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RESEARCH PAPER

Physical and Chemical Characteristics of Water in Sangu-Matamuhuri Rivers along the South-Eastern part of Bangladesh and Heavy Metal Contamination with Associated Health Risk

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ABSTRACT

The study was conducted to determine the physical and chemical characteristics and heavy metal contamination in water along with associated health risks in Sangu and Matamuhuri rivers, located in the hilly watershed of south-eastern part in Bangladesh. Water samples were collected from five selected locations of both rivers during October, 2022 - September, 2023 and analyzed for pre-monsoon (February – May, 2023), monsoon (June – September, 2023) and post-monsoon (October, 2022 – January, 2023) seasons considering physical parameters including temperature, electrical conductivity (EC), turbidity, total dissolved solid (TDS), total suspended solid (TSS), and chemical parameters including pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD) and chloride. For assessing health risk, the contamination factor (CF), pollution load index (PLI), hazard quotient (HQ), and hazard index (HI) were evaluated. Water quality index was higher than 100, indicates the water was unsuitable for drinking. The mean concentration of heavy metals in water of Sangu river showed the pattern as Fe > Mn > Zn > Pb > Cr > Ni > Cu > Hg > Co > Se > Cd > Be, whereas for the Matamuhuri river as Fe > Mn > Pb > Zn > Cr > Ni > Cu > Hg > Co > Se > Cd > Be during September, 2023. Fe and Pb concentrations were found higher than the standard limit of inland surface water, suggested by Department of Environment (DoE), Bangladesh. The CF values for Sangu river ranged from 0.001 to 1.6 and for Matamuhuri river ranged from 0.003 to 3.9, suggest low contamination. The PLI values (Sangu = 0.055, Matamuhuri = 0.084) showed the pollution level not influenced by presence of less amount of heavy metals. Cancer risk for adults in surface water showed low cancer risk (CR < 10^{-6}) for Cd, Cr, and Pb. The implications of these findings may help to raise awareness among the river water users for keeping water in good condition and thereby getting more ecosystem services.

Key words: Cd, Cr, Pb, health risks, Sangu-Matamuhuri river, water Quality

Introduction

Surface water resources particularly rivers worldwide are now under increasing threats of pollution (Hossain, 2001; Chakrabarthi *et al.* 2013; Mul *et al.* 2015). The reasons behind are the clearing of forest covers, agricultural development and settlement that have been increased globally over last several decades, and making direct effect on watershed with its water resources in terms of both quantity and quality (Rudra *et al.* 2023; Hossain *et al.* 2021; Santos *et al.* 2018). Water quality has paramount importance in both environmental and economic aspects as the poor condition of water is not only the indicator of environmental degradation but also causes health hazards as well as severe economic losses in all respects including domestic, industrial and agricultural sector (Nabeela *et al.* 2014; Rakiba and Ferdousi, 2013). Water resources are susceptible to contamination because of its unique property to dissolve and suspend a huge variety of chemicals generated from various land use activities. So, surface water quality monitoring in terms of physical and chemical characteristics along with its heavy metal contamination is very important for the protection of aquatic lives and human health in order to understand the water quality of river before using for any other purposes.

Several studies showed that surface water quality of most of the rivers in Bangladesh is highly polluted day by day (Hossain, 2001; Chakrabarthi *et al.* 2013; Bhuiyan *et al.* 2015; DoE, 2018). Water quality of Halda river in the south-eastern part of Bangladesh was assessed by Islam *et al.* (2020), where temporal water quality indexes were determined from three selected stations by weighted arithmetic water quality index based on several physical and chemical parameters including temperature, transparency, total dissolved solid (TDS), electrical conductivity (EC), pH, dissolved oxygen (DO), biological oxygen demand (BOD), calcium, total hardness, and total alkalinity; and found that water quality was good to poor in different seasons. Mustari and Afsana (2021) investigated the status of water quality of Buriganga river, located in the north-central region of the country considering various water quality parameters such as temperature, pH, DO, BOD, chemical oxygen demand (COD), TDS, total suspended solid (TSS), alkalinity, EC and chloride during March, 2015 – February, 2016. This study revealed that the water quality of Buriganga is not safe for aquatic life. A study on temporal distribution of shellfish assemblages along with water quality data in the Sangu river estuary of Bangladesh carried out by Begum *et al.* (2020); and found that ecological parameters mainly temperature, salinity, transparency, dissolved oxygen and pH varied with season to season (Begum *et al.* 2020).

As heavy metals are toxic and accumulate in waterbodies, their contamination in aquatic habitats is a serious concern (Hossain *et al.* 2020; Mondol *et al.* 2011; Islam *et al.* 2015). Heavy metals are continually discharged into aquatic systems from natural sources and anthropogenic activities, posing a severe concern to fish consumers including humans and other wildlife due to their toxicity, bioaccumulation, long persistence and bio magnification in the food chain (Gupta, 2017; Mehnaz *et al*. 2022). Several studies revealed the presence of heavy metals in river water (Dey *et al*. 2015; Ahmed *et al.* 2019; Islam *et al.* 2020) and suggested that regular monitoring of heavy metals concentration in river water is indispensable for protecting aquatic habitat and lessening human health risk.

Sangu and Matamuhuri are the two main rivers of Bandarban District of Chittagong Hill Tracts region in Bangladesh. These river flow parallel from south to north and are the major sources of upland freshwater inflows to the south-eastern part of Bangladesh (Rudra *et al.* 2023; Rasul *et al.*, 2004). More than 80% of Bandarban's population are dependent on these two major rivers for water. Both the rivers, once vibrant, are now gradually deteriorating and posing a threat to navigability and serious water scarcity, and subjected to pollution simultaneously. Continued deforestation, hill cutting, relentless stone extraction and shifting cultivation are the main reasons behind which induces flash flood and landslides in the study area, and thus, responsible for increasing soil erosion, sedimentation in the stream channels and causing deterioration of water quality in the surrounding area (Hossain *et al*. 2021). It was reported that 1800 mounds of hill rocks and boulders are collected daily from the upstream area of Sangu-Matamuhuri watershed in Bandarban (The Daily Star, 2018). The main causes of the deteriorating water quality in this area are abrupt changes in land use and land cover as well as poor tourism management (Hossain *et al.* 2021, Islam *et al*. 2015).

However, a notable number of research has been conducted on different rivers in the south-eastern part of Bangladesh, and a very few researches were recorded in Sangu and Matamuhuri rivers. Hence, this study was designed to determine i) the physical and chemical characteristics of water including temperature, electrical conductivity, turbidity, TDS, TSS, pH, DO, BOD, COD and chloride; ii) the heavy metal contamination in surface water including Fe, Pb, Zn, Cd, Cr, Cu, Zn, Be, Se, Ni, Co and Hg; and iii) human health risks (HHR) in terms of contamination factor (CF), pollution load index (PLI), hazard quotient (HQ), hazard index (HI) and cancer risk (CR) of surface water in Sangu and Matamuhuri rivers.

Materials and Methods

Study area

The study area is situated in the upstream of Sangu and Matamuhuri rivers at Bandarban district of Chittagong Hill Tracts (CHT's), Bangladesh (Figure 1). Both the rivers are located in the south-eastern part of Bangladesh and run parallel throughout Bandarban district of CHT's in its upper parts and Chittagong and Cox'sbazar districts in its lower parts. The watershed area of both Sangu and Matamuhuri rivers was 310316.67 ha with the Sangu watershed covering 212000.16 ha and Matamuhuri watershed covering 98,316.51 ha (Rudra *et al.* 2023). Sangu river originates in the Arakan hills of Myanmar at 21°13´ N and 92°37´ E and enters Bangladesh near Remarki, Thanchi upazila of Bandarban district whereas Matamuhuri river originates in the North Arakan hills of Myanmar and enters Bangladesh near Chokhyong, Alikadam Upazila, Bandarban district from the east (Ahmed and Stecey, 2016; Khan and Haque, 2003). For this investigation, the study area was divided into 10 sampling sites (Figure 1) where five in Sangu river namely Sangu Bridge (S1), Kya Ching Ghata (S2), Near Helipad (S3), Milonchari (S4) and Boroitoli (S5), and five in Matamuhuri river namely Matamuhuri Bridge (M1), Bamu Bilchari (M2), Bilchari (M3), Choto Bamu (M4) and Merakhola (M5). The GPS locations of study area with site descriptions are described in Table 1.

Collection of water samples

For analyzing physical and chemical properties of water, samples were collected monthly from five sampling points selected at 1000 m apart in Sangu and Matamuhuri rivers starting from Sangu Bridge and Matamuhuri Bridge, respectively during the period from October, 2022 – September, 2023. The sampling period was divided into three seasons: pre-monsoon (February - May), monsoon (June -September) and post-monsoon

(October - January) season. Three water samples were collected each time from each sampling points, thus a total 90 samples were collected. Water samples were collected in 1.5 liter polypropylene bottles. Before sample collection, all bottles were properly cleaned and washed with de-ionized water and were dried. After sampling the bottles were labeled with date and sampling source.

