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Seasonal variation of trace elements in water and sediment of the Turag and Balu Rivers, Bangladesh

Nurer Zaman Bhuiyan[1], M. Belal Hossain[2,3*], Mir Mohammad Ali[4], Ahasan Habib[2,5*], Md. Simul Bhuyan[1], Takaomi Arai[6]

1.Institute of Marine Sciences, Faculty of Marine Sciences & Fisheries, University of Chittagong, Bangladesh.
2.Department of Fisheries and Marine Science, Noakhali Science and Technology University, Bangladesh.
3.School of Engineering and Built Environment, Griffith University, Brisbane, Queensland, Australia.
4.Department of Aquaculture, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh.
5.Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, Kuala Nerus, Terengganu, Malaysia.
6.Environmental and Life Sciences Programme, Faculty of Science, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong, BE 1410, Brunei Darussalam.

[*]**Corresponding Author: a.habib@umt.edu.my; mbhnstu@gmail.com**

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ABSTRACT

The Turag and Balu Rivers are heavily polluted due to the large quantities of untreated municipal sewage and industrial wastewater received from Dhaka City, the capital of Bangladesh. Thus, this study aimed to assess the pollution in trace metal levels in water and sediment over time and space. Trace elements were found in the following descending order: Fe>Ca>Mn>Mg>Zn>Pb>Cu>Cd in Turag River water. Trace elements were found in the following descending order: Fe>Mn>Ca>Mg>Zn> Pb>Cu>Cd in Balu River water. In the Turag River and the Balu River, trace metals were measured in the following descending order in the sediment:Fe>Mn>Pb>Zn>Cu>Ca>Cd>Mg and Fe>Mn>Cu>Zn>Ca> Pb> Mg> Cd, respectively. Metals exhibited no significant differences ($p>0.05$), except for Ca ($p<0.05$) in both the Turag and Balu Rivers. The correlation matrix (CM) demonstrated a sizeable anthropogenic metal influx in the water and sediment of the rivers. Ca, Mg, Cu, and Cd showed significant seasonal fluctuations ($P<0.05$) in Turag River water, whereas Fe, Mn, Zn, Pb, and Cd showed noteworthy differences ($P<0.05$) in the Balu River water. Ca vs Mg (r=0.963) revealed a very high linear solid relationship in Turag River water. A solid linear relationship was determined for Ca vs Fe (r=0.981) in Balu River water and for Cd vs Pb (r=0.977). A solid linear relationship was observed between Cd and Pb (r=0.870) in Turag River sediment. The water and sediment quality of the rivers have deteriorated due to anthropogenic sources of industrial, household and irrigation discharges. The present research can be beneficially used for the management and protection plan of the river for environmental monitoring and assessment.

INTRODUCTION

Heavy metal pollution and its effect have gained a worldwide major concern due to its toxicity, long-term environmental persistence, non-biodegradable nature and accumulative behavior **(Bhuyan *et al.*, 2017a, 2019; Ahmed *et al.*, 2019; Chen *et al.*, 2019; Ali *et al.*, 2022; Bat *et al.*, 2022)**. A large portion of heavy metals in the surface water has caused significant concern among governments and the general population for their excessive accumulation and biomagnification **(Ali & Khan, 2018, 2019)**. The sources of heavy metals are generally originated from anthropogenic activities and nature **(Mortvedt, 1996; Wei & Yang, 2010; Muhammad *et al.*, 2011)**. The anthropogenic sources are industrial output,

fertilizer use and sewage outflow (**Ntengwe, 2006; Krishna *et al.*, 2009; Bhuiyan *et al.*, 2011)**. Bedrock weathering is the most common natural source **(Kumar *et al.*, 2017)**. The heavy metals are undestroyable as they are deposited, assimilated, or incorporated in water, sediment, and aquatic organisms, thus contaminating aquatic ecosystems (**Islam *et al.*, 2016; Ali & Kha**n**, 2019; Farsani *et al.*, 2019)**. Although some of these metals are necessary micronutrients, their high concentration in the food chain can cause toxicity and negative environmental consequences for aquatic ecosystems and their users **(Tiwari & Singh, 2014; Arbind *et al.*, 2015)**. Sediments are ecologically essential components with a crucial role in maintaining the trophic state of a water body. Their quality might determine how far water is polluted **(Zahra *et al.*, 2014)**.

Sediment, an essential component of riverine ecosystems, acts as a sink and a source of heavy metals **(Pejman *et al.*, 2015; Huang *et al.*, 2019)**. After entering the rivers, most heavy metals are immediately deposited in the sediment in a significantly more concentrated form than in the water body of riverine systems **(Liu *et al.*, 2018; Shyleshchandran *et al.*, 2018; Ali *et al.*, 2022)**. Heavy metals are deposited in rivers from domestic, industrial, and agricultural sources in untreated or poorly treated wastewater **(Ali *et al.*, 2018, 2020a; Zheng *et al.*, 2019)**. Heavy metal pollution is wreaking havoc on rivers worldwide **(Akcay *et al.*, 2003; Olivares-Rieumont *et al.*, 2005)**, particularly in the developing countries (**Wang *et al.*, 2011; Li *et al.*, 2013)**. In addition, heavy metals in the sediment may desorb or resuspend during physicochemical or hydrological conditions change **(Liang *et al.*, 2015; Kouidri *et al.*, 2016)**. The accumulation of heavy metals in sediment directly impacts benthic animals and indirectly affects many other organisms through the food web **(Krasnići *et al.*, 2013)**, jeopardizing the aquatic environment. Thus, numerous interventions have been implemented to control the sources of heavy metal contamination **(Akpor & Muchie, 2010; Kumar *et al.*, 2017)**.

The Turag and Balu Rivers are particularly important in Bangladesh. Rivers become hypoxic due to massive industries, urbanisation and domestic sewage **(Bhuyan *et al.*, 2017b)**. These rivers are becoming devoid of living species such as fish. Biologically, these rivers are considered dead. Heavy metals form a significant issue in some waterways. Only a few studies on heavy metal pollution have been published. Hence, the current study aimed to discover hazardous metals in the water and sediment of these rivers from this perspective. Scavenging of these metals was also investigated in terms of season and location.

MATERIALS AND METHODS

Study area

The present study was conducted in Turag and Balu Rivers (Fig. 1). The Turag River is one of the most important rivers of Dhaka and the Gazipur district. A lot of industries are established on the bank of the river. Samples were collected from Bhawal Mirzapur (T_1) (24°05.231 N & 90°20.592 E), Ahsulia (T_2) (23°53.053 N & 90°21.065 E), and Tongi Bridge (T_3) (23°52.084 N & 90°23.072 E). The Balu River is another important river of the Dhaka district. Different types of industries are situated on the bank of the river. Samples were collected from Pubail (B_1) (23°56.056 N & 90°29.439 E) and Demra Bazar (B_2) (23°44.002 N & 90°29.719 E).

