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Spatiotemporal discrepancies and risk assessment of toxic heavy metals in surface water of Shitalakhya River around Narayanganj port in Bangladesh

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ABSTRACT

The urban rivers of developing countries like Bangladesh have been severely affected by toxic heavy metal pollution, posing serious ecological and human health risks. This study aimed to investigate the concentrations, spatiotemporal discrepancies, and associated risks of five alarming toxic metals (Pb, Cd, Cr, Cu and Mn) in the surface water of urban Shitalakhya River around Narayanganj port, one of the biggest and most important river ports in Bangladesh. Water samples were collected for three prevailing seasons i.e., pre-monsoon, monsoon, and post-monsoon from five selected sites. Physicochemical properties (color, odor, temperature, DO, pH, EC and TDS) of river water were also assessed, while heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and degree of contamination (CD) were calculated to evaluate the risks associated with toxic metal pollution in river water. The findings revealed that several physicochemical parameters, especially DO, EC and TDS, were not within the standards. The hierarchy of mean heavy metal concentrations in Shitalakhya River water was found as Mn>Cr>Cu>Cd>Pb during pre-monsoon, Mn>Cu>Cr>Cd>Pb during monsoon, and Mn>Cr>Cu>Pb>Cd during post-monsoon season. The metal concentrations were found to be higher in pre-monsoon and post-monsoon seasons, whereas the concentrations of all the heavy metals excluding Mn were within the standards recommended for domestic use, surface water, fisheries and irrigation purposes. The comparative analysis exhibited that the water quality of Shitalakhya River is deteriorating day by day at an alarming rate. HPI showed a critical pollution index value (drinking) for all three seasons, whereas HEI revealed low heavy metal contamination for all sampling stations. The values of CD indicated a high level of contamination in pre-monsoon and post-monsoon but monsoon season. The results confirmed the spatiotemporal discrepancies in toxic metal concentrations and associated ecological and human health risks, possibly resulting from the hydrological and anthropogenic interventions not only associated with port activities. Hence, urgent collective effort and proper monitoring are of utmost importance to safeguard the public health and this urban riverine ecosystem.

Keywords: Potentially toxic elements (PTEs), Spatiotemporal variations, Pollution indices, Urban River health

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Introduction

Water is the most pivotal resource for sustaining life on Earth, indicating the importance of sustainable use, protection and management of water resources (Begum *et al.*, 2019). Water quality and its changes have a significant impact on people's health and the aquatic environment (Kabir *et al.*, 2020a). Rivers are one of the principal water resources, which serve various roles and functions including industrialization, transportation, aquaculture, and habitat (Ali *et al.*, 2022). However, due to human activities and a lack of proper management, river water quality has been deteriorating especially in the urban areas of developing countries like Bangladesh (Latif *et al.*, 2022). A wide variety of chemical contaminants are seriously affecting the urban rivers, which is considered as one of the high-priority environmental and public health issues (Proshad *et al.*, 2021).

Bangladesh is a riverine country, with above 230 large rivers flowing through it (Hasan *et al.*, 2019). However, being a highly-populated developing country, anthropogenic activities like speedy urban developments, industrial expansion, and intensive agriculture have undesirably affected the urban river ecosystems of Bangladesh through the release of toxic contaminants (Uddin and Jeong, 2021), of which heavy metal(loid)s such as arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cr), lead (Pb), manganese (Mn), nickel (Ni), and zinc (Zn) are of particular danger to aquatic organisms (fish and invertebrates) as well as humans (Nawab *et al.*, 2018; Zezhou and Xiaoping, 2017). Along with anthropogenic activities, natural sources are also known to be important sources of heavy metal contamination in the riverine environment (Sekabira *et al.*, 2010). Over the recent decades, environmental researchers around the world have paid significant attention to the problem of heavy metal pollution in riverine environment (Rahman *et al.*, 2014).

Although some heavy metals (e.g., Co, Cu, Mn, and Zn) are essential for the human body as they serve several functions at low concentrations, others (e.g., Cd, Cr, Pb, and Ni) are known as non-essential hazardous elements that can pose serious human health problems upon exposure (Mohmand *et al.*, 2015; Ali *et al.*, 2018). Thus, the prevalence of those hazardous heavy metals in river water is undoubtedly of great concern owing to their persistence, bioaccumulation and bio-magnification potential in the food chain (Rahman *et al.*, 2014). The acute and chronic health effects of these toxic elements include headaches, abdominal pain, high blood pressure, kidney damage and failure, skeletal damage and degradation, nerve damage, cancer, neurodegeneration, etc. (Ali *et al.*, 2019). However, the occurrence of such toxic effects is essentially reliant on the metal itself, its concentration, mode of action, route and duration of exposure (Ahmad *et al.*, 2010).

