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Appraisal of water quality and heavy metal concentration from the urban Balu River in Dhaka City, Bangladesh

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ABSTRACT

This study assessed the physicochemical parameters and heavy metal concentrations in the Balu River, an urban river that passes through Dhaka City. Water samples were collected from five sampling stations during the pre-monsoon, monsoon, and post-monsoon seasons from October 2021 to September 2022. River water controlling parameters such as temperature, pH, EC, TDS, DO, BOD, NO_3^-, NH_4^+, SO_4^{2-}, PO_4^{3-}, and heavy metals such as Pb, Cd, Cu, Mn, and Cr from the Balu River were monitored seasonally. The study showed seasonal variations in temperature (26.4 to 30.8°C), pH (7.12 to 7.63), EC (144.2 to 571.0 µS/cm), TDS (304.8 to 878.0 mg/L), DO (2.25 to 3.08 mg/L), and BOD (21.69 to 24.92 mg/L). The high BOD and low DO content indicated organic pollution, while elevated EC and TDS suggested significant inorganic contamination. The nutrient (NO_3^-, NH_4^+, SO_4^{2-}, PO_4^{3-}) levels also varied, with concentrations peaking in the post-monsoon season. Heavy metals Pb (0.010 to 0.063 ppm), Cd (0.0013 to 0.0091 ppm), Cu (0.021 to 0.071 ppm), Mn (0.032 to 0.108 ppm), and Cr (0.018 to 0.095 ppm) revealed that they were within the permissible limits set by the Environment Conservation Rules (ECR). However, metal concentrations were highest in the post-monsoon season. Despite being below critical pollution thresholds, the cumulative impact of pollutants and heavy metals compromised the river's suitability for aquatic life, irrigation, and drinking. Industrial waste discharge was identified as the primary cause of degradation. The study highlights the need for stringent monitoring and mitigation efforts to protect the river's ecosystem.

Keywords: Balu River, Seasonal variation, Water quality, Nutrients, Heavy metals

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Introduction

Bangladesh, characterized by its low-lying, flat terrain and extensive inland water bodies, is home to some of the world's largest rivers, making it particularly vulnerable due to its geographical location (Matin and Kamal, 2010). Water is a vital resource, essential for human survival, food production, and economic development, where the surface water is crucial for supporting human and animal life, aquatic ecosystems, agriculture, and navigation (Hasan *et al.*, 2015). In Bangladesh, environmental sustainability, development, and economic growth are highly dependent on the availability and quality of surface and groundwater, which vary by regions and seasons (Islam *et al.*, 2015). Water quality refers to the physical and chemical properties required for optimal aquatic life (Ahatun *et al.*, 2020). Key parameters like temperature, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), and biological oxygen demand (BOD) significantly impact aquatic ecosystems (Islam *et al.*, 2017). Human activities and inadequate environmental regulation often lead to increased concentrations of these elements, resulting in water quality degradation (Ehiagbonare and Ogunrinde, 2010). Monitoring water quality is essential, as rivers, lakes, and reservoirs serve as critical sources for domestic, industrial, agricultural, and aquaculture uses (Pal *et al.*, 2015). Nutrients, which are crucial for maintaining the balanced aquatic environments, influence the productivity of water bodies, while excess nutrients can lead to harmful algal blooms and eutrophication, that is, insufficient nutrients render water bodies unproductive (Rahman *et al.*, 2012a; Shukla *et al.*, 2013). Heavy metal concentration driven by industrial discharges poses additional risks for the aquatic environment. Metals such as chromium, copper, mercury, nickel, and lead, while necessary in trace amounts, become toxic at higher concentrations, accumulating in aquatic organisms and the food chain, potentially causing health hazards (Meghla *et al.*, 2013; Malik *et al.*, 2010). Toxic substances from industrial effluents and agricultural runoff pose significant risks to both aquatic life and human health (Ali *et al.*, 2018). The bioaccumulation of these metals can lead to chronic health conditions, including carcinogenic effects (Agah *et al.*, 2009; Islam *et al.*, 2021).

Bangladesh, like many developing nations, faces severe water pollution challenges due to rapid population growth, industrialization, and weak environmental enforcement (Islam *et al.*, 2018a; Islam *et al.*, 2018b). Despite large rivers such as the Padma, Meghna, Jamuna, and Brahmaputra maintaining acceptable water quality, smaller rivers like the Buriganga, Turag, Balu, and Shitalakhya have been declared ecologically critical due to pollution (DoE, 2016). The Balu River, in particular, suffers from the discharge of untreated organic and inorganic waste, negatively impacting nearby ecosystems and the livelihoods of local communities (Rahman *et al.*, 2012b). The rising demand for freshwater has heightened concerns about water quality, with safe drinking water being a fundamental human need (Pal *et al.*, 2018). The pollution of the Balu River, which flows into the Shitalakhya River, threatens the Saidabad Water Treatment Plant, a key source of drinking water for the Dhaka megacity. Dhaka, one of the most polluted megacities globally, faces severe challenges due to unregulated industrial expansion and ineffective environmental controls. Industries, though minor water users, have a significant impact on water quality. The Tejgaon industrial area, for instance, discharges vast amounts of untreated waste into canals connected to the Balu River, ultimately affecting the Shitalakhya River and Dhaka's water supply (Roy *et al.*, 2014). Effective monitoring and regulation of heavy metal contamination in the Balu River is essential, since even slight exceedances of safe thresholds may cause significant ecological degradation and health hazards. In this context, the present study investigates the seasonal dynamics of physicochemical parameters and heavy metal levels in the Balu River, highlighting the necessity of timely management actions to safeguard both environmental integrity and human well-being.