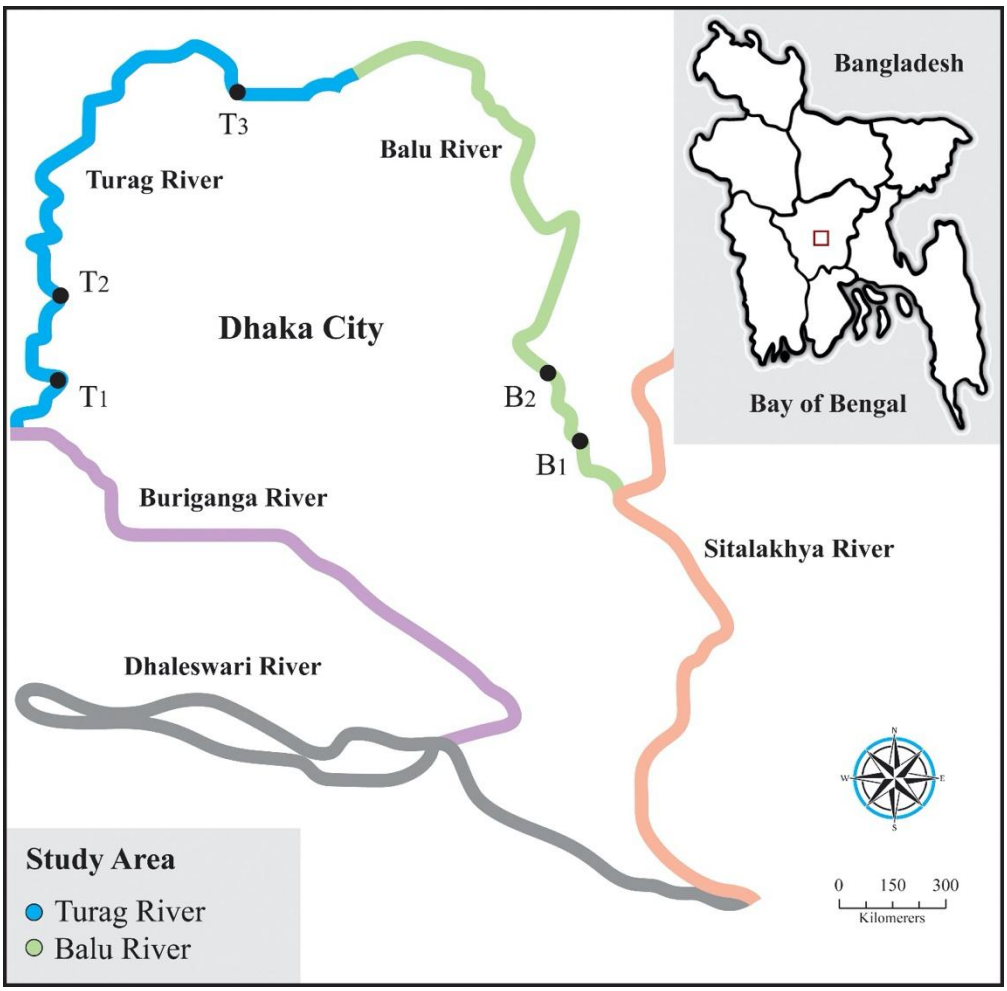

Fig. 1. Map showing different sampling stations of the Turag and Balu Rivers

Sample collection and preservation

Sub-surface river water and sediment samples were collected during pre-monsoon, monsoon and post-monsoon. Water samples were collected using a Ruttner sampler. The water samples were kept in acid-washed polyethylene bottles, acidified immediately after the collection with the addition of 2mL of ultra-pure HNO_3 per litre of water **(Morse *et al.*, 1993)**, and then carefully preserved in a refrigerator at –4°C before laboratory analysis.

The surficial sediments were collected with a stainless-steel Ekman grab sampler, which allows free water passage through the sampler during descent and sediment penetrations. The sampler was inspected for possible cross-contamination and ringed with ambient water at each site. Initially, a visual inspection was made of the sample using the small top doors on the top of the grab to ensure that the sample was collected in an undisturbed state. If water was present on top of the sample, it was siphoned off with a glass tube so that the sediment sample would remaine undisturbed. The upper 2–3cm of the sediment from the central part of the grab sampler, i.e., not in contact with the sides of the sampler, were removed and placed in precleaned polyethylene bags. The samples were frozen on the boat and transferred to the laboratory for further analysis.

Digestion of water samples

Two hundred fifty milliliters of well-mixed acidified water samples were kept in a pyrex beaker and evaporated samples on a water bath (temperature above 100°C), with a watch glass on each beaker. Then, 5 mL of concentrated HNO_3 was added to each beaker, and the solution was digested using a water bath. Digested samples were filtered using filter paper (Quantitative Whatman 541). Blank digestions were carried out simultaneously for each sample.

Preparation of standard solution

The standard solution of elements Fe, Cu, Zn, Pb., Cd, Ca, Mg, and Mn were prepared by pipetting the required amount of the solution from the stock solution for this study, manufactured by Fisher Scientific Company, New Jersey, USA.

Preparation of calibration curves

Calibration curves were prepared by plotting the absorbance against the concentration of the standard solutions for each element. The metal concentration in the samples was measured with the help of these calibration curves. The standard solutions were prepared with the concentration covering the optimum liner absorbance range for the calibration curve. In all absorbance measurements, the reading was taken after adjusting the instrumental zero. A calibration curve was automatically constructed and displayed on the monitor by measuring the standard solutions' absorbance for the respective elements. The calibration curve was occasionally checked and measured with the standard solutions, and, if necessary, a new calibration curve was occasionally checked determining measurements with the standard solutions.

Atomic absorption spectrophotometric measurements

The digested samples were then analyzed using air acetylene and a nitrous oxide flame with combination and single-element hollow cathode lamps in an atomic absorption spectrophotometer (GBC-902) (Table 1). The sample was injected by an automatic sampler, and the absorbance and concentration data were automatically printed out and displayed.

Table 1. Flame condition for the analysis of heavy metals in water

Element	Lamp wavelength (nm)	Silt width (nm)	Lamp current (MA)	Flame type
Cu	324.7	0.5	3	Air acetylene
Fe	248.3	0.2	7	Air acetylene
Pb	217.0	1.0	5	Air acetylene
Cd	228.8	0.5	3	Air acetylene
Zn	213.9	0.2	5	Air acetylene
Mn	279.5	0.2	5	Air acetylene
Ca	422.7	0.5	10	Nitrous oxide
Mg	285.2	0.5	3	Air acetylene

Sediment sample analysis

In the Bangladesh Fisheries Research Institute laboratory, at the riverine site, Chandpur, sediment samples were thawed, homogenised, and sieved using a 2mm mesh size to obtain a fine fraction. The sieved samples were oven dried at 105°C to a constant weight and gently ground. Samples were then stored in air-tight plastic vials and placed in desiccators until required for digestion.

Digestion of samples

An amount of 2g of finely ground sample was placed in a Gerhardth test tube with a few ml of water, then 10mL of concentrated H_2SO_4 was added and placed the test tube in the Gerhadt-Kieldathern digestion chamber and heated the digestion chamber to 150°C for 0.5h. Then, the temperature was increased to 250°C for 2h. A blank sample was digested with the same method. After digestion, the Gerhardth test tube was replaced from the chamber and kept in a stand to cool at room temperature. The sample was then transfered to a 50ml volumetric flank by repeated washing the sample. The recorded concentration of the sample was calculated by plotting the standard curve using the 0.0, 1.0, 2.0, 3.0, and 4.0 ppm of the metals.

Statistical analysis

Various statistical analyses were performed on the research data sets using SPSS (Ver. 22). One-way analysis of variance (ANOVA) was performed to determine the significant difference among the metals in terms of seasons and sites. Using SPSS 25, a correlation matrix (CM) was used to highlight the similarity between variables and determine their sources of origin.