The Shitalakhya River is one of the major rivers in central Bangladesh (Uddin and Jeong, 2021), which is considered to be a highly polluted urban peripheral river of Dhaka. The water quality of Shitalakhya River has been reported to be deteriorated at different points along the river as a consequence of significant anthropogenic interventions, including heavy loads of pollutants from industry, urban runoff, disposal of municipal and agricultural wastes and wastewater (Kabir *et al.*, 2020a). The major industries observed along this river include tannery, fertilizer industry, textile, dyeing industry, iron industry, jute industry, cement industry, and food processing industry. The Shitalakhya River has also been relentlessly affected by port activities and pollution as the country's one of the biggest and most important river ports, Narayanganj port, is located on the bank of this river. Thus, this study aimed to investigate the spatiotemporal discrepancies of physicochemical properties and heavy metal concentrations in the surface water of Shitalakhya River as well as evaluate the associated ecological and human health risks.

Materials and Methods

Study area

The Shitalakhya River is ~110 km long, silt-carrying, and navigable all year round. It passes through Narsingdi and Narayanganj districts before joining the Dhaleswari River (Kabir *et al.*, 2020b). The Narayanganj port is one of the oldest river ports in Bangladesh, which supports the industries established along the Shitalakhya River. As a result, the river water is subjected to anthropogenic pollution originating from the release of industrial effluents (treated or untreated), the discharge of municipal wastewater, spillage of oil and lubricants during the port operation (Hafizur *et al.*, 2017). Since the Saidabad water treatment plant (WTP), the largest surface WTP in Bangladesh, withdrawals water from this river through an intake at Sarulia, the Shitalakhya River water is especially important for the safe drinking water supply to the inhabitants of Dhaka and surrounding areas (Haque, 2018). The Shitalakhya River is also the primary source of water for industrial uses (e.g., cooling, process, steam generation, safety and miscellaneous purposes) in this region (Razee *et al.*, 2016).

Sample collection

Surface water samples were collected from the Shitalakhya River at Narayanganj (Fig. 1a) during the period from October 2021 to September 2022 considering all three prevailing seasons i.e., pre-monsoon (February to May), Monsoon (June to September), and post-monsoon (October to January). Water samples were taken from five different sampling stations (Fig. 1b) namely Demra Bridge as St-1 (23°43´14.60´´N to 90°30´0.67´´E), Katchpur Bridge as St-2 (23°42´14.24´´N to 90°31´1.67´´E), Adamjee EPZ as St-3 (23°40´47.79´´N to 90°31´47.24´´E), Narayanganj port as St-4 (23°40´1.80´´N to 90°31´35.82´´E), and Khanpur as St-5 (23°37´41.82´´N to 90°30´50.70´´E). About 500 mL of water was collected in plastic bottles from each sampling station with double stoppers. The bottles were cleaned, washed, and treated with 5%

nitric acid (HNO_3) for an entire night prior to sampling. Finally, deionized water was used to rinse the bottles before drying them. Before sampling began at each station, the sampling bottles were rinsed at least three times with the river water. For sampling, the bottles were submerged about 10 cm beneath the water's surface (Tareq *et al.,* 2013). The bottles were carefully screwed after sampling and tagged with the corresponding identification number. Color, odor, temperature, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS) were observed, sensed or measured onsite. Afterwards, the water samples were acidified with 10% nitric acid (HNO_3), put in an ice bath, and brought to the laboratory for the analysis of pH and heavy metals (Pb, Cd, Cr, Cu and Mn). Later, the samples were filtered using 0.45 m micro pore membrane filters and stored in the freezer at 4°C until chemical analysis (Ahmad *et al.,* 2010).