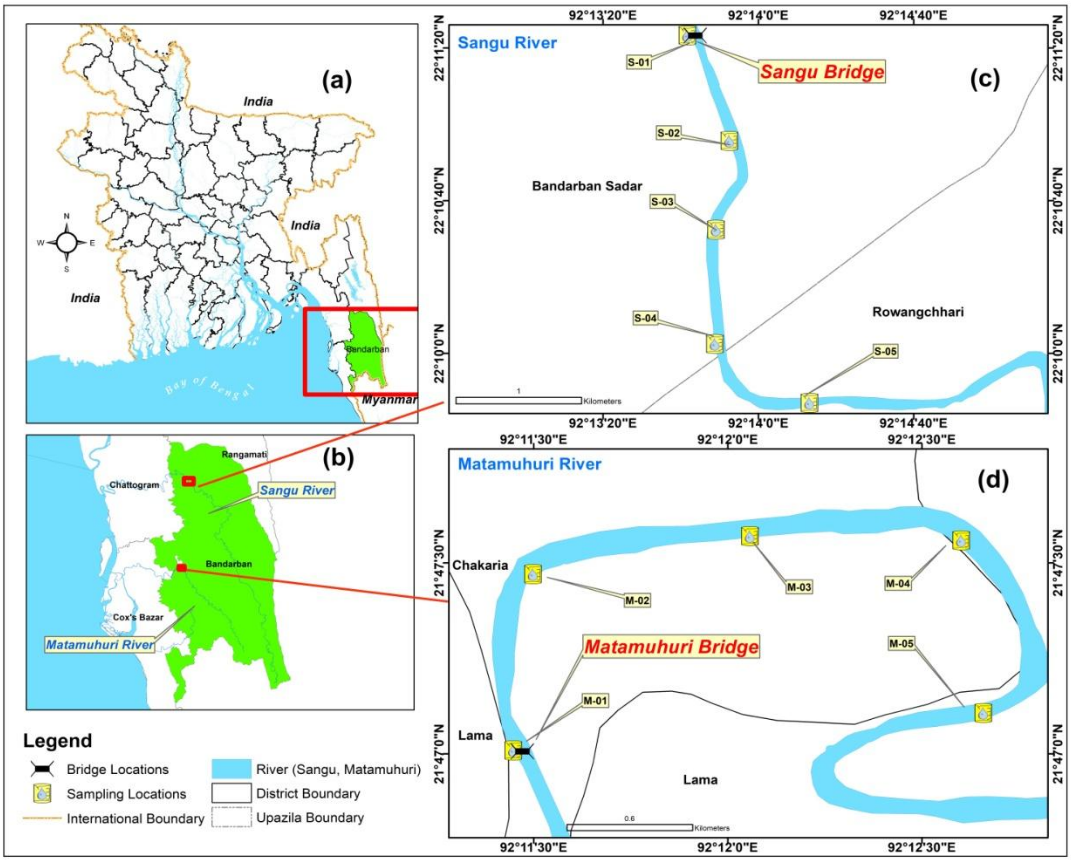

Figure 1. Map of study area in Sangu and Matamuhuri rivers showing (a) Map of Bangladesh, (b) Bandarban district showing two adjacent rivers - Sangu and Matamuhuri, (c) Sangu river showing sampling points (S1, S2, S3, S4, S5), and (d) Matamuhuri river (M1, M2, M3, M4, M5) showing sampling points.

Assessment of physical and chemical properties of water

The physical and chemical properties of water were determined by following the standard methods for the estimation of water quality (APHA, 2023). Water temperature, pH and dissolved oxygen (DO) were measured on the site instantly after sample collection by the digital thermometer, pH meter (Model: pH eP, Hanna), and DO meter (Model: DO 31P: TAO DK), respectively. Electrical conductivity (EC), turbidity, total dissolved solid TDS), suspended solid (SS), and chloride were determined by HACH 4300 Multimeter. Biological oxygen demand (BOD) and chemical oxygen demand (COD) were measured by HACH 4300 Multimeter, through respirometric method, and closed reflux colorimetric method, respectively (DoE, 2017).

Assessment of heavy metals in water

The concentration of heavy metals including Pb, Cr, Cd, Co, Cu, Ni, Mn, Zn, Fe, Hg Se and Be were determined using inductively coupled plasma-mass spectrometry (ICP-MS; PerkinElmer, Model: NexION 2000; USA). The nebulized sample enters the ICP-MS system's argon (Ar) plasma core at a rate of about 0.35 milliliters per minute. The mass to charge ratio (m/z) of the heavy metal ions generated at high-temperature plasma was measured using a quadrupole mass detector. The standard calibration curve at ppb levels was prepared using the ICP-multi-element standard solution XIII (Merck, Germany) (Wolfs and Adams, 2015). An ICP-multi-element standard solution XIII (Merck, Germany) was used to prepare standard calibration curve at ppb levels (Wolfs and Adams, 2015).

Quality assurance and quality control in analysis of heavy metals

In order to minimize the risk of contamination during sample preparation and analytical procedures, all glassware utilized in this investigation were thoroughly cleaned and washed with ultrapure acid and water. Prior to calibration with standards, ICP-MS equipment's performance was checked by NexION setup solution

(PerkinElmer, USA). Five-point calibration variance (R2 > 0.9995) was obtained throughout a dynamic range of 1.0–25 ng mL^{-1}. The instrument's stability was verified through the execution of a minimum of three duplicates. A maximum relative standard deviation (RSD) of 5–8% was taken into consideration. The response for a particular metal was defined as three and ten times greater than background noise for the detection limit (DL) and for the quantification limit (QL) of the instrument. A standard reference material SRM 1643f (Heavy metals in Water) from the National Institute of Standards (NIST) was applied to check the elements recovery percentage in the sample and the result indicated 96–103.7% recovery for significant elements. Procedure blanks, SRM recoveries, and spike recoveries were carried out as part of the quality control process to minimize error. The recovery and blank sample analyses were used to adjust the heavy metal concentrations.

Table 1: GPS locations of the study area with site description

Station	Station name	GPS co-ordinates	Observed anthropogenic activities
S1	Sangu Bridge	22°11'23.29"N, 92°13'41.70"E	Hospital, Town settlement, Saw mill, Municipal waste dumping
S2	Kya Ching Ghata	22°10'55.69"N, 92°13'52.55"E	Agriculture, Homestead, Forest, Settlement
S3	Near Helipad	22°10'32.40"N, 92°13'49.11"E	Agriculture, Homestead,Settlement, Hill Forest
S4	Milonchari	22°10'02.48"N, 92°13'48.80"E	Agriculture, Homestead,Settlement, Hill Forest
S5	Boroitoli	22° 09'47.06"N, 92°14'13.19"E	Agriculture, Homestead settlement
M1	Matamuhuri Bridge	21°47'00.55"N, 92°11'26.86"E	Agricultural land, Homestead, Settlement, Sawmill, Bazar, Garbage dumping
M2	Bamu Bilchari	21°47'28.23"N, 92°11'29.91"E	Agricultural land, Homestead, Settlement
M3	Bilchari	21°47'34.18"N, 92°12'03.45"E	Agriculture, Settlement, Forest
M4	Choto Bamu	21°47'33.53"N, 92°12'36.10"E	Agriculture, Homestead, Settlement
M5	Merakhola	21°47'06.41"N, 92°12'39.51"E	Agriculture, Homestead, Settlement

Assessment of water quality index (WQI) by using physical and chemical properties

Water quality index (WQI) briefly indicates the several water quality parameters into a single term such as excellent, good, poor, extremely poor, and unsuitable for drinking, irrigation, aquatic lives or any other purposes for easy understanding to the concerned users (Hulya, 2009). Water quality index of Sangu and Matamuhuri river was calculated based on water quality standards for drinking, aquatic lives, irrigation and recreational purposes, using data obtained in pre-monsoon, monsoon and post-monsoon seasons by following the weighted arithmetic index method (equation i) (Tyagi *et al*. 2013).

Water quality index, $WQI = \Sigma (Wn \times Qn)/\Sigma Wn$ ………(i)
where, Wn (Unit weight for each water quality parameter) = K/Sn, K is the proportionality constant which was calculated using the equation (ii):

$$K = 1/\sum(1/Sn) \quad \text{......(ii)}$$

$$Qn = 100\,[Vn - Vio] / [Sn - Vio] \quad \text{..(iii)}$$

where, Qn = Quality rating for the nth water quality parameter,
Vn =Calculated value of the nth parameter of a given sampling location,
Vio = Ideal value of the nth parameter in clean water,
Sn = Standard permissible value of nth parameter

Following Chartterji and Raziuddin (2002) a relationship between water quality index (WQI) and status of water quality of a water body was proposed (Table 2).

Table 2: Water quality index as per arithmetic water quality index method (Chartterji and Raziuddin, 2002)

WQI Level	Water Quality Status	Grading
< 25	Excellent	A
26-50	Good	B
51-75	Poor	C
76-100	Extremely poor	D
>100	Unsuitable	E

Assessment of contamination factor (CF) and pollution load index (PLI) for heavy metals

To determine the degree of heavy metal contamination, an integrated pollution load index (PLI) of the twelve metals was calculated as per Hossain et al. (2021). The pollution load index (PLI) indicates the number of times by which the heavy metal pollution in water exceeds the baseline concentration and provides a collective warning of the overall heavy-metal toxicity in a particular sample. The PLI was calculated as the nth root of the metals contamination factor (CF) multiplications (equation iv).