RESULTS AND DISCUSSION

Occurrence and abundance of heavy metals in surface water

The combined effect of greater vaporisations and lower rainfall during the summer season may result in higher surface water heavy metals (**Tiwari *et al.*, 2015; Ali *et al.*, 2016; Ali *et al.*, 2020b; Rakib *et al.*, 2021; Ali *et al.*, 2022)**. Several authors have reported similar trends (**Salem *et al.*, 2014; Rajeshkumar *et al.*, 2018; Farsani *et al.*, 2019).** Furthermore, the opposite outcome was recorded during the rainy season, which could be related to the rainfall effect, which increased the lixiviation process and continued the dilution of heavy metals throughout the rainy season **(Khattabi *et al.*, 2007; Ali & Khan, 2019)**.

In the present study, the average order of the metals in pre-monsoon (Fe>Ca>Mn>Mg>Zn>Cu>Pb>Cd), monsoon (Mn>Fe>Zn>Ca>Mg>Pb>Cu>Cd), and post-monsoon (Fe>Ca>Mg>Mn>Zn>Pb>Cu>Cd) metal concentrations were detected in the sediment at Bhawal Mirzapur (T1) in descending order. Pre-monsoon (Ca> Fe >Mg >Mn> Zn> Cu >Pb > Cd), monsoon (Fe>Mn>Zn>Ca>Mg>Pb>Cd>Cu), and post-monsoon (Ca>Fe>Mg>Zn>Mn>Pb>Cu>Cd) metal values were observed in the Ahsulia sediment (T2) . The metal concentration at Tongi bridge (T3) in pre-monsoon (Ca>Fe>Mg>Mn>Zn> Cu>Pb>Cd), monsoon (Fe>Mn>Ca>Zn>Mg>Pb>Cd>Cu), and post-monsoon (Ca>Mg>Fe>Mn> Zn>Pb>Cu>Cd) are presented in Table (2). At Pubail (B1), the concentration of metal was found in the water in descending order during pre-monsoon (Fe>Ca>Mg>Mn>Zn>Cu>Pb>Cd), monsoon (Fe>Mn>Zn>Ca>Mg>Cu>Pb>Cd) and post-monsoon (Fe>Mn>Ca>Mg>Zn>Cu>Pb>Cd) seasons, whereas at Demra Bazar (B2), the metal value was found in the sediment during pre-monsoon (Fe>Ca>Mn>Mg>

Zn>Cu>Pb>Cd), monsoon (Fe>Zn>Mn>Ca>Mg>Pb>Cu>Cd) and post-monsoon (Mn>Mg>Fe>Cu>Cd>Ca>Zn>Pb) seasons (Table 3).

The Ca content in water ranged from 0.86 to 21 mg/L at the five sampling sites of the Turag and Balu Rivers. The lowest and highest amounts were measured at sites T1 and T3 during the pre-monsoon and monsoon seasons, respectively (Table 3). Ca levels in the water of the Manuherikia River, New Zealand, were measured by **Ahlers *et al.* (1991)**.

These findings are almost identical to the ones presented above. Numerous ions in water samples from the Osun River serve as a primary water source for a significant portion of the eastern Nigeria's population. The calcium concentration in the Osun River varied from 2 to 60.8 mg/L. In comparison, it ranged from 3 to 52 mg/L in groundwater sources **(Olajire & Imeokparia, 2001)**.

Table 2. Seasonal variation of heavy metal concentrations (mg/l) in the Turag and Balu River waters

Turag River								
Sites	**Seasons**	**Metal concentration (mg/l)**						
		Ca	**Mg**	**Cu**	**Fe**	**Mn**	**Zn**	**Pb**	**Cd**
T_1	Pre-monsoon	12.00	6.80	0.020	14.73	8.18	3.13	0.0098	0.0010
	Monsoon	0.86	0.15	0.005	5.05	9.24	4.40	0.0126	0.0019
	Post monsoon	11.00	7.10	0.002	13.10	4.30	3.18	0.0091	0.0011
T_2	Pre-monsoon	16.00	7.20	0.010	9.32	5.25	3.72	0.0099	0.0012
	Monsoon	1.32	0.24	0.001	10.86	6.85	3.70	0.0113	0.0025
	post-monsoon	13.00	6.25	0.002	9.13	3.40	4.18	0.0075	0.0016
T_3	Pre-monsoon	21.00	9.70	0.020	10.18	3.09	1.02	0.0125	0.0015
	Monsoon	1.72	0.29	0.002	11.93	5.46	1.28	0.0067	0.0027
	Post monsoon	16.00	10.23	0.004	9.67	6.08	5.50	0.0097	0.0018
Balu River								
B_1	Pre-monsoon	18.4	10.2	0.02	28.01	6.05	3.81	0.0062	0.0012
	Monsoon	1.30	0.19	0.09	8.51	6.98	3.97	0.0083	0.0021
	Post monsoon	16.3	8.10	0.02	27.83	19.44	1.52	0.0075	0.0019
B_2	Pre-monsoon	12.0	6.80	0.02	24.73	11.18	4.03	0.0064	0.0015
	Monsoon	1.26	0.22	0.003	5.72	2.41	4.13	0.0085	0.0023
	post-monsoon	15.5	4.10	0.002	28.18	26.02	2.12	0.0075	0.0019

N.B. Bahwal Mirzapur (T_1), Ahsulia (T_2), Tongi Bridge (T_3), Pubail (B_1), Demra Bazar (B_2)

In addition, magnesium (Mg) is a mineral necessary for human health. Inadequate consumption of any element can have negative consequences on one's health. At a national and international levels, daily intakes of each element were determined by the World Health Organisation (WHO). Endothelial dysfunction, enhanced vascular responses, elevated circulating levels of C-reactive protein, and impaired insulin sensitivity are all linked to low magnesium levels. In addition, hypertension, coronary heart disease, type 2 diabetes, and metabolic syndrome have been linked to low magnesium levels **(Rosique-Esteban *et al.*, 2018)**. At the study sites of the Turag and Balu Rivers, Mg levels in water samples ranged from 0.15 to 10.2 mg/L. The lowest and highest amounts were measured at sites T_1 and B_1 (Table 3).

On the other hand, Cu concentrations in water in the Turag and Balu Rivers ranged from 0.02 to 0.19 mg/L. The lowest value was recorded at site T2 during monsoon season, while the maximum amount was recorded at site B_1 (Table 2). Cu enters water bodies through industrial effluents, including $CuSO_4$ used in metal plating and finishing activities **(Testing &Materials, 1985).** A study of organically associated Cu in the Ganga River detected differences in Cu's extractable and organically associated forms **(Singh & Mahaver, 1997)**. They speculated that the differences could be attributable to the combined effects of different factors, such as adsorption or particulate matter input from domestic trash disposal in river water **(Singh & Mahaver, 1997)**. Lower concentrations of Cu were reported in the studies of **Abdullah and Royle (1974)**, **Satyanarayana *et al.* (1985)** and **George (1986)**. The high concentrations recorded could be attributed to the industry's direct dumping of Cu compounds.

At the sampling sites, Fe values in water ranged from 5.052 to 28.18mg/L. The highest and minimum concentrations were measured at sites B2 and T1, respectively (Table 3) during the monsoon and post-monsoon periods. In the brackish water pond in West Bengal, 3095.7 to 4617.4 mg/L of Fe was found **(Mitra *et al.*, 2000)**. Fe concentrations in water were higher than those found in this study. The Cochin estuary (**Ouseph, 1992)**, and Karnafully River (**Khan & Rahman, 1994)** discovered negligible seasonal fluctuation in Fe concentrations. Sectional changes in Fe concentrations were minimal in the current analysis, and the present work supports the above observations. Fe concentrations in India's coastal areas are nearly identical to the present study **(Jagtap, 1983)**. Other few studies **(Abdullah &Royle, 1974; McCrea & Fischer, 1986)** have recorded much lower concentrations. Their research was limited to dissolved iron concentrations; on the contrary, total iron concentrations were measured showing more significance in the present study.