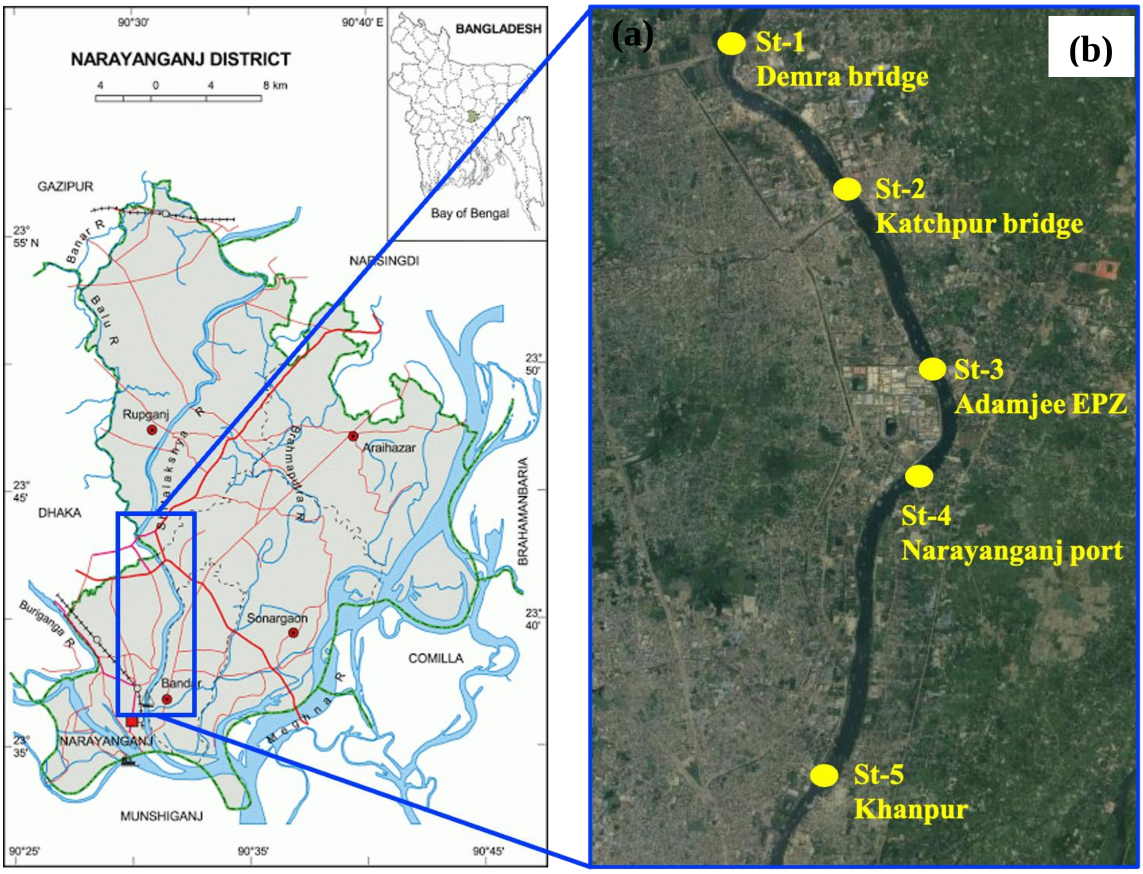

Fig. 1. Map showing the study area along the Shitalakhya River and corresponding sampling stations.

Sample analysis

Temperature, pH, and DO were determined by using a digital thermometer, pH (pH Scan WP 1, 2; Malaysia) and DO (Model-D, 4697, Taiwan) meter, respectively, while EC and TDS were measured by digital EC and TDS meter (HM digital, Germany), respectively. Prior to use, all the digital meters used for sample analysis were standardized by deionized water and buffer solution. For heavy metals, all water samples were subjected to acid digestion. Each water sample (100 ml) was digested by adding 5 ml of concentrated HNO_3 on a hot plate. Afterwards, the samples were filtrated into a 100 ml volumetric flask and made up to the mark with deionized water. The concentrations of heavy metals (Cd, Cr, Cu, Pb and Mn) in water samples were analyzed by atomic absorption spectrophotometer (AAS) with a digital read-out system under metal-specific command, standard, and wavelength.

Risk assessment

The water pollution status was assessed by using pollution indices and corresponding risks were evaluated. Three pollution indices including the heavy metal pollution index (HPI) stated by Prasad and Bose (2001), the heavy metal evaluation index (HEI) stated by Edet and Offiong (2002), and the degree of contamination (CD) stated by Brraich and Jangu (2015) were employed and weighted, which are frequently used to evaluate the overall water quality status in terms of heavy metal contamination.

Heavy metal pollution index (HPI)

To calculate the HPI, unit weightage (Wi) is used as a value that is inversely proportional to the recommended standard (Si) of the respective parameter as suggested by Reddy (1995).

The HPI was calculated by (Mohan *et al.*, 1996):

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

Where, Q_i is the sub-index of the ith parameter. W_i is the unit weightage of the ith parameter and *n* is the number of parameters considered. HPI<100 and HPI>100 indicate low and high heavy metal pollution, respectively, whereas HPI=100 indicates heavy metal pollution on the threshold risk (Prasad and Bose, 2001).

The sub-index (Q_i) of the parameter was calculated by:

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

Where, Q_i is the observed value of the heavy metal of the ith parameter and the sign (–) indicates the numerical difference between the two values, disregarding the algebraic sign. The weightage (Wi) was considered as the inverse of maximum admissible concentration (MAC), and S_i is the WHO standard for drinking water in ppb and the guide value for the chosen element in ppb.

Heavy metal evaluation index (HEI)

The HEI was computed as (Edet and Offiong, 2002; Edet *et al.*, 2003):

$$HEI = \sum_{i=1}^{n} \frac{Hc}{Hmac}$$

Where, H_c is the monitored value of the ith parameter and Hmac is the MAC of the ith parameter. HEI<400, 400<HEI<800 and HEI>800 indicate low, moderate and high levels of metal pollution, respectively.