$PLI = (Cf_1 \text{ X } Cf_2 \ldots\ldots\ldots..Cf_n)^{1/n}$ ………………… (iv)

Where, Cf_1 = contamination factor of the first metal, Cf_2 = contamination factor of the second metal, and Cfn= contamination factor of the nth metal. The ratio of each individual metal's concentration to its background values or natural abundance is referred to here (equation (v) as the metal contamination factor.

$CF_{metals} = C_{metals} / C_{background}$ ………………………. (v)

Therefore, the selection of heavy metal background value is crucial for assessment of heavy metal contamination. In this study, we chose the background value of each heavy metal as suggested by Banu (1995). PLI index values of water were categorized by following Jamil *et al.* (2014) (Table 3).

Table 3: PLI index with the corresponding pollution criteria (Jamil *et al.* 2014)

PLI	Degree of contamination
<2	Not contaminated
2 - 5	very low
5-10	Low
10-20	Medium
20-50	High
50-100	very high
> 100	Extreme

Assessment of health risk

Risk assessment is a combined effect of hazard and exposure (Adamu et al. 2015). The two main toxicity risk factors including reference dose (RfD) for non-carcinogen risk characterization (CRC) and slope factor (SF) for CRC were assessed in this study (Lim et al. 2008).

In this study, ingestion and dermal contact were assumed as the routes of exposure. For estimating the potential non-cancer health risk through drinking and dermal exposure of surface water, average daily ingestion of heavy metals through drinking ($ADI_{ingestion}$) and dermal exposure (ADI_{dermal}) was calculated using the following equation (USEPA, 2004):

$ADI_{ingestion} = (C \times DI \times EF \times AF \times ED) / (BW \times AT)$…(vi)

$ADI_{dermal} = (C \times EF \times ED \times ET \times SA \times Kp \times AF \times CF) / (BW \times AT)$…………………………………………. (vii)

where, ADI = average daily ingestion (mg $kg^{-1}day^{-1}$), C = mean concentration of heavy metal in water (mgL^{-1}), DI = Daily intake (Ld^{-1}), AF = Absorption factor, EF = exposure frequency (days $year^{-1}$), ED = exposure duration (years), BW = average body weight over the exposure period (kg), and AT = average time period of exposure (days), ET = exposure time (hour day^{-1}), SA = surface area of contact (cm^{-2}), K_P = dermal permeability coefficient (cm h^{-1}), CF = unit conversion factor (L cm^{-3}). Table 4 presents the input presumptions used for exposure assessment of heavy metals through ingestion and dermal adsorption of waters.

In this study, hazard quotients (HQ) and hazard index (HI) were calculated considering adult peoples as target group. The HQ of heavy metal through drinking and dermal adsorption of waters to the inhabitants of the area was determined using the equations (viii) and (ix), respectively:

$HQ_{ingestion} = ADI_{ingestion} / RfD_{ingestion}$………(viii)

$HQ_{dermal} = ADI_{dermal} / RfD_{dermal}$…………………(ix)

HI is the sum of all potential non-carcinogenic health risks resulting from heavy metals found in waters. In this study, the HI for the elements of Pb, Cd, Cr, Cu, Mn, Ni, Zn, and Fe through ingestion and dermal adsorption was calculated using the equations (x) and (xi), respectively (USEPA, 2018).

$HI_{ingestion} = \sum HQ_{ingestion}$………………………………(x)

$HI_{dermal} = \sum HQ_{dermal}$…………………………………(xi)

If HI > 1.0, there is a greater chance of non-carcinogenic health effects, and the chance increases with HI. When HI < 1.0, it is unlikely that the exposed populations will suffer hazardous health effects (Ahmed *et al.* 2019; Mohammodi *et al.* 2019).

Assessment of non-carcinogenic health risk

Table 4: Input presumptions used for exposure assessment of heavy metals through ingestion and dermal adsorption of waters

Parameters	Unit	Value		References
		Ingestion	Dermal adsorption	
Average daily intake (ADI)	L day^{-1}	2.2	-	Mohammadi *et al.* 2019
Average body weight (BW)	Kg	60	60	BBS, 2015
Skin surface area (SA)	cm^2	--	18000	USEPA, 2018
Average time (AT)	Day	2550	10950	USEPA, 2018; Wahab *et al*. 2020
Exposure time (ET)	hour/event	0.58		USEPA, 2004
Exposure frequency (EF)	Day $year^{-1}$	365	350	Wahab *et al.* 2020; USEPA, 2004
Exposure duration (ED)	Year	71.8	30	BBS, 2015 ; USEPA, 2004
Permeability coefficient (Kp)	cm $hour^{-1}$		Cd, Cr, Fe, Mn and Cu = 0.001; Pb = 0.0001 and Zn = 0.0006	USEPA, 2004
Conversion factor (CF)	L cm^{-3}		0.001	USEPA, 2004
Absorption factor (AF)	-	0.001	0.001	Wahab *et al*. 2020; USEPA, 2004

Assessment of carcinogenic health risk

The potential carcinogenic risk level posed by carcinogen chemical pollutants (CR) was computed by the equation (xii) (USEPA, 2010):

$$CR = ADI \times CSF \qquad \text{(xii)}$$

where, CR =Carcinogenic risk posed by heavy metals, CSF = Cancer slope factor (mg $kg^{-1}day^{-1}$). In this study, CR was calculated for Pb, Cr, Cd. When CR < 10^{-6}, indicating the negligible carcinogenic risk, CR > 10^{-4}, indicating significant risk of cancer in human beings, and when $10^{-6} < CR < 10^{-4}$, indicating an acceptable risk to human beings (Mohammadi *et al*. 2019; USEPA, 2018; Hadzi *et al*. 2015).

Results and Discussion

Physical characteristics of water in Sangu and Matamuhuri river

The seasonal variation of physical characteristics of water in the upstream of Sangu river including temperature, EC, turbidity, TDS and TSS during the period of October, 2022 - September, 2023 is shown in Figure 2(a-e). The mean water temperature in pre-monsoon, monsoon and post-monsoon season were recorded 26.62 (±1.18) ˚C, 24.33(±1.59) ˚C and 21.33(±0.31) ˚C, respectively (Figure 2a). The highest temperature (30.9 ℃) was found in the pre-monsoon season at Sangu Bridge (S1) and the lowest (19.7 ℃) was observed in post-monsoon season at Boroitoli (S5). The mean EC contents were recorded 310.1±14.49 µS/cm, 210.73±13.61 µS/cm and 186.44±5.63 µS/cm in pre-monsoon, monsoon and post-monsoon seasons, respectively. The highest EC was found 324.5 µs/cm in pre-monsoon season at Miloncharі (S4) and lowest was 177.42 µS/cm in post-monsoon season at near Helipad Point (Figure 2b). The mean values of turbidity ranged from 3.30 mg/L to 4.89 mg/L in pre-monsoon season, 3.63 mg/L to 4.26 mg/L in monsoon season and 4.43 mg/L to 4.67 mg/L in post-monsoon season, respectively. The highest turbidity was observed in pre monsoon season at Kya Ching Ghata Point (March, 2023) while the lowest in same season at Boroitoli (May 2023) (Figure 2c). The mean TDS contents were found 150.79±5.12 mg/L, 104.47±6.09 mg/L and 101.47±3.77 mg/L in pre-monsoon, monsoon and post-monsoon season, respectively (Figure 2d). The highest TDS was observed in pre monsoon season at Kya Ching Ghata Point (S2) (Feb, 2023) while the lowest in monsoon season at Sangu Bridge Point (August 2023) (Figure 2d). The mean TSS concentrations were found 18.65±1.18 mg/L, 63.65±17.17mg/L and 66.45±17.33 mg/L in pre-monsoon, monsoon and post-monsoon seasons, respectively. The highest TSS was observed in post monsoon season at Sangu Bridge Point (S1) (October, 2022) while the lowest in monsoon season at Miloncharі Point (S4) (February, 2023) (Figure 2e).