Materials and Methods

Study area

The Balu River, situated in central Bangladesh, serves as a tributary of the Shitalakhya River. Extending approximately 44 km, it originates from the Paruli and Sutia rivers in the Gazipur District. It flows through the wetlands of Beel Belai and adjoining low-lying areas east of Dhaka, before merging with the Shitalakhya near Demra. While the river conveys floodwaters from both the Shitalakhya and Turag during the monsoon season, its primary significance lies in supporting local drainage systems and providing navigational routes for small vessels (Chowdhury, 2012). This study was carried out on the Balu River in Dhaka City between October 2021 and September 2022, with the periods of February–May, June–September, and October–January classified as pre-monsoon, monsoon, and post-monsoon seasons, respectively. The sampling stations were selected based on topography, vegetation, industrial settings, and urbanizations of the Balu River for this study (Fig. 1). Five sampling sites were selected along the Balu River, designated as St-1 (Chanpara Bridge), St-2 (Chanpara Bondor), St-3 (Dakkhin Para), St-4 (Paschim Gao), and St-5 (Kheodhala), each spaced approximately 1 km apart. The selection of these sites was guided by factors such as the presence of streams and drainage channels, the characteristics of the catchment area, and variations in river water levels.

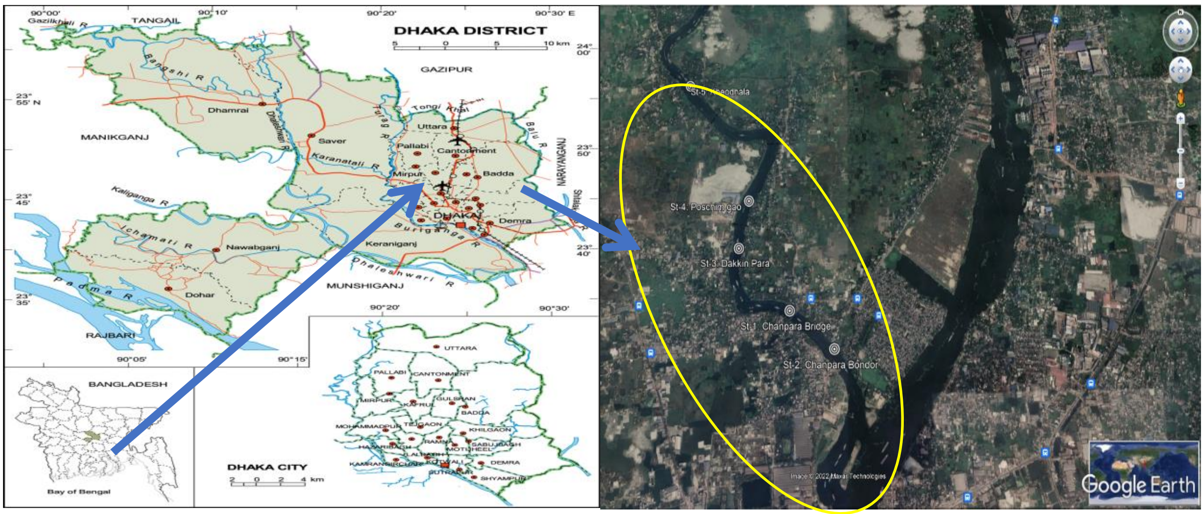

Fig. 1. Map showing the study area in the Balu River from where samples were collected.

Sample collection

Surface water samples were obtained from five designated stations along the Balu River to evaluate seasonal variations in water quality. The analyses included physicochemical indicators (temperature, pH, electrical conductivity, total dissolved solids, dissolved oxygen, and biochemical oxygen demand), nutrients (nitrate, ammonium, sulphate, and phosphate), and selected heavy metals (Pb, Cd, Cu, Mn, and Cr). For each site, 1 L of water was collected in high-density plastic bottles with double stoppers. Before use, the bottles were thoroughly cleaned with detergent, soaked overnight in 5% nitric acid (HNO_3), rinsed several times with deionized water, and dried. During collection, each bottle was rinsed three times with river water before being submerged approximately 10 cm below the surface to obtain the sample. After filling, bottles were tightly sealed, labelled with a station code, and transported in an icebox to the laboratory for subsequent analysis. The samples were filtered with pre-combusted (4h, 450°C) Whatman GF/C filters. After filtration, the samples were kept frozen (-20°C) (within 48 hrs) to avoid further contamination until analysis (Islam *et al.*, 2021).

Analysis of water quality parameters

Temperature and dissolved oxygen (DO) were recorded directly at each sampling location during field collection. Other physicochemical parameters, including pH, biochemical oxygen demand (BOD), electrical conductivity (EC), and total dissolved solids (TDS), were subsequently analyzed in the laboratory of the Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Tangail, Bangladesh using standard analytical protocols as outlined in Table 1.

Table 1. Water quality parameters, methods and instruments used for analysis.