Contamination index (CD)

The CD summarizes the integrated effects of several quality parameters pondered unsafe for domestic water (Backman *et al.*, 1998) and was calculated as:

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

$$C_{fi} = \frac{Cai}{Cni} - 1$$

Where, C_{fi}, C_{ai} and C_{ni} represent the contamination factor, the analytical value, and the upper permissible concentration of the ith component, respectively. CD can be grouped into three categories: low (CD<1), medium (CD=1-3) and high (CD>3) (Brraich and Jangu, 2015).

Table 1. Standards used for the index's computation

Metal	Unit	W_i	S_i	L_i	Mac
Pb	ppb	0.7	100	10	1.5
Cd	ppb	0.3	5	5	3
Cr	ppb	0.02	50	-	50
Cu	ppb	0.001	1000	2000	1000
Mn	ppb	0.0033	300	100	50

Source: Brraich and Jangu (2015); Kabir et al. (2020a)

Data and statistical analysis

For data and statistical analysis, Microsoft Office Excel 2010 and SPSS version 20.0 were utilized.

Results and Discussion

Physicochemical water quality

Table 2 provides a statistical summary of the selected physicochemical parameters of Shitalakhya River water quality for each sampling site. In all seasons, the visually observed color of river water was black, while the odor was sensed badly in all stations. The mean water temperature of the Shitalakhya River was recorded as 30.12, 32.73 and 27.36°C during pre-monsoon, monsoon, and post-monsoon seasons, respectively. Water temperature has a substantial impact on physicochemical characteristics, whereas higher temperatures are a result of solar radiation and atmospheric factors (Fatema *et al.*, 2018). It can be concluded that in both the pre-monsoon and post-monsoon seasons, the mean water temperature at all sample locations was within the acceptable range, but during the monsoon season, it exceeded the standard.

DO is the most important surface water quality indicator as all aquatic organisms rely on it for their survival. When DO is too low, no aquatic species including fish cannot survive in water (Islam *et al.*, 2017; Kabir *et al.*, 2020a). The DO values often remain lower than those found in areas with high rates of photosynthesis where there are high rates of respiration and organic decomposition (Islam and Azam, 2015). The DO value was found to range from 2.40 to 3.80 ppm in pre-monsoon, 3.42 to 3.70 ppm in monsoon, and 1.18 to 2.65 ppm in post-monsoon. The results showed that the DO of river water was found to be below the fisheries or aquatic environment standard. Since industrial activities considerably contribute to decline in DO levels in the study area, it is possible that greater temperatures and a higher rate of organic matter decomposition are to blame for the post-monsoon season fall in DO contents. The DO concentration of Shitalakhya River water indicated that the quality of water was poor and detrimental to fisheries and aquatic life.

Table 2. Observed physicochemical properties of Shitalakhya River water and their comparison with the standards.

Parameters	Stations	Pre-monsoon	Monsoon	Post-monsoon	Standard
Temp. (°C)	1	29.30	32.20	26.28	20-30 (EQS, 1997)
	2	30.20	32.44	25.63	
	3	30.80	33.37	28.20	
	4	31.40	34.30	29.29	
	5	28.92	31.33	25.40	
	Mean ± SD	30.12±1.02	32.73±1.14	27.36±1.47	
DO (ppm)	1	3.01	3.70	2.20	5 (EQS, 1997)
	2	2.40	3.66	1.18	
	3	3.80	3.40	2.65	
	4	2.42	3.42	2.26	
	5	2.40	3.52	1.19	
	Mean ± SD	2.806±0.61	3.54±0.13	1.896±0.67	
pH	1	7.20	7.57	6.69	6.5-8.5 (ECR, 1997)
	2	7.04	7.60	7.02	
	3	7.24	7.65	6.52	
	4	7.26	7.63	7.10	
	5	7.01	7.60	6.70	
	Mean ± SD	7.15±0.12	7.61±0.03	6.80±0.24	
EC (µS/cm)	1	821.00	733.00	1256.22	300 (WHO, 2011)
	2	932.67	747.00	1540.00	
	3	1122.00	756.10	1710.53	
	4	958.33	759.70	1183.00	
	5	941.56	750.00	1195.00	
	Mean ± SD	955.11±107.86	749.16±10.32	1376.95±236.20	
TDS (ppm)	1	540.72	480.10	834.00	500 (WHO, 2011)
	2	886.78	510.00	1175.00	
	3	763.00	534.00	1133.56	
	4	810.00	460.00	1178.44	
	5	584.33	470.00	922.00	
	Mean ± SD	716.97±148.55	490.82±30.54	1048.6±159.79	