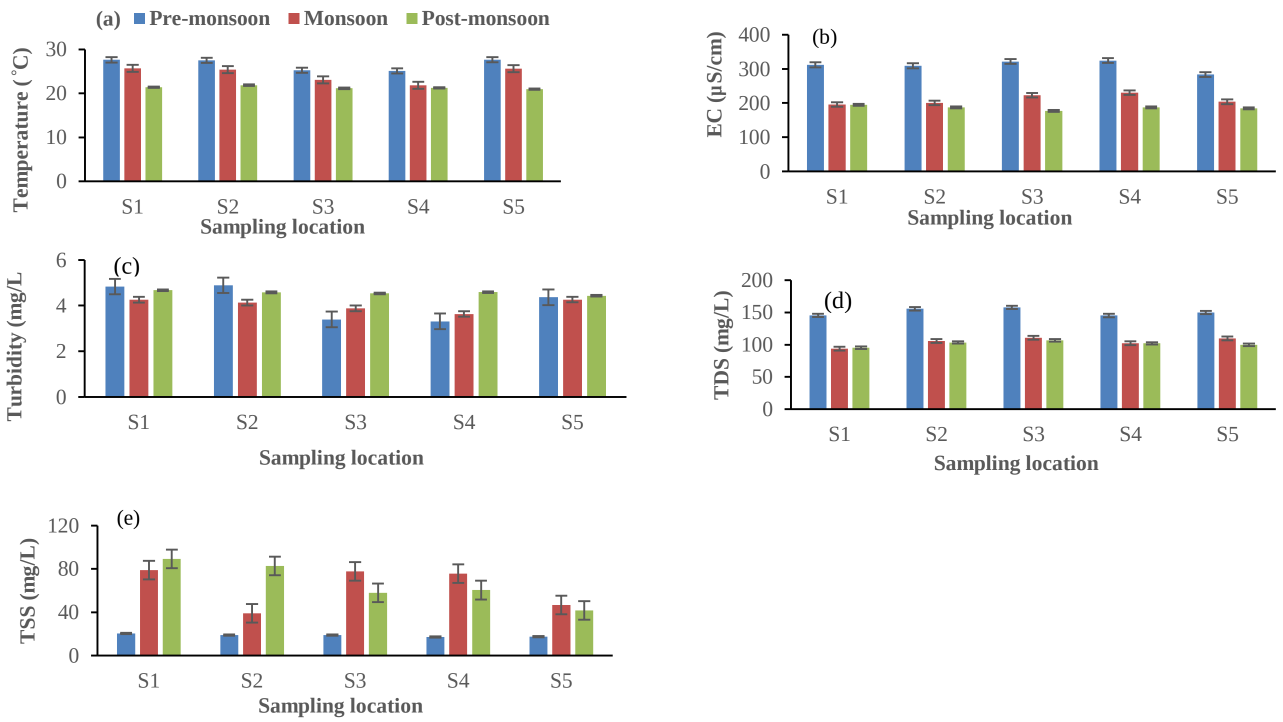

Figure 2. Seasonal variation of physical characteristics of water in the upstream of Sangu river: (a) temperature, (b) EC, (c) turbidity, (d) TDS and (e) TSS; vertical bars indicate SD.

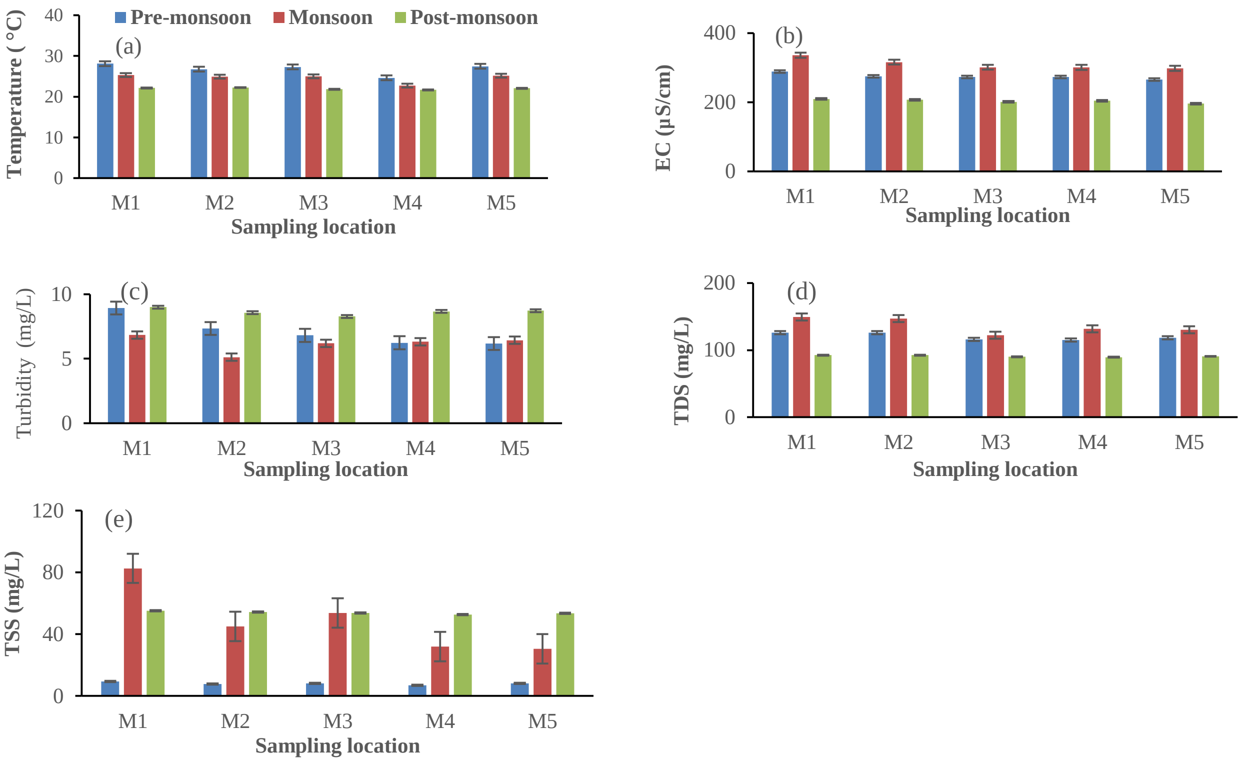

Figure 3. Seasonal variation of physical characteristics of water in the upstream of Matamuhuri river: (a) temperature, (b) EC, (c) turbidity, (d) TDS, (e) TSS; vertical bars indicate SD.

The seasonal variation of physical characteristics of water in the upstream of Matamuhuri rivers including temperature, EC, turbidity, TDS and TSS during the period of October 2022 - September 2023 is shown in Figure 3(a-e). The mean water temperature in pre-monsoon, monsoon and post-monsoon season was recorded 26.85(±1.19) ℃, 24.62 (±0.95) ℃ and 21.98 (±0.21) ℃, respectively (Figure 3a). The highest temperature (31℃) was found in the pre-monsoon season at Matamuhuri Bridge (M1) and the lowest (20℃) was observed in post-monsoon season at Choto Bamu (M4). The mean EC contents were recorded 275.09±7.53 µS/cm, 310.36±14.18 µS/cm and 203.55±4.7 µS/cm in pre-monsoon, monsoon and post-monsoon seasons, respectively (Figure 3b). The highest EC was found 335.9 µs/cm in monsoon season at Matamuhuri Bridge Point and the lowest was observed 195.9 µS/cm in the post-monsoon season at Merakhola Point. The mean values of turbidity of Matamuhuri river ranged from 6.18 mg/L to 8.94 mg/L in pre-monsoon season, 5.12 mg/L to 6.84 mg/L in monsoon season and 8.28 mg/L to 9.0 mg/L in post-monsoon season. The highest turbidity was observed 18.86 mg/L in post monsoon season at Matamuhuri Bridge Point (October, 2023) while the lowest 33.05 mg/L in same season at Choto Bamu (May, 2023) (Figure 3c). The mean TDS contents were found 120.32±4.73 mg/L, 136.09±10.46 mg/L and 91.07±1.26 mg/L in pre-monsoon, monsoon and post-monsoon season, respectively. The highest TDS (280 mg/L) was observed in monsoon season at Matamuhuri Bridge Point (July, 2023) while the lowest 54.30 mg/L in same season at same point (September, 2023) (Figure 2d). The mean TSS concentrations in Matamuhuri river were found 8.10±0.81 mg/L, 48.77±18.96 mg/L and 53.89±0.80 mg/L in pre-monsoon, monsoon and post-monsoon seasons, respectively (Figure 3e). The highest TSS (251 mg/L) was observed in monsoon season at Matamuhuri Bridge Point (July, 2023) while the lowest (4.00 mg/L) in pre-season at same point (March, 2023) (Figure 3e).

The water quality parameters are compared with water quality standards (DoE, 2023) for inland surface water used for fisheries, recreational activity, irrigation and drinking purposes as per ECR (2023) (Table 5). The standard requirements for temperature are 20-30℃ for fish culture and 20-30℃ for drinking water (ECR, 2023). The observed values of temperature were found within the acceptable limit standard suggested by DoE (2023) (Table 5). In a study carried out by Begum *et al.* (2020), water temperature was recorded from 25.47℃ to 30.8℃ in the Sangu river estuary. Das (2005) found the range of water temperature at Bakkhali (near to Matamuhuri river) from 23℃ to 30℃. Hasan (2013) recorded the water temperature range at Karnafully river estuary from 25℃ to 31℃. Thus, the water temperature in the Sangu and Matamuhuri river coincided with these findings.