Parameters	Units	Methods and instruments used
Temperature	°C	Digital Thermometer ((Celsius scale, directly in the field)
pH	-	Digital pH meter
Electrical Conductivity (EC)	µS/cm	Digital EC meter (Model: HM digital, Germany)
Total Dissolved Solids (TDS)	mg/L	Digital TDS meter (Model: HM digital, Germany)
Dissolved Oxygen (DO)	mg/L	Digital DO meter (Model: D.46974, Taiwan)
Biological Oxygen Demand (BOD)	mg/L	Incubation method, (DO_0-DO_5) × dilution factor
NO_3^-	mg/L	Cadmium Reduction Method
NH_4^+	mg/L	Salicylate method
SO_4^{2-}	mg/L	SulfaVer 4 method
PO_4^{3-}	mg/L	PhosVer 3 method

Analysis of nutrient concentrations

On the other hand, the concentrations of NO_3^-, NH_4^+, SO_4^{2-}, and PO_4^- were analysed in the laboratory of the Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka, by the following well-established analytical methods stated in Table 1.

Analysis of heavy metal concentrations

For metal digestion, 50 mL of the water sample was transferred into a beaker with the aid of a pipette, followed by the addition of 2 mL concentrated nitric acid (HNO_3). The mixture was placed on a hot plate for digestion. After completion, the digested sample was transferred to a 50 mL volumetric flask and diluted to the calibration mark with deionized water. Then, through a filter paper, it was filtered and preserved in a beaker, and this process was followed for every water sample. The heavy metal concentrations of Pb, Cd, Cu, Mn, and Cr in water samples were analysed by an atomic absorption spectrophotometer (AAS-Model: AA-7000, Shimadzu, Japan) following the procedure at the Wazed Mia Science Research Centre, Jahangirnagar University, Savar, Dhaka.

Statistical analysis

Data analysis and visualization were carried out using Microsoft Excel. Descriptive statistics such as mean, percentage, range, and standard deviation (SD) were applied to summarize the data. The processed results were presented through tables, charts, and graphical illustrations for clarity of interpretation.

Results and Discussion

Water quality parameters

Temperature

Temperature recorded in the Balu River water ranged from 27 to 30, 30 to 32, and 25 to 28°C in pre-monsoon, monsoon, and post-monsoon seasons, respectively. No significant variations were found among the temperatures of all five stations. The highest temperature (32°C) was found at St-3 during the monsoon season, and the lowest (25°C) was found at St-1 during the post-monsoon season (Table 2, Table 3). The recorded temperature reflects that it changed with the change of seasons. The temperature was found to be lower during the post-monsoon season than that of the monsoon and pre-monsoon seasons. According to Erdreich *et al.* (1985), the standard value of temperature is 25°C. Average water temperature recorded at 30.9°C in the monsoon season and 21.5°C in the post-monsoon season of the Bangshi river (Hoque *et al.*, 2012).

pH

The pH ranged from 7·34 to 7.95, 6.89 to 7.43, and 7.30 to 7.94 in pre-monsoon, monsoon, and post-monsoon seasons, respectively (Table 2, Table 3). The highest pH (7.95) was found at St-4 during pre-monsoon, and the lowest was 6.89 at St-1 during monsoon season. Mean pH concentrations were found to be 7.63 during pre-monsoon, 7.12 during monsoon, and 7.59 during post-monsoon season which mostly showed their alkaline nature. According to ECR (1997), the standard of pH for inland surface water is 6.5 to 8.5. It revealed that the pH of all the water samples was within the standard level. Pia *et al.* (2018) found that the pH of the Shitalakhya River ranged from 5.5 to 5.6 in pre-monsoon and 6.6 to 6.7 in post-monsoon season, which indicated the acidic nature of water.

Electrical conductivity (EC)

The EC recorded in the Balu River water ranged from 750 to 910, 247 to 370, and 820 to 960 µS/cm during pre-monsoon, monsoon, and post-monsoon seasons, respectively (Table 2, Table 3). The highest EC (960 µS/cm) was found at St-3 during post-monsoon, and the lowest (247 µS/cm) was found at St-2 during monsoon season (Table 2). According to ADB (1994), the standard levels of EC for fisheries and irrigation are 1000 and 750, respectively (Table 2). The observed mean EC during monsoon was lower than the standard level, whereas both in pre- and post-monsoon seasons were higher than the standard level for irrigation but within the permissible level for fishing purposes. It indicates the presence of ionic compounds in water and a higher concentration of inorganic pollutants. Many tanneries and textile industries are situated on the bank of the Balu River. All of these are a result of higher concentrations of industrial pollutants in water. Islam *et al.* (2015) found the mean EC content in the Tista River water was 84 and 145 µS/cm during the wet and dry seasons, respectively, which was lower than the present study. Pia *et al.* (2018) found EC of the Shitalakhya River ranged from 112.2 to 116.6 µS/cm in pre-monsoon and 200.3 to 215.2 µS/cm in the post-monsoon season.

Table 2. Water quality parameters of the Balu River during pre-monsoon, monsoon, and post-monsoon seasons.