Because the majority of their metabolic processes depend on pH, aquatic organisms are impacted by it. The pH of an aquatic system is a crucial sign of the water quality and the level of pollution in that environment (Islam and Azam, 2015). The pH of water is a measure of its acidity or alkalinity, wherein a minor change in water pH can make the water unfit for domestic use. The optimal range of pH for sustainable aquatic life is considered 6.5 to 8.5 (ECR, 1997). The pH value was found in water ranges from 7.01 to 7.26, 7.57 to 7.65, and 6.52 to 7.10 in pre-monsoon, monsoon, and post-monsoon seasons, respectively; indicating the alkaline condition throughout the year. However, an insignificant increase in pH at a few sampling stations can be explained by the influence of wastewater released from industries and/or municipal areas.

The EC is a sign of another important indicator of surface water quality, which can be affected by the fluctuation of water temperature as well as the presence of ions their concentrations and mobility (Irin *et al.*, 2016). The average EC in pre-monsoon, monsoon and post-monsoon was recorded at 955.11, 749.16, and 1376.95 µS/cm. For recreational water, the acceptable range of EC is 500 µS/cm, whereas it is 750 µS/cm for irrigation and 800 to 1000 µS/cm for aquaculture (ADB, 1994). The observed EC values of Shitalakhya River were found higher than the standard level, indicating the presence of the large number of ionic compounds in the water. Higher TDS concentrations frequently affect aquatic organisms inhabiting river water and, thus, are critical for the survival of many aquatic organisms (Islam *et al.*, 2012; Kabir *et al.*, 2020a). The average TDS in Shitalakhya River was recorded at 716.97, 490.82, and 1048.60 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively. All the observed TDS values in Shitalakhya River exceeded the standard level for drinking, irrigation water and fish culture.

Table 3 presents a comparison of physicochemical properties between Shitalakhya River and other rivers of Bangladesh, implying that the observed results regarding the river water quality in this study are comparable with the results of earlier studies. Kabir *et al.* (2020a) studied the water quality of Shitalakhya River at Narsingdi and reported relatively less polluted water quality as compared to the present study. These findings are reasonable because Narsingdi is located at the upper stream position of Narayanganj where the present study was conducted, which suggested the anthropogenic interventions at downstream areas in Narayanganj affected the river water quality by deteriorating its properties, especially DO, EC and TDS (Table 3). In 2015, Irin and her co-authors investigated the water quality of Shitalakhya River at two downstream locations of the present study (Irin *et al.*, 2016). The comparative evaluation of their results with the present study revealed that the EC and TDS values of Shitalakhya River were much lower just seven years ago (Table 3), indicating that the river water quality is deteriorating at an alarming rate in areas around Narayanganj port. In addition, the water quality of Shitalakhya River around Narayanganj port was also found to be highly polluted compared with the Buriganga and Brahmaputra rivers.

Table 3. Comparison of physicochemical parameters of the Shitalakhya River water observed in this study with other rivers of Bangladesh.

River	Temp. (°C)	DO (ppm)	pH	EC (µS/cm)	TDS (ppm)	Reference
Shitalakhya	28.74	2.351	7.603	1166.03	882.78	Present study
Shitalakhya	27.79	7.070	7.600	787.82	578.91	Kabir *et al.* (2020a)
Buriganga	27.08	0.890	8.740	354.71	-	Fatema *et al.* (2018)
Rupsha	29.70	-	8.500	16,705.00	8638.00	Islam *et al.* (2018)
Brahmaputra	-	7.520	7.660	168.00	155.00	Tareq *et al.* (2013)
Shitalakhya	-	1.970	7.550	809.00	421.00	Irin *et al.* (2016)
Standard	20-30 (EQS, 1997)	5 (EQS, 1997)	6.5-8.5 (ECR, 1997)	300 (WHO, 2011)	500 (WHO, 2011)	-

Heavy metal concentration in surface water

Table 4 displays the concentrations of studied toxic heavy metals (Pb, Cd, Cr, Cu, and Mn) in three seasons (pre-monsoon, monsoon, and post-monsoon). In pre-monsoon, heavy metal concentrations in Shitalakhya River water were found to be Mn>Cr>Cu>Cd>Pb, while the order was Mn>Cu>Cr>Cd>Pb and Mn>Cu>Cr>Pb>Cd in monsoon and post-monsoon season, respectively. Pre-monsoon season showed the highest Mn concentration (0.2426 ppm), whereas it dropped to 0.1221 ppm in monsoon and to 0.2153 ppm in post-monsoon season. The mean Mn concentration was recorded at 0.21752, 0.0836 and 0.18354 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively. The Mn concentrations in the river water are found to be higher than the standard. The causes of high Mn concentration in Shitalakhya River water are mainly industrial discharge and landfill leaching in the riverside industry-based area and also it could be due to the dumping of solid waste and run-off from agricultural activities.