Table 5: Standards for inland surface water usable for different purposes and observed physical and chemical characteristics of Sangu and Matamuhuri rivers (ECR, 2023)

Parameters	Unit	Standards for Inland surface water				Observed mean value	
		Water usable for fisheries	Water usable for irrigation purpose	Water usable for recreational activity	Drinking water	Sangu river	Matamuhuri
Temperature	° C	20-30	-	-	20-30	25.3	25.5
pH		9.00	6.5-8.5	6.5-8.5	6.5-8.5	7.99	8.0675
EC	μS/cm	800-1000	2250	-	250	312	288.5625
Chloride	mg/L	-	-	-	150-600	64.435	76.05
Turbidity	NTU	-	-	-	5	4.835	8.94
DO	mg/L	5 or more	-	5 or more	6 or more	3.81	6.245
TDS	mg/L	1000	1000	-	1000	145.475	125.97
TSS	mg/L	-	-	-	10	20.5	9.5
BOD	mg/L	6 or less	12 or less	3 or less	2 or less	3.0375	3.6
COD	mg/L	-		100	10	11.5875	12.0625

For inland surface water the EC contents were found from 800 to 1000 μS/cm, which is good for aquatic environment, 250 μS/cm for drinking water, and 2250 μS/cm for irrigation purposes (ECR, 2023). From the results it was found that the EC in water of Sangu and Matamuhuri river was comparatively lower than the standard in post-monsoon season which might be due to the lack of carbonate minerals dissolution, and release of wastewater, runoff from agricultural field and urban area. In case of Sangu river, the EC was higher in pre-monsoon season than the monsoon and post-monsoon seasons whereas in case of Matamuhuri river, the EC was higher in pre-monsoon and monsoon seasons than the post-monsoon season. However, in both the rivers water was found not suitable for drinking as there is organic pollution and too much suspended clay material. But it is also found that EC value is suitable for aquatic organisms and also for irrigation purposes in both the rivers as per standard suggested by DoE (2023). As per the Environmental Conservation Rules (2023), the acceptable limit for turbidity is 5 mg/L for drinking. It was found that in case of Sangu river turbidity level was found suitable for drinking purposes but in case of Matamuhuri river turbidity level was >5 mg/L in all seasons, and hence, not suitable for drinking purpose (Table 5). The mean turbidity of Karnafully River was found 31 mg/L, ranging from 14 to 50.1 mg/L (Sarwar et al. 2010). High turbidity levels can harm aquatic life and stream health (Ahmed and Alam, 2021).

The standard level of TDS in surface water for drinking, aquatic lives and irrigation purposes are 1000.00 mg/L (Table 5) (ECR, 2023) and the results depict that TDS of Sangu river ranged from 145.225 mg/L to 157.725 mg/L in pre-monsoon season whereas in monsoon and post-monsoon seasons ranged from 93.77 mg/L to 110.625 mg/L and 95.35 mg/L to 106.67 mg/L, respectively. In case of Matamuhuri river TDS ranged from 115.23 mg/L to 125.97 mg/L in pre-monsoon season whereas in monsoon and post-monsoon seasons TDS ranged from 122.16 mg/L to 149.34 mg/L and from 90.03 mg/L to 92.56 mg/L, respectively. It is found that TDS value was suitable for fish production and irrigation purposes. According to ECR (2023) Bangladesh Standard for TSS in terms of drinking water is 10 mg/L. TSS values in this study were found high in the monsoon and post-monsoon seasons but low in the pre-monsoon in both Sangu and Matamuhuri rivers. High concentrations of suspended solids can harm stream health and aquatic life (Ahmed and Alam, 2021).

Chemical characteristics of water in Sangu and Matamuhuri river

The seasonal variation of chemical characteristics of water in the upstream of Sangu rivers such as pH, DO, BOD, COD and chloride, during the period of October, 2022 – September, 2023 is shown in Figure 5. The average pH in the water of Sangu river was found 7.90±0.135, 7.80±0.093 and 6.24±0.11 in pre-monsoon, monsoon and post-monsoon, respectively. The highest pH value was observed in pre-monsoon season at Kya Ching Ghata Point while the lowest in post-monsoon (Figure 4a). The mean DO level in pre-monsoon, monsoon and post-monsoon season were 4.10±0.36, 5.33±0.239 and 5.01±1.36 mg/L, respectively (Figure 4b). The highest DO was observed in pre-monsoon season at Kya Ching Ghata Point while the lowest in monsoon season at Sangu Bridge Point (Figure 4b). The mean BOD level was found 2.89±0.12 mg/L, 1.98±0.11 mg/L, and 2.35±0.074 mg/L in pre-monsoon, monsoon and post-monsoon, respectively. The highest BOD was observed in pre-monsoon season at Sangu Bridge Point while the lowest in monsoon season at Boroitali point (Figure 4c). The mean COD levels were 17.67±0.74 mg/L, 12.06±0.65 mg/L and 13.41±0.37 mg/L in pre-monsoon, monsoon and post-monsoon season, respectively (Figure 4d). The highest COD was observed in monsoon season at Boroitali Point while the lowest in post-monsoon season at Milonchari Point (Figure 4d). The mean chloride contents in pre-monsoon, monsoon and post-monsoon were 66.46±2.88 mg/L, 62.05±3.16 mg/L and 52.69±3.18 mg/L, respectively (Figure 4e). The highest chloride content was observed in pre-monsoon at near Helipad Point while the lowest in post-monsoon season at Sangu Bridge Point (Figure 4e).

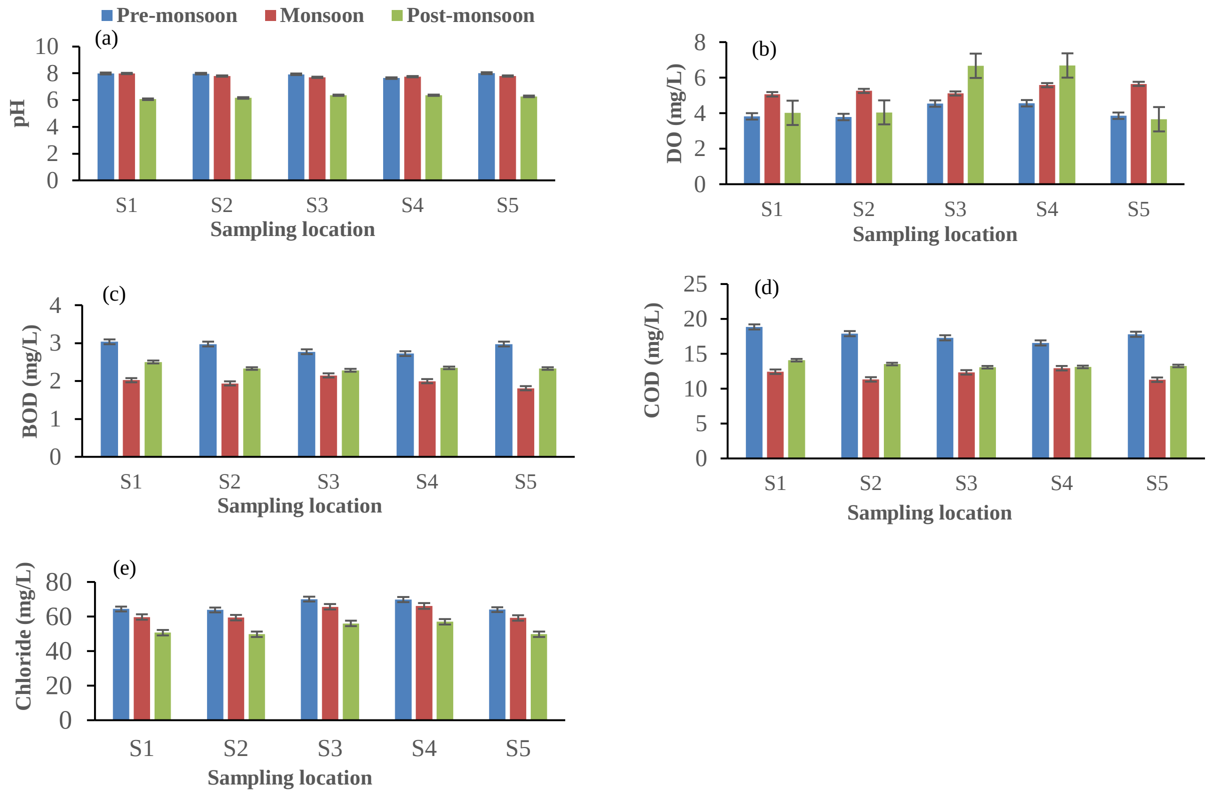

Figure 4. Seasonal variation of chemical characteristics of water in the upstream of Sangu river: (a) pH, (b) DO, (c) BOD, (d) COD and (e) Chloride; vertical bars indicate standard deviation.