Parameter	Sampling Stations	Seasons				Standard
		Pre-monsoon	Monsoon	Post-monsoon	Average	
Temp. (°C)	St-1	28	31	25	28	25°C (Erdreich *et al.*, 1985)
	St-2	28	30	26	28	
	St-3	30	32	28	30	
	St-4	29	31	26	28.7	
	St-5	27	30	27	28	
	Mean±SD	28.4±1.14	30.8±0.85	26.4±1.14	28.54±0.87	
pH	St-1	7.57	6.89	7.30	7.25	6.5-8.5 (ECR, 1997)
	St-2	7.34	7.32	7.53	7.39	
	St-3	7.79	7.38	7.94	7.70	
	St-4	7.95	6.91	7.68	7.51	
	St-5	7.52	7.43	7.48	7.48	
	Mean±SD	7.63±0.23	7.12±0.26	7.59±0.23	7.45±0.17	
EC (µS/cm)	St-1	850	355	900	701.7	1000 (Fisheries) 750 (Irrigation) (ADB, 1994)
	St-2	760	247	820	609	
	St-3	910	370	960	746.7	
	St-4	820	282	880	660.7	
	St-5	750	270	830	616.7	
	Mean±SD	818±66.10	304.8±54.41	878±56.74	666.96±58.1	
TDS (mg/L)	St-1	405	180	605	396.7	<400 (Fisheries) 2000 (Irrigation) (ADB, 1994)
	St-2	369	102	510	327	
	St-3	482	208	690	460	
	St-4	395	98	470	321	
	St-5	430	133	580	381	
	Mean±SD	416.2±42.79	144.2±48.46	571±85.61	377.14±56.9	
DO (mg/L)	St-1	2.57	3.63	3.15	3.12	5 (ECR, 1997)
	St-2	2.10	3.21	2.62	2.64	
	St-3	1.90	2.56	2.53	2.33	
	St-4	2.15	3.20	2.91	2.75	
	St-5	2.53	2.81	2.23	2.52	
	Mean±SD	2.25±0.29	3.08±0.4	2.67±0.35	2.67±0.3	
BOD (mg/L)	St-1	27.2	19.4	20.05	22.22	10 (Irrigation) (ECR, 1997)
	St-2	21.6	20.54	23.15	21.76	
	St-3	27.4	24.63	28.8	26.94	
	St-4	24.8	22.32	26.6	24.57	
	St-5	23.6	21.59	25.6	23.59	
	Mean±SD	24.92±2.46	21.69±1.97	24.82±3.4	23.85±2.07	

Total dissolved solids (TDS)

The concentration of TDS was found to be from 369 to 482, 98 to 208, and 470 to 690 mg/L during pre-monsoon, monsoon, and post-monsoon seasons, respectively, in the Balu River water sample. The highest content of TDS (690 mg/L) was found at St-3 during post-monsoon and the lowest (98 mg/L) was found at St-4 during monsoon season (Table 2, Table 3). The mean TDS concentrations were found to be 416.2, 144.2 and 571 mg/L during pre-monsoon, monsoon, and post-monsoon seasons, respectively. According to ADB (1994), the standard levels of TDS for drinking, irrigation and fish culture are 1000, 2000 and <400 mg/L, respectively. All the observed TDS contents were within the standard level for drinking and irrigation purposes. But the average concentration of 416.2 and 571 mg/L during pre- and post-monsoon seasons was higher than the standard level for fish culture. Rehnuma *et al.* (2016a) found that the mean TDS content in the Bangshi River water was 100 and 487.3 mg/L during the wet and dry seasons, respectively, which were comparatively higher than in the present study. Pia *et al.* (2018) found TDS of the Shitalakhya River ranged from 111.5 to 115.3 mg/L in pre-monsoon and 96.20 to 99.30 mg/L in post-monsoon season, which indicates the permissible limit for drinking, fishing and irrigation.

Dissolved oxygen (DO)

The concentrations of DO in Balu River water were found to vary from 1.90 to 2.57, 2.56 to 3.63 and 2.23 to 3.15 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively. The highest DO content was 3.63 mg/l at St-1 during the monsoon and the lowest was 1.90 mg/L at St-3 during the pre-monsoon season, respectively (Table 2, Table 3). The mean DO concentrations were found 2.25, 3.08 and 2.67 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively. According to ECR (1997), the standard level of DO for drinking, fisheries, and irrigation is 5 mg/L or more. The DO contents of all stations showed that the values were so marginal as to support the fish or other aquatic life of the river. Fish and other aquatic organism's experience a deficiency of DO level. Some fish and other organisms may not survive in this condition. Meghla *et al.* (2013) found that the DO contents of different sampling points of the Turag River ranged from 1.22 to 3.66 mg/L.

Biological oxygen demand (BOD)

The concentrations of BOD in Balu River water were found to be varied from 21.60 to 27.40, 19.40 to 24.63 and 20.05 to 28.80 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 2, Table 3). The highest content of BOD was 28.8 mg/L at St-4 during post-monsoon and the lowest was 19.4 mg/L observed in St-1 during monsoon (Table 2). Mean BOD concentrations were found to be 24.92, 21.69 and 24.82 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively. According to ECR (1997), the standard levels of BOD for drinking and irrigation are 2 or less and 10 or less, respectively. Consequently, it indicates that the water of the Balu River is not suitable for drinking and irrigation purposes. Pia *et al.* (2018) found BOD of the Shitalakhya River ranged from 4.46 to 4.66 mg/L in the pre-monsoon and 3.01 to 3.13 mg/L in the post-monsoon season.