Table 4. Observed heavy metal concentrations (ppm) in the water of Shitalakhya River with standard values.

Heavy metals	Sampling station	Pre-monsoon	Monsoon	Post-monsoon	Standard
Pb	St 1	0.0059	0.0025	0.0038	0.05 (ECR, 1997)
	St 2	0.0089	0.0020	0.0080	
	St 3	0.0110	0.0022	0.0093	
	St 4	0.0098	0.0021	0.0081	
	St 5	0.0095	0.0010	0.0079	
	Mean ± SD	0.0090±0.0019	0.0012±0.0006	0.0074±0.0021	
Cd	St 1	0.0071	0.0025	0.0048	0.005-0.05 (ECR, 1997)
	St 2	0.0052	0.0027	0.0037	
	St 3	0.0047	0.0028	0.0039	

	St 4	0.0049	0.0031	0.0032	
	St 5	0.0063	0.0032	0.0055	
	Mean ± SD	0.0056±0.0010	0.0029±0.0002	0.0042±0.0009	
Cr	St 1	0.0371	0.0122	0.0389	0.05 (ECR, 1997)
	St 2	0.0487	0.0283	0.0492	
	St 3	0.0372	0.0201	0.0375	
	St 4	0.0487	0.0294	0.0467	
	St 5	0.0353	0.0189	0.0388	
	Mean ± SD	0.0414±0.0067	0.0218±0.0071	0.0422±0.0053	
Cu	St 1	0.0103	0.0321	0.0611	0.5 to 3.0 (ECR, 1997)
	St 2	0.0221	0.0382	0.0711	
	St 3	0.0123	0.0154	0.0017	
	St 4	0.0320	0.0322	0.0693	
	St 5	0.0223	0.0331	0.0162	
	Mean ± SD	0.0198±0.0087	0.0302±0.0086	0.0439±0.0325	
Mn	St 1	0.2404	0.0294	0.1973	0.05 (USEPA, 1999)
	St 2	0.2417	0.1221	0.2153	
	St 3	0.2426	0.0955	0.2101	
	St 4	0.2340	0.0923	0.1992	
	St 5	0.1289	0.0789	0.0958	
	Mean ± SD	0.2175±0.0496	0.0836±0.0341	0.1835±0.0496	

The maximum Cr concentration in the Shitalakhya River water was determined as 0.0487 ppm in the pre-monsoon season, while it was 0.0294 ppm in the monsoon and 0.0492 ppm in the post-monsoon season. The mean Cr concentrations were found 0.0414, 0.0218 and 0.04222 ppm during pre-monsoon, monsoon, and post-monsoon seasons, respectively. However, all the observed values for Cr are lower than the standard level except for post-monsoon season but higher than the toxicity reference value (TRV) mentioned by USEPA (1999) for drinking water which is 0.0110 ppm. The reasons for getting some Cr are wastes from the ceramics manufacturing industry, textile industry especially the dyeing industry and improper landfills of solid wastes. Pre-monsoon season showed the highest Cu concentration (0.0320 ppm), whereas the concentration declined in monsoon season to 0.0382 ppm and in post-monsoon season to 0.0711 ppm. According to ADB (1994), the standard level of Cu is 0.02 to 1.0 ppm. Here, all the observed values are lower than the standard level and higher than the toxicity reference value (TRV) mentioned by USEPA (1999) for drinking water which is 0.009 ppm.

The maximum Pb concentration in the Shitalakhya River was recorded as 0.0110, 0.0010, and 0.0093 ppm in pre-monsoon, monsoon, and post-monsoon seasons, respectively. The higher Pb concentration in the river water can be attributed to the discharge of industrial effluents possibly from adjacent battery and textile industries as well as lead-based paints from the nearby dyeing industry. The mean Pb concentration was found 0.0090, 0.0012 and 0.0074 ppm in pre-monsoon, monsoon and post-monsoon season, which was lower than that of the ECR standard (0.05 ppm). In the case of Cd, the highest concentration (0.0071 ppm) was recorded in pre-monsoon, whereas it was 0.0032 ppm in monsoon and 0.0055 ppm in post-monsoon. According to ADB (1994), the standard level of Cd for drinking, irrigation and livestock water is 0.05, 0.10 and 0.05 ppm, respectively. Hence, all the observed values are lower than the standard level except few stations for the pre-monsoon season and higher than the toxicity reference value (TRV) mentioned by USEPA (1999) for drinking water, indicating average level of Cd pollution and showing that the Shitalakhya River is not at alarming condition in terms of Cd pollution but may pose substantial risk of toxic contamination.