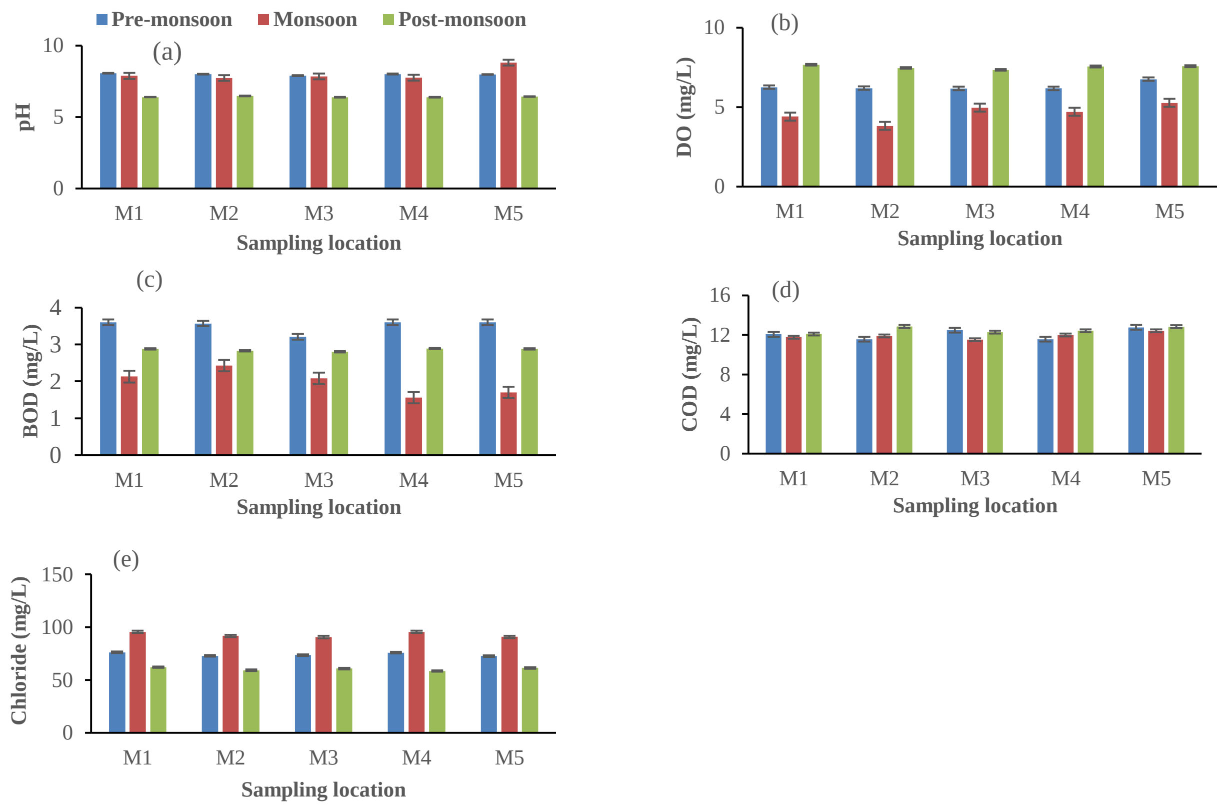

Figure 5. Seasonal variation of Chemical characteristics of water in the upstream of Matamuhuri river; (a) pH, (b) DO, (c) BOD, (d) COD and (e) Chloride; Vertical bars indicate standard deviation.

The seasonal variation of chemical characteristics of water in the upstream of Matamuhuri rivers such as pH, DO, BOD, COD and chloride, during the period of October, 2022 – September, 2023 is shown in Figure 5. The mean water pH was found 7.99±0.05, 8.00±0.40 and 6.42±0.035 in pre-monsoon, monsoon and post-monsoon, respectively. The highest water pH was observed in pre-monsoon season at Matamuhuri Bridge Point (April, 2023) while the lowest in pre-monsoon season at same point (March 2023) (Figure 5a). The mean DO level in pre-monsoon, monsoon and post-monsoon season were 6.31±0.22, 4.60±0.49 and 7.51±0.10 mg/L, respectively (Figure 5b). The highest DO was observed in post-monsoon season at Merakhola while the lowest (4.00 mg/L) in monsoon season at Bilchari Point (Figure 5b). The mean BOD level was found 3.51±0.15 mg/L, 1.98±0.31 mg/L, and 2.85±0.034 mg/L in pre-monsoon, monsoon and post-monsoon, respectively. The highest BOD was observed in pre-monsoon season at Choto Bamu Point while the lowest in monsoon season at Matamuhuri Bridge Point (Figure 5c).

The mean COD levels were 12.08±0.48 mg/L, 11.91±0.29 mg/L and 12.49±0.29 mg/L in pre-monsoon, monsoon and post-monsoon, respectively (Figure 5d). The highest COD was observed in monsoon season at Merakhola point while the lowest in pre-monsoon season at Bamu Bilchari Point (Figure 5d). The mean chloride contents were 74.16±1.51 mg/L, 92.84±2.24 mg/L and 60.37±1.37 mg/L in pre-monsoon, monsoon and post-monsoon, respectively (Figure 5e). The highest chloride content was observed in monsoon season at Matamuhuri Bridge Point while the lowest in monsoon season at Bilchari Point (Figure 5e).

The pH values of all sampling locations were found to be within the standard limit of 6.5 to 8.5 (ECR, 2023). DO level varied from 3.77 mg/L to 6.67 mg/L in case of Sangu and 4.62 to 7.5 mg/L in case of Matamuhuri river (Table 5). Islam (2012) recorded the Sangu river estuary's DO content as 4.67 mg/L to 8.5 mg/L. The standard limit of DO as suggested by ECR (2023) is 5 mg/L or more for fish culture and for recreational purposes, 6 mg/L or more for drinking. It was found that DO level was suitable for fish production and recreational purposes. According to WHO (2006), the acceptable threshold of chloride in drinking water is 250 mg/L and according to ECR (2023) of Bangladesh standard, the acceptable limit is 150 mg/L to 600 mg/L (Table 5). It was found that chloride content was below the acceptable threshold of DoE standard (2023) for drinking water, hence not suitable for drinking purposes. According to Environmental Conservation Rules (2023), the standards of BOD are 6 of less mg/L for fish culture, 2.0 or less mg/L for drinking water, 12 or less for irrigation purposes and 3 mg/L or less for recreational activity. It was found that, BOD level was not suitable for drinking purposes but suitable for fish cultivation, irrigation and recreational purposes. The higher BOD of the river is the result of pollution from various sources. The high value of BOD also suggests that there are too many microorganisms in the water, which consumes the oxygen to degrade organic waste materials in the river (Mustari and Afsana, 2021). During the study period, COD values were found higher in the pre-monsoon and post monsoon season compared to the monsoon season in both the rivers. COD value was found above from its acceptance limit of 10 mg/L according to ECR (2023). So, the river water is not suitable for drinking, but suitable for aquatic lives and agricultural activities.

Water quality index

In order to calculate the water quality index (WQI) of the Sangu and Matamuhuri River, the physical and chemical parameters including pH, EC, Turbidity, DO, TDS, TSS, BOD, COD and chloride were selected. Figure 6 shows the seasonal (Pre-monsoon, Monsoon, Post-monsoon) variation of WQI of Sangu and Matamuhuri river during October, 2022 - September 2023.

The calculated values of WQI at studied site of Sangu river were found >100 during three seasons, and hence indicate unsuitable for drinking. In case of Sangu river, the highest WQI was observed at Sangu Bridge Point (S1) during post-monsoon whereas the lowest at Milonchari Point (S4) in pre-monsoon season. In case of Matamuhuri river, the highest WQI was observed during pre-monsoon season at Matamuhuri Bridge Point (M1) whereas the lowest in monsoon season at Choto Bamu Point (M4). The sequence of seasonal water quality index (WQI) during the study period was Pre-monsoon> Monsoon > Post-monsoon in case of Sangu river and in case of Matamuhuri river WQI showed the patterns as monsoon > post-monsoon > pre-monsoon. From the analysis it was observed that the water of both rivers was not suitable for drinking in pre-monsoon, monsoon and post-monsoon seasons .

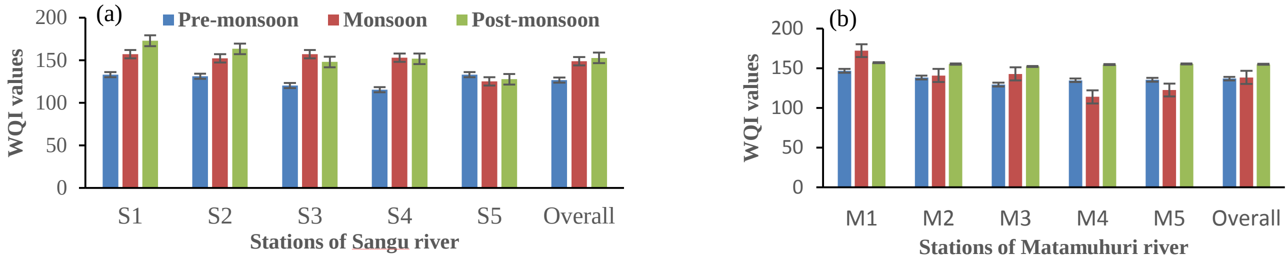

Figure 6. Seasonal variation of WQI of Sangu (a) and Matamuhuri (b) rivers during the study period; vertical bars indicate SD.