The amount of Mn in the water of the Turag and Balu Rivers ranged from 2.41 to 26.02 mg/L. During the monsoon and post-monsoon seasons, the highest and lowest values were observed at site B_2. The National Research Council (NRC, 1995) recommends Mn concentrations of 2.51 to 0.36 mg/L for near-shore seawater and 17.1 mg/L for estuary water. The Mn concentrations discovered in this study are close to the recommended range. In the water of the old Brahmaputra River, **Bhuyan *et al.* (2019)** noted 1.44 mg/L of Mn. The Mn concentration level was 0.157 mg/L in the waters of Buriganga River and 0.80 mg/L in Tembi River waters **(Shanbehzadeh *et al.*, 2014)**. In Turag River water (the present study site), Mn concentration was 0.06 mg/L in 2012 **(Mokaddes *et al.*, 2012)**. In comparison, the present findings recorded a much higher level than those of the previous studies (Table 3).

Table 3. Comparison between the observed values (mg/l) of heavy metals in the water of the Turag & Balu River and other national and international rivers

River	Ca	Mg	Cu	Fe	Mn	Zn	Pb	Cd	References
Turag River	**10.3**	**5.3**	**0.007**	**10.4**	**5.8**	**3.35**	**0.01**	**0.002**	**Present study**
Balu River	**10.8**	**4.9**	**0.03**	**20.5**	**12.01**	**3.26**	**0.007**	**0.002**	**Present study**
Old Brahmaputra River	-	-	0.12	-	1.44	0.01	0.11	0.001	**(Bhuyan *et al*., 2019)**
Buriganga	-	-	0.163	-	-	-	0.07	0.009	**(Ahmad *et al*., 2010)**
Buriganga	-	-		-	0.157	0.332	0.112	0.059	**(Bhuiyan *et al*., 2015)**
Balu	-	-	0.01	-	0.03	0.02	0.001	0.008	**(Mokaddes *et al*., 2012)**
Dhaleshwari	-	-	0.15	-	-	-	0.05	0.006	**(Ahmed *et al*., 2009)**
Dhaleshwari	-	-	0.00	-	-	-	0.20	0.00	**(Ahmed *et al*., 2012)**
Khiru	-	-	0.004	-	0.17	0.006	0.02	0.13	**(Rashid *et al*., 2012)**
Karatoa	-	-	Trace	-	0.101	Trace	Trace	-	**(Zakir *et al*., 2012)**
Karnofuly	-	-	0.05	-	0.12	0.28	0.14	0.01	**(Islam *et al*., 2013)**
Meghna	-	-	-	-	0.009	0.036	BDL	0.003	**(Hassan *et al*., 2015)**
Shitalakhya	-	-	0.005	-	0.05	0.02	0.001	0.01	**(Mokaddes *et al*., 2012)**
Shitalakhya	-	-	0.04	-	-	0.72	0.05	0.003	**(Islam *et al*., 2014)**
Turag	-	-	0.004	-	0.06	0.02	0.002	0.01	**(Mokaddes *et al*., 2012)**

Tembi River	-	-	0.52	1.17	0.80	0.28	1.40	0.21	**(Shanbehzadeh *et al.,* 2014)**
Taihu Lake	-	-	0.50	-	-	-	3.40	0.31	**(Rajeshkumar *et al.,* 2018)**
Gogabil lake	-	-	0.48	-	-	0.07	0.14	0.07	**(Kumar *et al.,* 2018)**
Kovada lake	-	-	0.54	-	-	5.18	BDL	0.19	**(Kayrak and Ozan, 2018)**
Gadilamn River	-	-	0.50	-	-	0.10	0.46	1.46	**(Ambedkar and Muniyan, 2012)**
Koshi River	-	-	0.014-0.026	-	-	0.017-0.024	0.004-0.123	0.009-0.026	**(Singh *et al.,* 2016b)**
Ghaghara River	-	-	0.016-0.032	-	-	0.013-0.031	0.005-0.019	0.003-0.043	**(Singh *et al.,* 2016b)**
Kali River	-	-	0.049	-	-	0.36	0.058	0.009	**(Maurya and Malik, 2016)**
Gomti River	-	-	0.003	-	-	0.287	0.027	0.0005	**(Vinod *et al.*, 2005)**
Ganga River	-	-	0.03	-	-	0.122	0.086	0.012	**(Gupta *et al.*, 2009)**
Aras Dam Lake	-	-	0.38	-	-	0.05	0.11	0.05	**(Farsani *et al.,* 2019)**

Zn levels in water samples ranged from 1.02 to 26.02 mg/L for the five sampling locations of the Turag and Balu Rivers. During the pre-monsoon and post-monsoon seasons, maximum and minimum concentrations were measured at sites T_3 and B_2 (Table 3). Zn is released into the water as a result of industrial contamination **(Jia *et al.*, 2020)**. Higher Zn concentrations are most likely due to suspended and particulate contaminants **(George, 1986; Pfeiffer *et al.*, 1986; Sinclair *et al.*, 1989)**. It was reported that Zn entered the water body as a result of industrial, surface and municipal run-off. The current finding supports the assertions made above. Seasonal fluctuations in Zn concentrations were minimal in the present study. The pollution levels in the Foujderhat coastal zone in Chittagong found very little seasonal change in the Karnafully River **(Khan &Rahman, 1994)**. As a result, the current results are nearly identical to those of**Khan and Rahman (1994)**. The weathering of milestones and feldspars was the primary source of significant ions, consistent with the current findings.

In Turag and Balu Rivers, the level of lead in the water ranged from 0.0062 to 0.0126 mg/L. The highest and lowest values were reported at sites B_1 and T_1 during the pre-monsoon and monsoon seasons, respectively (Table 3). This could happen due to the discharge of untreated industrial wastes, oils, and municipal wastes, among other things. Studies investigated dissolved Pb and concluded that it was introduced into river water due to industrial, municipal, or surface discharge, which is consistent with the findings of the current study **(Zingde *et al.*, 1985; Shen *et al.*, 1989)**. Pb concentrations in particulate and suspended materials were examined and were found to be higher **(Pfeiffer *et al.*, 1986; Sinclair *et al.*, 1989)**. The present finding coincides with the previously mentioned ones. However, the National Research Council (**NRC, 1995)** proposed a Pb concentration of 0.027 mg/L. The quantities of Pb recorded in this study are greater than the NRC's recommended values, which could be hazardous to water quality and the aquatic environment. A detailed comparison of Pb concentrations with other national and international rivers is shown in Table (3).

Cd levels in water samples ranged from 0.0012 to 0.0127 mg/L at the five examined sites along the Turag and Balu Rivers. The lowest and maximum concentrations were measured at sites T_1 and T_3 (Table 3). A high level of Cd was reported in a Brazilian River and the researchers attributed it to the industrial waste disposal **(Pfeiffer *et al.*, 1986)**. This finding is in consistent with the current outcome. The Cd standard for Bangladeshi coastal water is 0.3 mg/L (EQS, 1991). Near-shore seawater should have a Cd concentration of 0.030 mg/L, while estuary water should have a Cd value of 0.019 mg/L according to the **NRC (1995)**. The Cd amounts registered in this study are lower than the Bangladesh EQS value. In terms of Cd concentration, water quality has not degraded and is not detrimental to living biota. The seasonal change in Cd concentrations was minimal in this study. Table (4) shows a detailed comparison of Pb contents in other national and international rivers.

