result of dilution, deposition in bottom sediments, or binding with dissolved suspended particles during the monsoon (Wu et al., 2016).

The concentration of several major heavy metals far crosses the World Health Organization (WHO) and Bangladesh Drinking Water Standards (BDSW) given safety thresholds, especially mercury(Hg), which was found close to 1600 times above the provided guideline threshold (Afzal et al., 2024). This increases possibility of severe ecological dangers such as toxicity to aquatic lives and bioaccumulation of contaminants through the food chain, consequently threatening human health(Bose-O'Reilly et al., 2010; Clarkson & Magos, 2006). Exposure for long period of time to these contaminants can result in serious health outcomes like neurological, renal, and gastrointestinal conditions (Sarker et al., 2022; Tchounwou et al., 2012). The persistence of elevated metal concentrations in the Rupsha River an economically and ecologically important waterway located adjacent to the environmentally sensitive Sundarbans mangrove ecosystem raises urgent concerns for sustainable river-water management and conservation. If left unaddressed, continued contamination may cause irreversible ecological degradation and ultimately threaten the livelihoods of local communities that depend on the river's resources (Hossain et al., 2019; World Health Organization, 2017). This study underscores the need for stringent regulation enforcement to control effluent discharge, enhanced monitoring programs, and improved waste handling practices at shipyards and associated industries. Public awareness initiatives are also necessary to highlight the major health risks and to galvanize community action toward mitigation and prevention of pollution (Rahman et al., 2019)

The ecological and human health risk assessment also supports the concern raised by the concentration and contamination-factor results. The ecological risk factor values indicated high ecological concern for mercury in both seasons. Nickel, lead, manganese, arsenic, chromium and copper also showed risk levels in the pre-monsoon period. In the -monsoon period mercury and arsenic remained the major ecological-risk contributors. This pattern suggests that ecological risk in the studied river reach is not controlled by total metal concentration. It is also controlled by the toxicity weight of metals like mercury and arsenic. The screening-level human health assessment also showed non-carcinogenic risk through ingestion exposure. This is for arsenic and mercury(Sarker et al., 2022). Adult and child hazard quotient values exceeded 1 for metals. The child hazard quotient values are consistently higher because of assumed body weight. These results suggest that direct use or accidental ingestion of river water may pose potential health concerns. This is for children. However, these risk estimates should be interpreted cautiously. This is because site-specific water-use behaviour, exposure duration and metal speciation were not measured (Singh et al., 2015). Therefore, future studies should include exposure surveys. They should also include sediment and biota analysis and confirmatory testing of elevated mercury and arsenic concentrations. This will produce a complete ecological and human health risk assessment, for mercury and arsenic.

CONCLUSION

This study suggests that Rupsha River experiences significant heavy-metal pollution, with concentrations which keeps increasing during the post-monsoon period due to several processes such as increased river and rainwater runoff and sediment resuspension (Ahmed Shakik et al., 2025). The toxicity risk, particularly from mercury (Hg), arsenic (As), cadmium (Cd), lead (Pb), and chromium (Cr), severely exceeds both national and international safety thresholds which is highly alarming and also indicating a critical risk of environmental degradation and adverse public health impacts (Clarkson & Magos, 2006; World Health Organization, 2017). The probable source of this pollution is supposedly the shipbuilding sites near the study area. So, constructing this kind of heavy metal releasing industries near an important water body must be under strong monitoring and regulations. Moreover, proper governance and heavy metal remediation structures should be practiced. Although this study had several limitations due to time shortage, vehicle availability during different seasons and budget constrain, analysis quality has been thoroughly maintained in order to bring an overview of an important water body of the coastal region of Bangladesh. Further studies are highly needed in order to find the impact of this concentration of heavy metal on the ecology, ecosystem and community residing there.

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