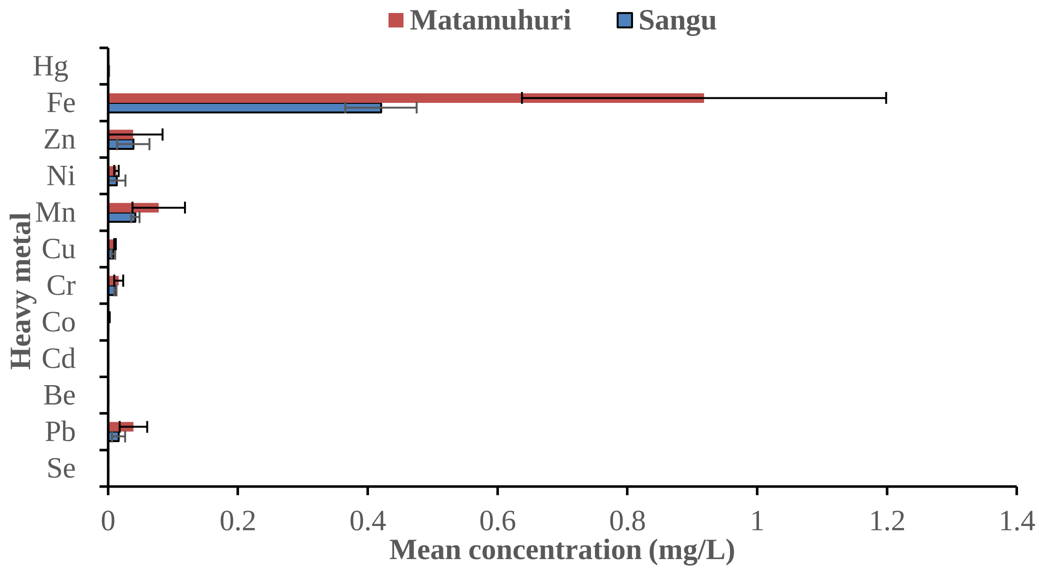

Figure 7. Mean concentration of heavy metals in water of Sangu and Matamuhuri Rivers in September 2023; vertical bars indicate standard deviation.

Concentration of heavy metals in water sample

The concentration of heavy metals along with the recommended standards of DoE (2023), USEPA (2018), WHO (2017) and FAO (1984) have been summarized in Figure 7 and Table 6. In case of Sangu river, the average concentration of Fe, Zi, Mn were 0.42 mg/L, 0.039 mg/L and 0.042 mg/L, average concentration of Pb, Cr, Ni, Cu were 0.016 mg/L, 0.011 mg/L, 0.013 mg/L, 0.008 mg/L and Hg, Se, Co, Cd, and Be were 0.00097 mg/l, 0.00018 mg/L, 0.00043 mg/L, 0.000084 mg/L, 0.000035 mg/L, respectively (Table 6). In case of Matamuhuri rivers, the average concentration of Fe, Zi, Mn were 0.92 mg/L, 0.039 mg/L, 0.078 mg/L, respectively. The average concentration of Pb, Cr, Ni, Cu were 0.039 mg/L, 0.016 mg/L, 0.013 mg/L, 0.01 mg/L, and Hg, Se, Co, Cd, and Be were 0.0005 mg/L, 0.0002 mg/L, 0.000136 mg/L, 0.00013 mg/L, 0.00011 mg/L, respectively (Table 6).

Table 6: Comparison of mean concentration of heavy metals in water of Sangu-Matamuhuri rivers with different standards of surface water

Study site / Standard	Mean concentration (mg/L) of heavy metals											
	Pb	Cr	Cu	Mn	Ni	Zn	Fe	Se	Be	Cd	Co	Hg
Sangu river (In this study)	0.0160	0.0110	0.0080	0.0420	0.0130	0.0390	0.4200	0.0002	0.0000	0.0001	0.0004	0.0010
Matamuhuri river (In this study)	0.0390	0.0160	0.0107	0.0779	0.0128	0.0386	0.9182	0.0002	0.0001	0.0001	0.0001	0.0005
DoE (2023) - Drinking water standard	0.0100	0.0500	1.5000	0.4000	0.0500	5.0000	0.3 1	0.0100	0.0050	0.0030	0.0500	0.0010
USEPA (2018) - Drinking water standard	0.0150	0.1000	1.3000	1.6000	-	5.0000	0.3000	-	-	0.0050	-	-
WHO (2017) - Drinking water standard	0.0100	0.0500	2.0000	0.4000	-	-	-	-	-	0.0030	-	-
DoE (2008) - Irrigation water standard	0.1000	1.0000	3.0000	5.0000	-	10.0000	2.0000	-		0.5000	-	-
FAO (1984) - Irrigation water standard	5.0000	0.1000	0.2000	0.2000		2.0000	5.0000			0.0100	-	-

Except Fe and Pb, the amount of all other heavy metals in Sangu and Matamuhuri river water were found much lower than the limit for drinking endorsed by DoE (2023), USEPA (2018), and WHO (2017) (Table 6). The sources of the higher amount of Fe and Pb in both rivers are likely natural (rocks and minerals deteriorating due to weathering, wind, and waves) or man-made (stone queries, urban and agricultural activities). Excess iron accumulation in water if subjected to human consumption may pose a risk to human health (Stevens, 1990). The order of mean concentration of heavy metals in the water of Sangu river was found to be Fe> Mn > Zn> Pb > Cr > Ni>Cu>Hg> Co> Se> Cd>Be in September, 2023 whereas for the Matamuhuri river, it was found to be Fe> Mn> Pb>Zn> Cr> Ni> Cu> Hg> Co> Se> Cd>Be during September, 2023 (Table 6). The reason behind the presence of heavy metals at relatively high level in Sangu and Matamuhuri river may be the weathering of rocks through natural process or stone queries, urban and agricultural activities including disposal of wastes, excessive use of fertilizers and metal based pesticides.

Heavy metal pollution

Contamination factor and Pollution load index

Metal pollution index (MPI) was calculated using equations (iv) and (v) and depicted in Table 7. In case of Sangu river, the values of contamination factor (CF) for all metals except Pb were detected <1 which is a sign of low level of contamination. Pb was detected as >1 at S1, S2 and S4 points which showed moderate contamination. MPI for all sampling locations were ranged from 0.037 to 0.058 and the mean PLI was 0.055. In all sites, PLI were <1 (Table 7) which indicates that the Sangu River is not polluted. In case of Matamuhuri river, the values of contamination factor for all metals except Pb were detected <1 which is a sign of low level of contamination. Pb was detected as >1 at M1 and M5 points which showed moderate contamination. The mean PLI was 0.084. In all sites, PLI were <1 (Table 7) which suggests that the Matamuhuri river is not polluted by the studied heavy metals. MPI for water samples of Matamuhuri river was higher than that of Sangu river.

Health risk

The USEPA (2004) protocol was followed for assessment of the non-carcinogenic and carcinogenic health risks through ingestion and dermal exposure of water in this study. Table 8 presents the estimated average daily metal ingestion (ADI) resulting from oral and dermal exposure of waters of Sangu and Matamuhuri rivers in Bangladesh along with the upper tolerable intake level (UTIL), oral and dermal reference doses (RfD), and cancer slope factor (CSF).

Table 7: Contamination factors (CF) and Pollution load index (PLI) of heavy metals in Sangu and Matamuhuri river

Study rivers	CF values of heavy metals						PLI	Degree of pollution
Sangu river	Pb	Cd	Co	Cr	Cu	Mn	0.055	Not impacted
	1.613	0.028	0.009	0.227	0.005	0.105		
	Ni	Zn	Fe	Hg	Se	Be		
	0.264	0.008	0.421	0.975	0.018	0.001		
Matamuhuri river	Pb	Cd	Co	Cr	Cu	Mn	0.084	Not impacted
	3.902	0.044	0.027	0.326	0.007	0.195		
	Ni	Zn	Fe	Hg	Se	Be		
	0.256	0.008	0.918	0.515	0.020	0.003		

Table 8: Estimated average daily metal ingestion (ADI) due to oral and dermal exposure of waters of Sangu and Matamuhuri river, Bandarban, Bangladesh in September, 2023

Parameters	Pb	Cd	Cr	Cu	Mn	Ni	Zn	Fe
$ADI_{ingestion}$ (mg kg^{-1} day^{-1}) for Sangu	6.07×10^{-7}	3.16×10^{-9}	4.26×10^{-7}	3.05×10^{-10}	1.58×10^{-6}	4.97×10^{-7}	1.46×10^{-6}	1.58×10^{-5}
$ADI_{ingestion}$ (mg kg^{-1} day^{-1}) for Matamuhuri	1.47×10^{-6}	5.00×10^{-9}	6.13×10^{-7}	4.01×10^{-7}	2.93×10^{-6}	4.81×10^{-7}	1.45×10^{-6}	3.45×10^{-5}
ADI_{dermal} (mg kg^{-1}day^{-1}) for Sangu	1.12×10^{-10}	5.85×10^{-12}	7.9×10^{-10}	5.65×10^{-10}	2.03×10^{-9}	1.84×10^{-10}	1.63×10^{-9}	2.93×10^{-8}
ADI_{dermal} (mg kg^{-1}day^{-1}) for Matamuhuri	2.72×10^{-10}	9.27×10^{-12}	1.14×10^{-9}	7.44×10^{-10}	5.43×10^{-9}	1.78×10^{-10}	1.62×10^{-9}	6.40×10^{-8}
UTIL (mg day^{-1}person^{-1})	0.24[g]	0.064[g]	Ne[h]	10[h]	11[h]		40[h]	45[h]
$RfD_{ingestion}$ (mg kg^{-1}day^{-1})	0.0035[d]	0.001[f]	0.003[e]	0.04[f]	0.014[f]	0.02	0.3[f]	0.7[f]
RfD_{dermal}(mg kg^{-1}day^{-1})	0.00042[c]	0.000025[b]	0.000015[c]	0.012[c]	0.0008[c]	0.0054	0.06[c]	0.3[b]
CSF(mg kg^{-1}day^{-1})	0.0085[a]	15[a]	0.42[a]			0.84		

a = OEHHA, 2019; b = Khalili *et al.* (2019); c = Tripathee *et al.* (2016); d = Khan *et al.* (2008); e = IRIS (1987); f = USEPA (2010); g = Garcia-Rico *et al.* (2007); h = FDA, (2001)