Occurrence and abundance of heavy metals in the sediment

Few studies have been carried out in various nations to assess sediment (**Ali *et al.*, 2016; Ali and Khan, 2018b; Ali *et al.*, 2018).** The near-bottom water layer was affected due to resuspension or dissolving processes (**Edet and Offiong, 2002).** Polluted sediments can pollute the aquatic environment as a secondary source of pollution. Metal concentrations in sediments can be used to predict pollution patterns in the future (**Salomons, 1985).** The distribution of metals in sediment is not related to the equivalent distributions in water in this study. The sediment composition and structure have a significant impact on the accumulation effects. Heavy metal concentrations in water are low, while sediments contain a large amount of the same metals. Many researchers agree that higher concentrations of heavy metals in

sediment in the winter and summer than in the rainy season may be related to a heavy metal (**Ali *et al.*, 2016; Rajeshkumar *et al.*, 2018; Farsani *et al.*, 2019).**

At Bhawal Mirzapur, the concentration of metal was found in the sediment in descending order during pre-monsoon (Fe>Pb>Mn>Cu>Zn>Ca>Cd>Mg), monsoon (Fe>Pb>Mn>Zn>Cu>Ca>Cd>Mg), and post-monsoon (Fe>Mn>Pb>Cu>Zn>Ca>Cd>Mg) seasons, whereas at Ahsulia, the metal value was found in the sediment during pre-monsoon (Fe>Pb>Mn>Zn>Cu>Ca>Cd >Mg), monsoon (Fe>Zn>Mn>Pb>Cu>Ca>Mg>Cd), and post-monsoon (Fe>Pb>Mn>Zn>Cu>Ca>Cd>Mg) seasons. At Tongi Bridge, the concentration of metals during pre-monsoon followed the sequences: Fe>Pb>Mn>Cu>Zn>Ca>Cd>Mg, monsoon: Fe>Mn>Pb>Cu>Zn>Ca>Mg>Cd), and post-monsoon: Fe>Mn>Pb>Cu>Ca> Zn>Cd>Mg.

Pre-monsoon (Fe>Mn>Cu>Zn>Pb>Cd>Ca>Mg), monsoon (Fe>Mn>Cu>Zn> Ca>Pb> Mg>Cd), and post-monsoon (Fe>Cu>Mn>Zn>Ca>Mg>Pb>Cd) metal concentrations were detected in the Pubail sediment in descending order. Pre-monsoon (Fe>Mn>Cu>Zn>Ca>Pb>Cd>Mg), monsoon (Fe>Mn>Zn>Cu>Ca>Pb>Mg>Cd), and post-monsoon (Ca>Fe>Mn>Cu>Zn>Pb>Mg>Cd) metal values were detected in the sediment at Demra Bazar.

Ca contents in water samples ranged from 0.74 to 1.76 mg/kg in the five monitoring sites of the Turag and Balu Rivers. During the pre-monsoon period, the maximum concentration was observed at site T_3, while the lowest was reported at site B_1. In the Waipori River, New Zealand, Kim and Hunter (2000) made observations. Ca concentrations ranged from 1.3 to 2.1 mg/kg, slightly higher than the current results. A comparison of the recorded amount of heavy metals in the sediment of the Turag and Balu Rivers with other national and international rivers is shown in Table 4.

Mg values in the sampling locations of the Turag and Balu Rivers fluctuated between 0.10 and 0.31 mg/kg. The maximum value was recorded at site T3 during the post-monsoon season, whereas the lowest value was observed at site B_1 during the pre-monsoon season. Mg concentrations ranged from 0.0 to 0.3 mg/kg, which matches the current findings.

In the research area, the concentration of Cu in sediment samples varied from 1.93 to 6.38 mg/kg. During the pre-monsoon season, the lowest concentrations were reported at site B_1, while the highest concentrations were obtained at site B_2 during the monsoon season. Heavy metal concentrations in Eastern Mississippi sediments ranged from 1.0 to 23.0 mg/kg, according to (**Presley *et al.*, 1992).** The centration of Cu (1.0 to 15.5 mg/kg) was reported in Galveston Bay sediments (**Morse *et al.*, 1993).** The trace element geochemistry of clay fractions and bulk sediments from the Vamsadhara river basin on the Indian coast found a much greater concentration of Cu (231 mg/kg) than in the present study (**Varma *et al.*, 1993).** The Cu content of the present study compared with the other national and international rivers is shown in Table 4.

Iron has been utilized to indicate natural variations in the sediment's heavy metal carrying capacity (**Rule, 1986).** Its concentration has been linked to the amount of metal-reactive molecules unaffected by leading causes (**Zhang *et al.*, 2014).** Fe concentrations ranged from 26 to 125 mg/kg in sediment samples taken from the five test locations along the Turag and Balu Rivers. During the pre-monsoon season, the lowest concentration was reported at site B_1, while the lowest value was recorded at site T_1 during the monsoon season. A recent study of heavy metal concentration from water and sediment in Bangladeshi rivers found

unacceptable heavy metal concentrations and that water is unsafe for drinking and cooking. In addition, it could pose a severe risk to the aquatic ecology of the riverine (**Ali *et al.*, 2021).**

Mn in sediment samples varied from 10 to 32 mg/kg in the study area. The maximum concentration was recorded at site T_1 during the post-monsoon seasons, and the minimum concentration was recorded at site T_1 during the monsoon season. **Ahlers *et al.*, (1991)** recorded a lower amount of Mn at the Manuherikia River in New Zealand. Manganese is an element of low toxicity, and it has considerable biological significance. It is one of the more biochemical and active transition metals in the aquatic environment (**Evans *et al.*, 1997**). The present investigation agrees with the above statements. **Presley *et al.*, (1992)** determined the Mn concentration (40 to 1239 mg/kg) in sediments of Eastern Mississippi Bight. **Morse *et al.*, (1993)** recorded 165 to 2365 mg/kg Mn in sediments of Galvaston Bay. The present study's findings are far lower than the findings by **Presley *et al.*, (1992)** and **Morse *et al.*, (1993).**

As a micronutrient necessary for plant growth, zinc performs a crucial role. In the Turag and Balu Rivers, Zn values in sediment samples ranged from 1.52 to 11.50 mg/kg. During the monsoon season, the maximum amount was recorded at location T_2. The minimum concentration was measured at site B1 during pre-monsoon and post-monsoon seasons. The current study's findings are significantly lower than Singh and Mahaver's (1997) findings at the Ganga River. Zn concentrations were consistently lower and homogenous across all sites. Zn deficiency in rice and other fields and fruit crops has been documented in Bangladesh (**BRRI, 1980; Rahman, 1980; Rahman *et al.*, 1980).** Due to a paucity of non-detrital sources in the silt and sediment formed from organic materials, the sediment has a low concentration of Zn (**Varma *et al.*, 1993).** The Zn value of the present study compared with the other national and international rivers is shown in Table 4.