Table 3. Comparison of water quality parameters of the Balu River observed in this study with those of other rivers of Bangladesh.

River	Temp. (ºC)	DO (mg/L)	pH	EC (µS/cm)	TDS (mg/L)	Reference
Balu	28.54	2.67	7.45	666.96	377.14	Present study
Shitalakhya	28.74	2.35	7.60	1166.03	882.78	Sultana *et al.* (2024)
Someshwari	18.11	5.31	7.68	78.66	33.86	Sarker *et al.* (2024)
Shitalakhya	27.79	7.07	7.60	787.82	578.91	Kabir *et al.* (2020a)
Korotoa	25.86	2.17	-	297.41	98.86	Ahatun *et al.* (2020)
Buriganga	27.08	0.89	8.74	354.71	-	Fatema *et al.* (2018)
Rupsha	29.70	-	8.50	16705.00	8638.00	Islam *et al.* (2018a)
Shitalakhya	-	1.97	7.55	809.00	421.00	Irin *et al.* (2016)
Brahmaputra	-	7.52	7.66	168.00	155.00	Tareq *et al.* (2013)
Standard	20-30	>5.00	6.5-8.5	1200	2100	DoE (2016)

Dissolved nutrient concentrations

Nitrate (NO_3^-)

The concentrations of NO_3^- were found from 0.98 to 2.21, 0.83 to 1.91 and 1.10 to 2.33 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively (Fig. 2). The highest content was 2.33 mg/L at St-5 during post-monsoon and the lowest was 0.83 mg/L observed in St-2 during monsoon season. According to DoE (2016), the permissible limit of NO_3^- for drinking water is 10 mg/L. The NO_3^- concentration of all water samples was below this level. In a similar study on the Balu River, Hadiuzzaman *et al.* (2006) found that NO_3^- concentration in water was 0.40 to 1.05 mg/L.

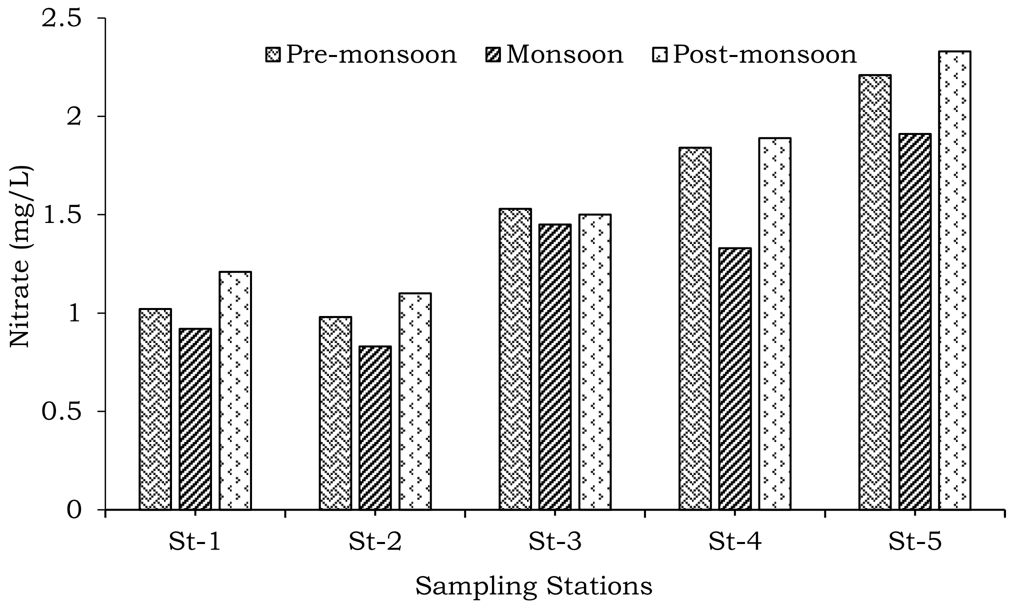

Fig. 2. Nitrate (NO_3^-) concentrations at different sampling stations of the Balu River.

Ammonium (NH_4^+)

The concentration of NH_4^+ was found from 8.21 to 12.13 mg/L, 2.45 to 5.41 and 9.01 to 11.56 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively (Fig. 3). The highest concentration of NH_4^+ was 12.13 mg/L at St-3 during pre-monsoon and the lowest was 2.45 mg/L at St-4 during monsoon season. Mean concentration of NH_4^+ contents were 9.89, 4.33 and 10.14 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively. According to DoE (2016), the permissible limits for NH_4^+ for drinking water and irrigation are 5 mg/L and 15 mg/L, respectively. All of the observed NH_4^+ values of Balu River water were much higher than the standard level for drinking, but within the permissible limit for irrigation. Sattar and Islam (2005) observed that the Balu River NH_4^+ concentration of sample water ranged from 2.80 to 12.13 mg/L, and this is similar to the present study.