The metal concentrations in the water of the Shitalakhya River vary periodically and may be related to complicated processes including a lack of precipitation during the pre-monsoon season, which could lead to metal precipitation, re-suspension, and deposition. In comparison to the monsoon season, the concentrations are higher in the pre-monsoon and post-monsoon seasons. The diluting effect of river water may be responsible for the minimal value of heavy metals during the monsoon season. Additionally, since Bangladesh is primarily an agricultural nation, the majority of its agricultural activities take place during the pre-monsoon and post-monsoon periods. Therefore, the greater concentration of Cu in the pre-monsoon season may be directly related to the agricultural waste and sewage from the farmland. The concentration of heavy metals during the pre-monsoon and post-monsoon season is further raised by increasing man-made activities including brick manufacture, excavation, power production, carrying industrial emissions, electroplating, smelting, dumping sludge, fuel production, etc. The variations in metal concentration also exhibited that the more distant the sampling sites are from the industrial and residential sewage discharge area, the less pollution there is. The concentration of some metals, in general, exceeded numerous widely accepted quality standards and were consistent with some earlier studies (Table 5).

Table 5. Comparisons of heavy metals concentrations among river waters in Bangladesh.

River	Pb	Cd	Cr	Cu	Mn	Reference
Shitalakhya	0.0082	0.0050	0.0418	0.0318	0.2005	Present study
Shitalakhya	0.0082	0.0029	0.0042	0.0201	-	Kabir *et al.* (2020b)
Rupsha	0.0072	0.0012	0.0080	0.0057	-	Proshad *et al.* (2021)
Buriganga	0.0072	-	1.9900	0.6900	-	Hossain *et al.* (2021)
Turag	0.0032	-	0.6100	0.7500	-	Hossain *et al.* (2021)
Bangshi	0.0135	0.0012	-	0.0700	1.36	Rehnuma *et al.* (2016)
Shitalakhya	0.023	0.007	-	0.025	-	Irin *et al.* (2016)
Standard	0.05 (ECR, 1997)	0.005-0.05 (ECR, 1997)	0.05 (ECR, 1997)	0.5-3.0 (ECR, 1997)	0.05 (USEPA, 1999)	
TRV[a]	0.003	-	0.011	0.009	-	

Note: TRV[a] (toxicity reference value) for freshwater proposed by USEPA (1999).

Risk assessment of toxic metals

Table 6 exhibits that the river water at all the sampling stations is contaminated with toxic heavy metals based on the employed pollution indices (HPI, HEI, and CD). The mean HPI in pre-monsoon, monsoon and post-monsoon seasons were 318.97, 241.51 and 337.25, respectively (Fig. 2). These results imply that, regardless of the seasons, the Shitalakhya River water around port areas is in critical condition and not potable (i.e., unsafe for drinking or domestic uses). However, the mean HEI values for pre-monsoon, monsoon and post-monsoon seasons were calculated at 13.090, 5.244 and 10.910, respectively. These results exhibited low heavy metal contamination for all sampling stations over the three seasons (Fig. 3). On the other hand, the mean CD values in pre-monsoon, monsoon and post-monsoon seasons were 8.090, 0.502 and 6.010, respectively, indicating higher CD values for all seasons. The overall CD value suggests that the Shitalakhya River water is highly polluted with heavy metals, while the condition remains worse in pre- and post-monsoon seasons (Fig. 4).

Table 6. Heavy metal pollution indices (HPI, HEI and CD) of water.

Seasons	Stations	HPI	HEI	CD
Pre-monsoon	St-1	338.60	11.86	6.86
	St-2	364.82	13.49	8.51
	St-3	345.58	14.51	9.52
	St-4	351.07	13.85	8.82
	St-5	282.26	11.74	6.72
Monsoon	St-1	194.22	7.58	2.59
	St-2	240.52	5.28	0.26
	St-3	249.58	4.73	0.73
	St-4	268.20	4.90	-0.10
	St-5	255.04	3.73	-0.97
Post-monsoon	St-1	313.45	8.92	3.92
	St-2	346.72	11.92	6.92
	St-3	329.17	12.45	7.45
	St-4	333.96	11.44	6.95
	St-5	271.55	9.81	4.81