In the five sampling sites along the Turag and Balu Rivers, Pb values in sediment samples ranged from 0.710 to 1.513 mg/kg. The highest concentration was observed at site T1 during the post-monsoon season, whereas the lowest concentration was detected at site B_2 during the monsoon season. This could be due to a combination of oil leakage and other hydrocarbons from launch, mechanised boats, and other sources. Rugrowjwanich et al. (2003) found that heavy metal concentrations in sediment were higher in the dry season than in the wet season. The above statement is consistent with the current research. In the Manuherikia River, New Zealand, **Ahlers *et al.* (1991)** detected 7.2 to 15.3 mg/kg of Pb. This Pb concentration was far lower than what was found in the current study. In Galveston Bay, **Morse *et al.* (1993)** found 12.0 to 46.0 mg/kg of Pb, much higher than the current study. Pb concentrations of the present study compared with the other national and international rivers are shown in Table 4.

Table 4. Comparison of the observed values (mg/kg) of heavy metals in the sediment of the Turag & Balu River with other national and international rivers.

River	Ca	Mg	Cu	Fe	Mn	Zn	Pb	Cd	References
Turag River	1.3	0.21	3.41	74.67	12.88	4.24	11.84	0.32	Present study
Balu River	1.22	0.36	10.85	100.17	19.86	3.25	0.96	0.14	Present study
Old Brahmaputra	-	-	6.2	-	126.2	52.7	7.6	0.48	**(Bhuyan *et.al.*, 2019**)

Sundarbans Sela River	1507.8	14311	33.7	30255	476.6	74.4	25.58	1.37	**(Chudhury *et al.*, 2021)**
Buriganga	-	-	27.85	-	-	-	69.75	3.33	**(Ahamad *et al.*, 2010)**
Buriganga	-	-	184.4	-	-	502.3	79.8	0.8	**(Saha and Hossain, 2010)**
Buriganga	-	-	344.2	-	4036	481.8	31.4	1.5	**(Mohiuddin *et. al.*, 2015a2015)**
Bangshi	-	-		-	483.4	117.15	59.99	0.61	**(Rahman *et al.*, 2014)**
Dhaleshwari	-	-	37.45	-	-	-	15.79	2.08	**(Ahamad *et al.*, 2010)**
Khiru	-	-	34.7	-	28.56	97.77	5.60	2.05	**(Rashid *et al.*, 2012)**
Karnofuly	-	-	1.22	-	15.30	16.30	4.96	0.24	**(Islam *et al.*, 2013)**
Karatoa	-	-		-	-	-	58	1.20	**(Islam *et al.*, 2015b)**
Meghna	-	-	-	-	442.6	79.02	9.47	0.23	**(Hassan *et al.*, 2015)**
Shitalakhya	-	-		-	-	75	28.36	5.01	**(Islam *et al.*, 2014)**
Shitalakhya	-	-	143.7	-	-	200.6	-	-	**(Islam *et a*l., 2016)**
Turag	-	-	1.576	-	-	1.08	1.64	1.4	**(Banu *et al.*, 2013)**
Tembi River	-	-	58.3	235.9	423.3	37.9	203	19.5	**(Shanbehzadeh *et al.*, 2014)**
Taihu Lake	-	-	2.8	-	-	-	3.61	0.24	**(Rajeshkumar *et al.*, 2018)**
Mahananda River	-	-	49.51-82.78	-	-	83.64-141.7	17.91-29.52	0.53-1.05	**(Kumar *et al.*,2017)**
Ghaghara River	-	-	2.76 - 11.74	-	-	13.26 - 17.59	10.71-14.26	0.21-0.28	**(Singh *et al.* 2017*)***
Kali River	-	-	258.5	-	-	3.4	81.53	3.38	**(Maurya and Malik, 2016)**
Cauvery River	-	-	11.2	-	-	93.1	4.3	1.3	**(Raju *et al., 2012)***
Ganga	-	-	39-73	-	-	72-140	15 -27	0.45-1	**(Tiwari & Singh, 2014)**
Gadilm River	-	-	0.60	-	-	0.20	0.48	1.64	**(Ambedkar and Muniyan, 2013)**
Plitvice Lakes Park	-	-	115	-	-	258	62.8	10.9	**(Vukosav *et al., 2012)***
Mljet National Park	-	-	300	-	-	377	62.8	14.8	**(Cuculić *et al.*, 2009)**
Aras Dam	-	-	106.3	-	-	86.11	8.44	5.56	**(Farsani *et al.*, 2019)**

Lake									
Ikpoba river	-	-	1900	7900	4600	4700	3300	1500	**(Akcay *et al*., 2003)**
Xiangjiang	-	-	71.29	-	-	257.17	102.52	23.31	**(Huang *et al*., 2020)**
Jinjiang River	-	-	7.24	-	-	48.09	32.79	0.07	**(Zhuang *et al*., 2018)**
Hanjiang River	-	-	9.28	-	-	62.47	26.97	0.10	**(Zhuang *et al*., 2018)**
Yangtze River	-	-	25.14	-	-	82.92	25.13	0.17	**(He *at al*., 2019)**

Cd levels in sediment fluctuated between 0.091 and 0.402 mg/kg in the study sites. The maximum value was recorded at site T1 during the post-monsoon season, while the lowest was reported at site B1. The high amount of Cd in this study may be related to run-off from agricultural areas. Cd is found in phosphate fertilisers that include metal, untreated sewage effluents, organics, and fine grain sediments (**Ray and Macknight, 1984).** The level of Cd was found to be from 1.45 to 3.05 mg/kg in the Ganga River, India. Cd concentrations are lower than the current study's findings (**Singh, 1997).** The Cd value of the present study compared with the other national and international rivers are shown in Table 4.

Spatio-temporal variations in heavy metal concentration (ANOVA Analysis)

Spatial variation

In Turag River sediment, there were no significant variations in terms of sites for Mg ($F=1.136$, $p=0.382$), Cu ($F=2.787$, $p=0.139$), Fe ($F=0.336$, $p=0.727$), Mn ($F=0.571$, $p=0.593$), Zn ($F=0.993$, $p=0.424$), Pb ($F=0.572$, $p=0.593$), and Cd ($F=0.354$, $p=0.716$), except for Ca ($F=16.989$, $p=0.003$), at a significance level of 0.05 (Fig. 2).

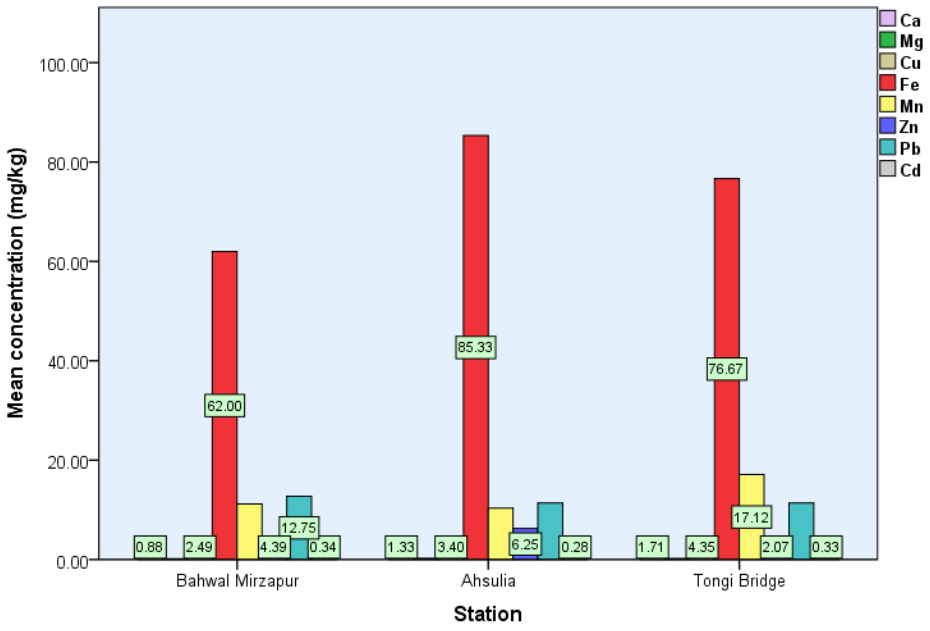

Fig. 2. Spatial variation of heavy metals in sediment of the Turag river.