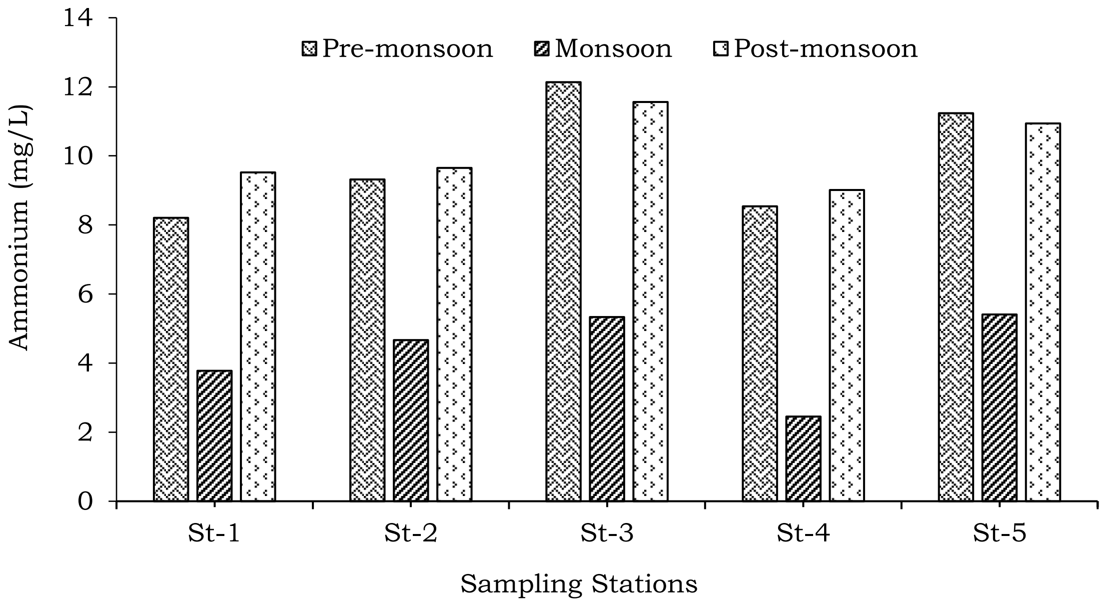

Fig. 3. Ammonium (NH_4^+) concentrations at different sampling stations of the Balu River.

Sulphate (SO_4^{2-})

The sulphate content of all water samples collected from the study area ranged from 23.55 to 26.24, 10.52 to 13.52 and 22.24 to 25.52 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively (Fig. 4). The highest concentration of sulphate was 26.24 mg/L at St-4 during pre-monsoon. The lowest was 10.52 mg/L at St-5 during monsoon season. The observed mean concentration of SO_4^{2-} values were 24.44, 12.05 and 23.85 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively. The maximum permissible limit of sulphate in drinking water is 100.00 mg/L (WHO, 2011), whereas 20.00 mg/L for irrigation water (Ayers and Westcot, 1985).

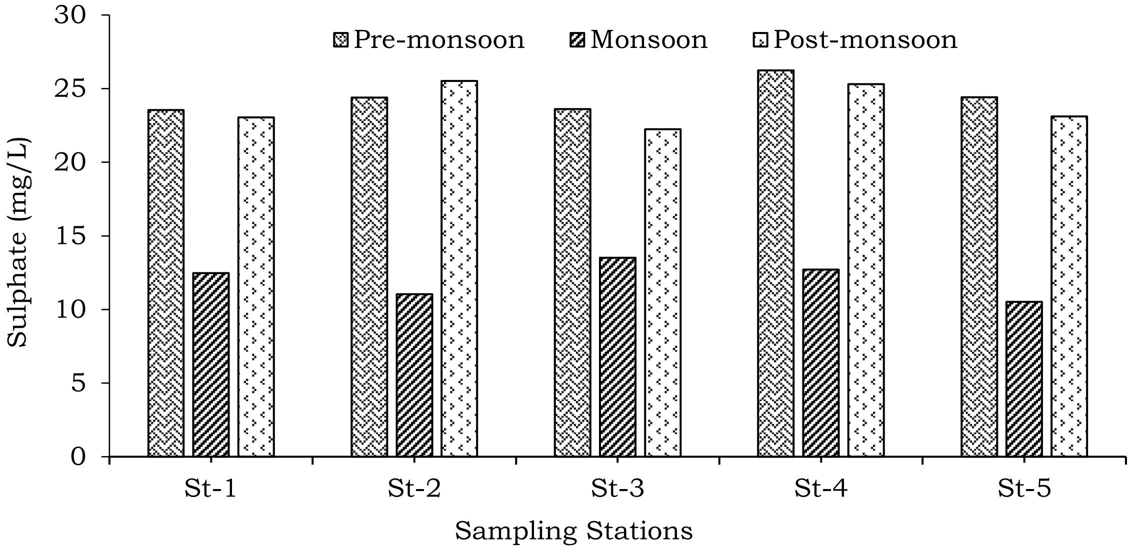

Fig. 4. Sulphate (SO_4^{2-}) concentration at different sampling stations of the Balu River.