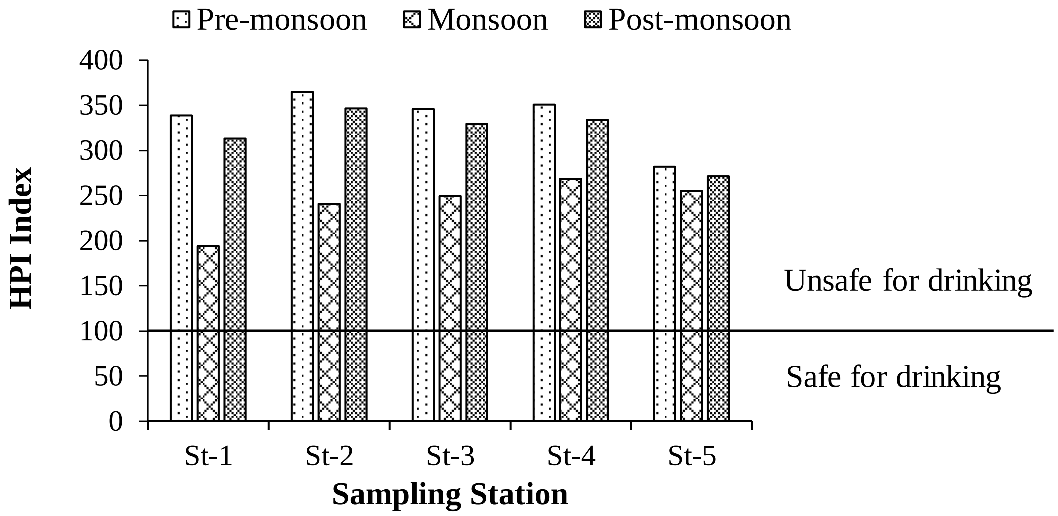

Fig. 2. Heavy metal pollution index (HPI) of different surface water sampling locations in the Shitalakhya River.

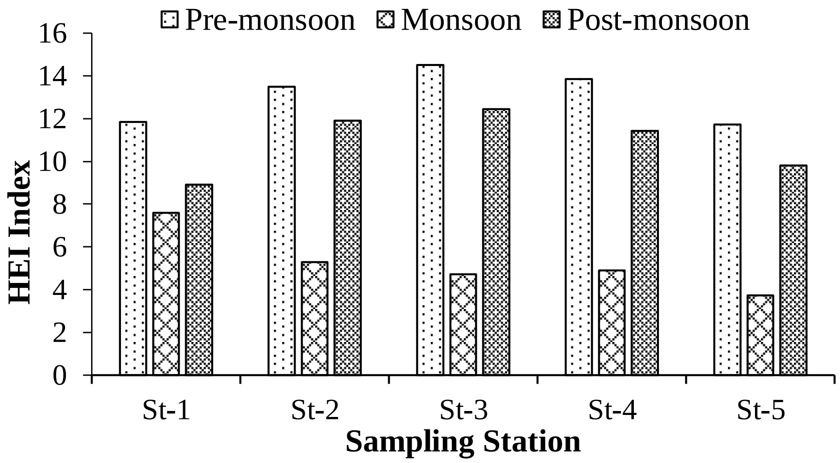

Fig. 3. Heavy metal evaluation index (HEI) of different surface water sampling locations in the Shitalakhya River.

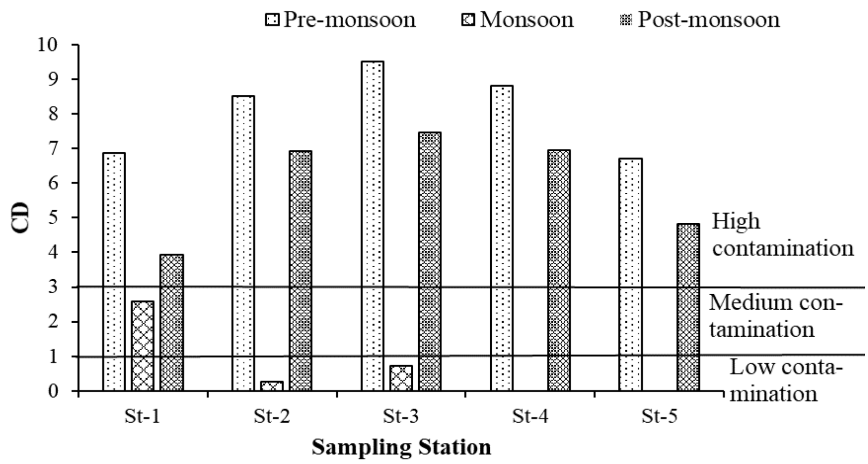

Fig. 4. The contamination index (CD) of different surface water sampling locations in the Shitalakhya River.

Conclusion

The findings of physicochemical properties and heavy metal concentrations suggested that the water of Shitalakhya River is of poor quality and considerably polluted with toxic metals, suggesting that the water is unfit for domestic, irrigation, fishing, livestock, and recreational activities. A higher load of toxic metals and worse water quality was observed in pre-monsoon and post-monsoon seasons with spatiotemporal discrepancies in toxic metal concentrations and associated ecological and human health risks, possibly resulting from the hydrological and anthropogenic interventions not only associated with port activities in the study area. The study highlighted that the water quality of Shitalakhya River is deteriorating day by day at an alarming rate, which demands urgent collective effort and proper monitoring to save this ecologically critical urban river as well as to safeguard public health.

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