In Turag River water, Ca (F=0.280, p=0.765), Mg (F=0.221, p=0.808), Cu (F=0.284, p=0.762), Fe (F=0.115, p=0.894), Mn (F=1.222, p=0.359), Zn (F=0.571, p=0.593), Pb (F=0.157, p=0.858), and Cd (F=0.957, p=0.436) showed no substantial difference at an alpha level of 0.05.

In Balu River sediment, Ca (F=0.860, p=0.406), Mg (F=0.654, p=0.464), Cu (F=0.051, p=0.832), Fe (F=0.700, p=0.450), Zn (F=1.35, p=0.351), Pb (F=0.165, p=0.705), and Cd (F=0.855, p=0.407) showed no significant variations in terms of sites, except for Mn (F=8.32, p=0.04), at a significance level of 0.05 (Fig. 3).

In Balu River water, Ca (F=0.123, p=0.743), Mg (F=0.647, p=0.532), Cu (F=2.117, p=0.219), Fe (F=0.40, p=0.851), Mn (F=0.086, p=0.784), Zn (F=0.101, p=0.766), Pb (F=0.024, p=0.885), and Cd (F=0.217, p=0.665) showed no substantial difference at an alpha level of 0.05.

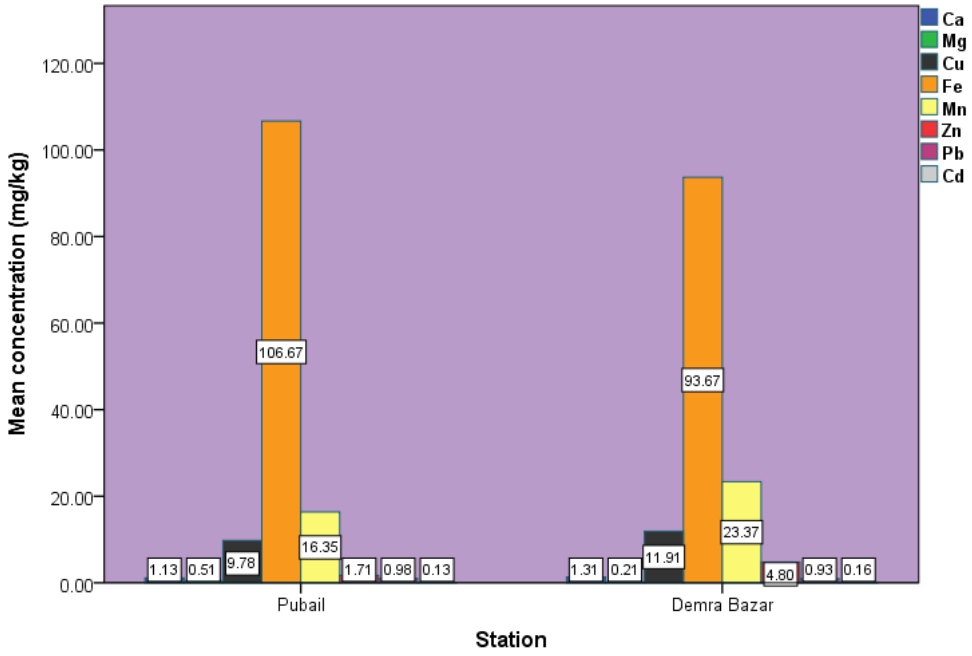

Fig. 3. Spatial variation of heavy metals in sediment of the Balu river.

Temporal variation

In Turag River sediment, Ca (F=0.147, p=0.867), Mg (F=1.278, p=0.345), Cu (F=0.905, p=0.454), Mn (F=4.247, p=0.071), and Zn (F=3.312, p=0.107) showed no substantial difference, except for Cd (F=19.962, p=0.002), Fe (F=14.029, p=0.005), and Pb (F=5.590, p=0.043) at a significance level of 0.05 (Fig. 4).

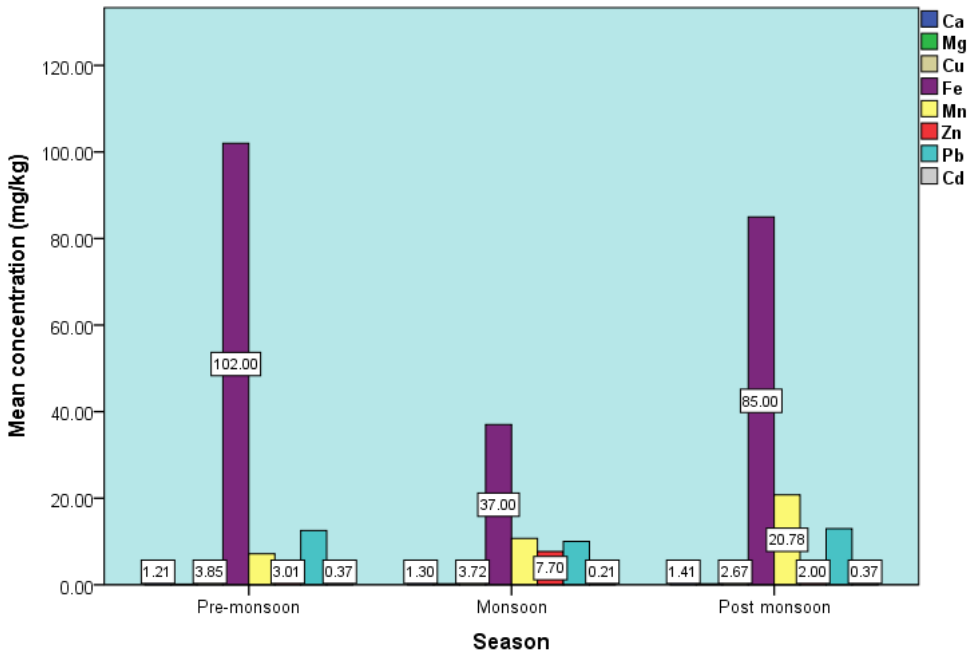

Fig. 4. Seasonal variation of heavy metals in sediment of the Turag river.

In Turag River water, Ca (F=21.217, p=0.002), Mg (F=25.585, p=0.001), Cu (F=15.077, p=0.005), and Cd (F=8.618, p=0.01) showed significant variation, while Fe (F=0.390, p=0.693), Mn (F=1.290, p=0.342), Zn (F=1.083, p=0.397), and Pb (F=0.703, p=0.532) showed no substantial difference at an alpha level of 0.05.

In Balu River sediment, Ca (F=1.028, p=0.457), Mg (F=1.489, p=0.355), Fe (F=7.873, p=0.064), Mn (F=0.695, p=0.565), Zn (F=1.114, p=0.435), Pb (F=9.135, p=0.053), and Cd (F=2.683, p=0.215) showed no substantial difference, except for Cu (F=77.503, p=0.003), at a significance level of 0.05 (Fig. 5).