Phosphate (PO_4^{3-})

The phosphate content of all water samples collected from the study area ranged from 5.18 to 7.50, 2.52 to 3.64 and 5.80 to 8.10 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively (Fig. 5). The highest content of phosphate was 8.10 mg/L at St-5 during post-monsoon and the lowest was 2.52 mg/L at St-2 during monsoon season. According to DoE (2016), the permissible limit for PO_4^{3-} for drinking water and irrigation are 6 mg/L and 10 mg/L, respectively. The observed mean PO_4^{3-} values of Balu River water were slightly higher than the standard for drinking, but within the permissible limit for irrigation. Sattar and Islam (2005) observed that PO_4^{3-} concentration of water ranges from 7.07 to 16.87 mg/L during September, whereas it varied from 1.77 to 9.66 mg/L during October.

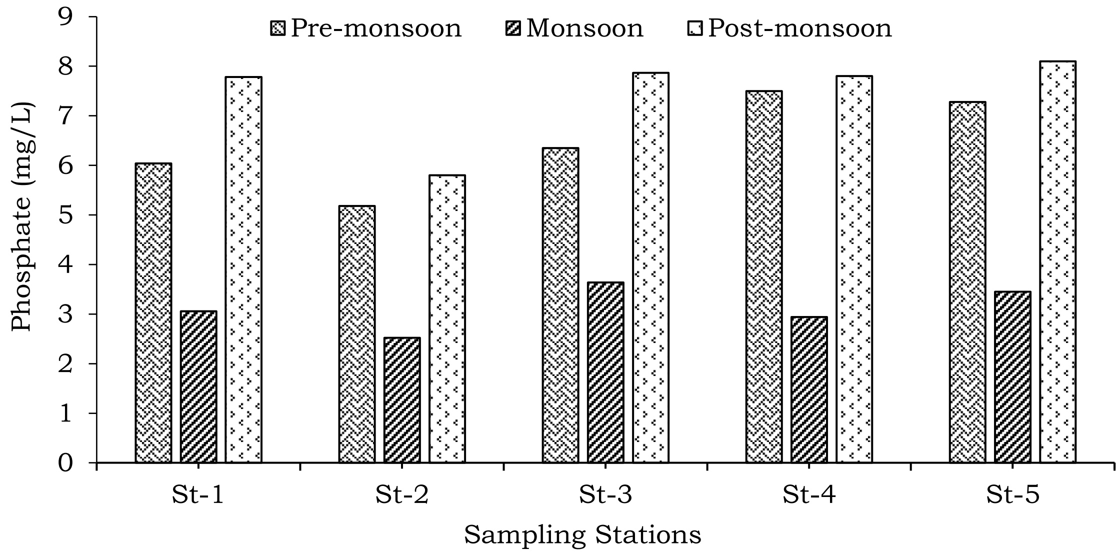

Fig. 5. Phosphate (PO_4^{3-}) concentration at different sampling stations of the Balu River.

Heavy metal concentrations

Lead (Pb)

Lead is a ubiquitous toxic metal and is detectable in practically all phases of the environment and in all biological systems. The concentrations of Pb in the river water ranged from 0.010 to 0.049, 0.012 to 0.045 and 0.026 to 0.063 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 4). The highest concentration of Pb (0.063 ppm) was found at St-1 in the post-monsoon season and the lowest concentration (0.010 ppm) was found at St-5 in the pre-monsoon season. These variations are likely to be due to different collection spots and seasons. Mean concentrations of Pb were found to be 0.025, 0.016 and 0.042 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively. Both of these values are lower than the drinking and fishing purposes but higher than the irrigation and surface water standard levels according to ECR (1997) and ADB (1994). Islam *et al.* (2020) found that the level of Pb in Shitalakhya river water was 0.0065, 0.0029 and 0.0040 ppm during pre-monsoon, monsoon and post-monsoon seasons (Table 5).

Table 4. Heavy metal concentrations of the Balu River water during pre-monsoon, monsoon and post-monsoon seasons.

Heavy metals (ppm)	Sampling stations	Seasons			Mean±SD	Standard (ECR, 1997)
		Pre-monsoon	Monsoon	Post-monsoon		
Lead (Pb)	St-1	0.0490	0.0450	0.0630	0.027± 0.010	0.05
	St-2	0.0210	0.0260	0.0370		
	St-3	0.0310	0.0230	0.0520		
	St-4	0.0150	0.0120	0.0330		
	St-5	0.0100	0.0140	0.0260		
Cadmium (Cd)	St-1	0.0019	0.0013	0.0029	0.0035± 0.001	0.005
	St-2	0.0020	0.0017	0.0021		
	St-3	0.0026	0.0019	0.0034		
	St-4	0.0049	0.0037	0.0078		
	St-5	0.0019	0.0031	0.0091		
Copper (Cu)	St-1	0.0540	0.0350	0.0710	0.047± 0.010	1
	St-2	0.0410	0.0210	0.0530		
	St-3	0.0460	0.0450	0.0620		
	St-4	0.0540	0.0330	0.0670		
	St-5	0.0430	0.0290	0.0510		
Manganese (Mn)	St-1	0.0920	0.0710	0.1010	0.064± 0.010	0.1
	St-2	0.0780	0.0570	0.1080		
	St-3	0.0430	0.0460	0.0610		
	St-4	0.0410	0.0430	0.0470		
	St-5	0.0610	0.0480	0.0660		
Chromium (Cr)	St-1	0.0420	0.0310	0.0530	0.045± 0.010	0.05
	St-2	0.0290	0.0180	0.0480		
	St-3	0.0320	0.0390	0.0250		
	St-4	0.0750	0.0620	0.1210		
	St-5	0.071	0.049	0.092		