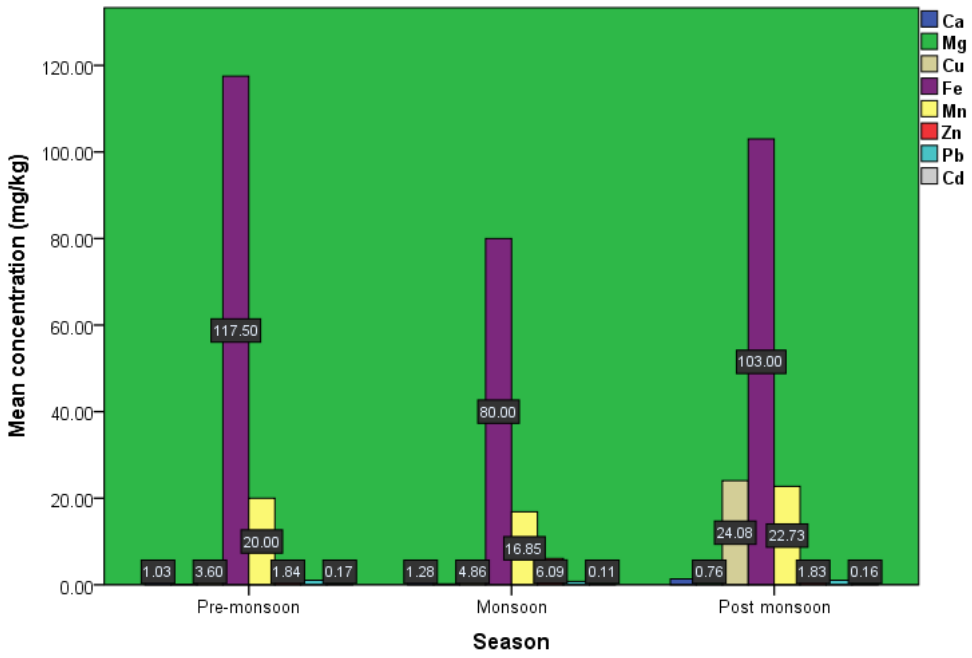

Fig. 5. Seasonal variation of heavy metals in sediment of the Balu river.

In Balu River water, Fe (F=86.774, p=0.002), Mn (F=11.931, p=0. 037), Zn (F=43.317, p=0.006), Pb (F=166.500, p=0.001), and Cd (F=17.154, p=0.023) showed significant variation, while Ca (F=19.615, p=0.019), Mg (F=7.933, p=0.063), and Cu (F=0.518, p=0.641) showed no substantial difference at an alpha level of 0.05.

Correlation of heavy metals in water and sediment of the Turag and Balu Rivers

The interrelationship between metals in water and sediment in an aqueous environment provides valuable knowledge about the sources and pathways of heavy metals (**Ali *et al.*, 2016; Bhuyan *et al.*, 2017).** The correlations between heavy metals submitted and the results confirm the existence of a new relationship between parameters. Furthermore, their sources are similar, particularly from industrial effluents, metropolitan squanders, and agricultural sources, as demonstrated by their robust, high, and moderate correlation.

In Turag River water, a solid linear relationship was found for Ca vs Mg (r=0.963) at a significance level of 0.01. In terms of Balu River water, a solid linear relationship was found for Ca vs Fe (r=0.981) and Cd vs Pb (r=0.977) at an alpha level of 0.01 (Table 6). Ca vs Mg (r=0.915) showed a solid relationship in Balu River water at a significance level of 0.05. A strong relationship was reported for Fe vs Mg (r=0.875) at an alpha level of 0.05. A moderate relationship was recorded for Mn vs Fe (r=0.670) and Mn vs Ca (r=0.580). A strong negative relationship was found for Pb vs Mg (r= –0.883), Zn vs Mn (r= –0.873), and Cd vs Mg (r= –0.868) at a significance level of 0.05 (Table 6).

Regarding Turag River sediment, a robust linear relationship was found for Cd vs Pb (r=0.870) at a significance level of 0.01. Cd vs Zn (r=0.751) showed a strong relationship at a significance level of 0.05 (Table 6). In terms of Balu River sediment, a robust linear relationship was found for Pb vs Fe (r=0.843) at an alpha level of 0.05 (Table 6). Cu vs Mg (r=0.703) showed a strong relationship in Balu River sediment. A strong negative relationship was reported for Pb vs Zn (r= –0.779) and Zn vs Fe (r= –0.687) in Balu River sediment (Table 6).

Table 6. Correlation of heavy metals in water & sediment of the Turag and Balu river.

Correlations in Turag River water

	Ca	Mg	Cu	Fe	Mn	Zn	Pb	Cd
Ca	1							
Mg	**0.963****	1						
Cu	0.576	0.482	1					
Fe	0.163	0.237	0.269	1				
Mn	-0.597	-0.511	0.011	-0.178	1			
Zn	-0.049	0.095	-0.405	-0.397	0.384	1		
Pb	0.074	0.025	0.414	-0.420	0.342	0.070	1	
Cd	-0.683*	-0.708*	-0.553	-0.243	0.152	-0.133	-0.134	1

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

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

Correlations in Balu River water

	Ca	Mg	Cu	Fe	Mn	Zn	Pb	Cd
Ca	1							
Mg	**0.915***	1						
Cu	0-.471	-0.349	1					
Fe	**0.981****	**0.875***	-0.425	1				
Mn	0.580	0.256	-0.301	0.670	1			
Zn	-0.571	-0.325	0.298	-0.595	-0.873*	1		
Pb	-0.783	-0.883*	0.276	-0.782	-0.116	-0.0231		
Cd	-0.749	-0.868*	0.154	-0.724	-0.019	-0.088	**0.977****	1

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

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

Correlations in Turag River sediment

	Ca	Mg	Cu	Fe	Mn	Zn	Pb	Cd
Ca	1							
Mg	0.556	1						
Cu	0.560	0.283	1					
Fe	0.240	-0.016	0.075	1				
Mn	0.308	0.079	-0.244	-0.104	1			
Zn	-0.301	-0.130	-0.209	-0.575	-0.272	1		
Pb	-0.284	-0.285	-0.333	0.563	0.212	-0.549	1	
Cd	-0.030	-0.345	-0.192	0.736*	0.265	**-0.751***	**0.870****	1

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

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

Correlations in Balu River sediment

	Ca	Mg	Cu	Fe	Mn	Zn	Pb	Cd
Ca	1							
Mg	0.359	1						
Cu	0.527	0.703	1					
Fe	-0.568	0.191	0.029	1				
Mn	0.463	0.023	0.550	0.009	1			
Zn	0.129	-0.206	-0.217	-0.687	0.063	1		
Pb	-0.043	0.463	0.429	**0.843***	0.329	-0.779	1	
Cd	-0.295	-0.241	0.249	0.552	0.672	-0.288	0.517	1

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

CONCLUSION

The metal concentrations in the water and sediment of the Turag and Balu Rivers were investigated in this study. The findings show that the concentrations of heavy metals in water and sediment samples at different sites vary significantly. These differences can be attributed to the amount of industrial and sewage waste dumped into the river at different sampling locations. As a result, the sediment had a higher quantity of heavy metals than water. The discharge of hazardous heavy metals and pesticides from point and non-point sources has severely polluted the Turag and Balu Rivers. Because these toxic compounds do not dissolve, they remain in the environment for a long time and have the potential to bioaccumulate in the food chain, posing long-term risks. Heavy metal pollution in river water and sediment could be compared to identify major pollution sources entering the Turag and Balu Rivers. These baseline data are critical for developing Turag and Balu River management and conservation policies.

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