Cadmium (Cd)

Cadmium is a non-essential element and it is both bioavailable and toxic. The concentrations of Cd were found to vary from 0.0019 to 0.0062, 0.0013 to 0.0037 and 0.0021 to 0.0091 ppm in pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 4). The highest concentration of Cd (0.0091 ppm) was found at St-5 during the post-monsoon and the lowest concentration (0.0013 ppm) was found at St-1 during the monsoon season. All the stations during post-monsoon showed relatively higher concentration than monsoon and pre-monsoon. The mean concentration of Cd along the river was 0.0035, 0.0020 and 0.0051 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively, which were lower than the surface water standard levels (Table 5). Islam *et al.* (2020) reported the mean concentration of Cd in Shitalakhya River water was 0.0044, 0.0015 and 0.0029 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively.

Copper (Cu)

The concentrations of Cu were found to vary from 0.041 to 0.054, 0.021 to 0.045 and 0.051 to 0.071 ppm in pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 4). The highest concentration of Cu (0.0071 ppm) was found at St-1 during post-monsoon and the lowest concentration (0.021 ppm) was found at St-2 during the monsoon season. All the stations during post-monsoon showed relatively higher concentrations than others. The mean concentration of Cu along the river was 0.048, 0.033 and 0.061 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively, which were lower than the surface water standard levels (Table 5). Islam *et al.* (2020) recorded concentrations of Cu of the Shitalakhya River during pre-monsoon, monsoon and post-monsoon seasons, which were 0.0240, 0.0151 and 0.0212 ppm, respectively.

Manganese (Mn)

Manganese is an essential trace element, but is toxic at higher concentrations. The concentrations of Mn were found to vary from 0.041 to 0.092, 0.043 to 0.071 and 0.047 to 0.108 ppm in pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 4). The highest concentration of Mn (0.108 ppm) was found at St-2 during the post-monsoon and the lowest concentration (0.041 ppm) was found at St-4 during the pre-monsoon season. All the stations during post-monsoon showed relatively higher concentrations than others. The mean concentration of Mn along the river was 0.063, 0.053 and 0.077 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively, which were lower than the surface water standard levels (Table 5). Bhuyan *et al.* (2019) observed that the concentration of Mn in the water of the Brahmaputra River during the dry season (post-monsoon) was 2.5 ppm.

Chromium (Cr)

Chromium is the 21st most abundant element in Earth's crust. The concentrations of Cr were found to vary from 0.029 to 0.075, 0.018 to 0.062 and 0.025 to 0.121 ppm in pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 4). The highest concentration of Cr (0.121 ppm) was found at St-4 during post-monsoon and the lowest concentration (0.018 ppm) was found at St-2 during the monsoon season. The mean concentration of Cr along the river were 0.037, 0.031 and 0.068 ppm during pre-monsoon, monsoon and post-monsoon seasons, respectively, in which the mean values of pre-monsoon and monsoon seasons were within the permissible limit and the post-monsoon values were slightly higher than the standard level (Table 5). Shitalakhya River was 0.0069, 0.0019 and 0.0039 ppm during pre-monsoon, monsoon and post-monsoon seasons (Islam *et al.*, 2020).

Table 5. Comparison of heavy metal concentrations among river waters in Bangladesh.

River	Pb	Cd	Cr	Cu	Mn	Reference
Balu	0.0270	0.0035	0.0450	0.0470	0.0640	Present study
Shitalakhya	0.0082	0.0050	0.0418	0.0318	0.2005	Sultana *et al.* (2024)
Someshwari	0.0105	0.0191	DBL	0.2090	0.0685	Sarker *et al.* (2024)
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)
Shitalakhya	0.0082	0.0029	0.0042	0.0201	-	Kabir *et al.* (2020b)
Bangshi	0.0135	0.0012	-	0.0700	1.36	Rehnuma *et al.* (2016b)
Shitalakhya	0.023	0.0070	-	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)	-

Conclusion

The findings of this study highlight significant concerns regarding both the physicochemical properties and heavy metal contamination of the Balu River water. While some parameters, such as temperature, pH, EC, and TDS, fall within acceptable limits, the DO and BOD levels indicated an environment unsuitable for sustaining healthy aquatic ecosystems. Additionally, nutrient concentrations remain within permissible limits across the seasons, but the overall water quality still poses risks to aquatic life, human health, and the surrounding environment. Heavy metal analysis revealed the seasonal variations, with post-monsoon concentrations of metals like Pb, Cd, Cu, Mn, and Cr exceeding permissible limits in some locations. Although average concentrations were generally within acceptable standards, the presence of these metals signals contamination that can harm aquatic biota and disrupt ecosystem balance. Addressing these issues requires a multifaceted approach. The implementation of effluent treatment plants (ETPs) in industries, stricter regulation of industrial discharges, and the development of cost-effective water treatment solutions are essential steps. Continuous monitoring and assessment of water quality are crucial for early detection and mitigation of pollution. Additionally, raising public awareness through mass media can foster community involvement in protecting water resources. Ultimately, coordinated efforts between government agencies, industries, and the public will be necessary to restore and safeguard the ecological health of the Balu River.

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