Non-carcinogenic risk

Considering adult population as target group and on the basis of HQ and HI, the potential non-carcinogenic health risk through ingestion and dermal exposure of waters were calculated. In case of Sangu river, the calculated $ADI_{ingestion}$ values obtained from this study were 6.07×10^{-7}, 3.16×10^{-9}, 4.26×10^{-7}, 3.05×10^{-7}, 1.58×10^{-6}, 4.97×10^{-7}, 1.46×10^{-6} & 1.58×10^{-5} mg kg^{-1}day^{-1} for Pb, Cd, Cr, Cu, Mn, Ni, Zn, and Fe respectively (Table 8). While in case of Matamuhuri river, the calculated $ADI_{ingestion}$ values were 1.47×10^{-6}, 5.0×10^{-9}, 6.13×10^{-7}, 4.01×10^{-7}, 2.93×10^{-6}, 4.81×10^{-7}, 1.45×10^{-6}, and 3.45×10^{-5} mg kg^{-1}day^{-1} for Pb, Cd, Cr, Cu, Mn, Ni, Zn and Fe, respectively (Table 8). Hence, the order of heavy metals in respect of the calculated mean $ADI_{ingestion}$ values for an adult human was Cd > Cu > Cr > Ni

> Pb> Zn > Mn>Fe for Sangu and for Matamuhuri ADI $_{ingestion}$ was Cd > Cu > Ni > Cr > Zn> Pb > Mn>Fe (Table 8).

In case of Sangu river, the mean calculated $HQ_{ingestion}$ values for Pb, Cd, Cr, Cu, Mn, Ni, Zn and Fe were 1.73×10^{-4}, 3.16×10^{-6}, 1.42×10^{-4}, 7.63×10^{-6},1.13×10^{-4}, 2.48×10^{-5}, 4.88×10^{-6} and 2.26×10^{-5} mg $kg^{-1}day^{-1}$, respectively (Table 9). The calculated $HQ_{ingestion}$ values for all metals were <1.0, indicating that those metals were within a permissible limit of non-carcinogenic harmful health risk in all locations of Sangu river. In case of Matamuhuri river, the mean calculated $HQ_{ingestion}$ values for Pb, Cd, Cr, Cu, Mn, Ni, Zn, and Fe were 4.2×10^{-4}, 5.0×10^{-6}, 1.0×10^{-5}, 2.0×10^{-4}, 2.4×10^{-5}, 4.85×10^{-6}, 4.93×10^{-5} and 9.26×10^{-4} mg $kg^{-1}day^{-1}$, respectively (Table 9). The calculated $HQ_{ingestion}$ values for all metals were <1.0, indicating that those metals were within a permissible limit of non-carcinogenic risk to human health in all locations of Matamuhuri river. In order to determine the total potential non-carcinogenic risks on human health caused by all studied heavy metals found in Sangu and Matamuhuri river, the $HI_{ingestion}$ value was calculated. The calculated mean values of $HI_{ingestion}$ for Sangu and Matamuhuri river were found 4.9 $\times10^{-4}$ and 9.26×10^{-4}, respectively and < 1, suggesting that there are no possible non-carcinogenic health risks to the inhabitants of those locations of the study area.

Table 10 presents the calculated hazard quotients (HQ dermal) and hazard index (HI dermal) values as a result of dermal exposure of heavy metals in water samples collected from Sangu and Matamuhuri rivers. According to the mean HQ_{dermal} values it can be simplified that the contribution of heavy metals to the non- carcinogenic risk to human health was in the order of Zn > Ni > Cu > Fe > Cd > Pb > Mn. Like the estimated HQ $_{ingestion}$ values, the calculated HQ dermal values for all metals were <1.0 indicating that all of these metals were within an acceptable limit of non-carcinogenic risk to human health in all locations of Sangu and Matamuhuri rivers. The calculated mean value of HI $_{dermal}$ was found 5.70 $\times10^{-5}$ for Sangu and 8.39×10^{-4} for Matamuhuri river. The observed HI dermal values for all water samples were <1.0, suggesting that there is no possible non-carcinogenic health risks to the inhabitants of the study area.

Table 9: Calculated hazard quotients ($HQ_{ingestion}$) and hazard index ($HI_{ingestion}$) values due to oral exposure of heavy metals in water samples collected from the study area of Sangu and Matamuhuri rivers of Bangladesh in September, 2023

Study site	**Hazard quotients (HQ $_{ingestion}$) values**							**HI $_{ingestion}$ values**
	Pb	Cd	Cr	Cu	Mn	Ni	Zn	Fe
Sangu	1.73×10^{-4}	3.16×10^{-6}	1.42×10^{-4}	7.63×10^{-6}	1.13×10^{-4}	2.48×10^{-5}	4.88×10^{-6}	2.26×10^{-5}	4.91×10^{-4}
Matamuhuri	4.19×10^{-4}	5×10^{-6}	2.04×10^{-4}	1.0×10^{-5}	2.09×10^{-4}	2.41×10^{-5}	4.85×10^{-6}	4.93×10^{-5}	9.26×10^{-4}

Table 10: Calculated hazard quotients (HQ dermal) and hazard index (HI dermal) values due to dermal exposure of heavy metals in water samples collected from Sangu and Matamuhuri rivers of Bangladesh in September, 2023

Study site	**Hazard quotients (HQ $_{dermal}$) values**								**HI $_{dermal}$ values**
	Pb	Cd	Cr	Cu	Mn	Ni	Zn	Fe	
Sangu	2.68×10^{-7}	2.34×10^{-7}	5.27×10^{-5}	4.70×10^{-8}	3.66×10^{-6}	3.41×10^{-8}	2.71×10^{-8}	9.77×10^{-8}	5.70×10^{-5}
Matamuhuri	1.73×10^{-4}	1.73×10^{-5}	1.73×10^{-6}	1.73×10^{-7}	6.79×10^{-6}	3.3×10^{-8}	2.7×10^{-8}	2.13×10^{-7}	8.39×10^{-5}

Table 11: Estimated cancer risk (CR) values caused by oral and dermal exposure of toxic heavy metals in water samples collected from Sangu and Matamuhuri rivers of Bangladesh in September, 2023

Water source	**CR values**						**∑CR values**
	Pb		Cd		Cr		
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	
Sangu	5.15×10^{-9}	1.32×10^{-8}	4.74×10^{-8}	3.9×10^{-13}	1.79×10^{-7}	1.88×10^{-9}	2.47×10^{-7}
Matamuhuri	1.25×10^{-8}	3.2×10^{-8}	7.50×10^{-8}	6.18×10^{-13}	2.58×10^{-7}	2.71×10^{-9}	3.8×10^{-7}

Carcinogenic risk

Exposure to Pb, Cd, and Cr in water could increase a person's risk of developing cancer (Zakir *et al.* 2020). Moreover, out of 12 metals studied, only three heavy metals have CSF values as mentioned by OEHHA (2019). The estimated cancer risks resulting from these toxic metals through ingestion and dermal exposure to the inhabitants of the study area are presented in Table 11. The results revealed that in case of Sangu river, the estimated mean CR values for Pb, Cd and Cr were 5.15×10^{-9}, 4.74 $\times10^{-8}$, and 1.79×10^{-7} for ingestion and 1.32×10^{-8}, 3.9 $\times10^{-13}$, and 1.88×10^{-9} for dermal exposure, respectively. In case of Matamuhuri river, the estimated mean CR values for Pb, Cd, and Cr were 1.25×10^{-8}, 7.5 $\times10^{-8}$, and 2.58×10^{-7} for ingestion and 3.2×10^{-8}, 6.18 $\times10^{-13}$, and 2.71×10^{-9} for dermal exposure, respectively (Table 11).

In case of both Sangu and Matamuhuri rivers, the calculated mean CR values for Pb, Cd and Cr were found < 1 for ingestion and dermal exposure. As per the USEPA (2018), cancer risks with a value < 1 is considered insignificant. Therefore, it may be concluded that there is very little chance of developing cancer from Pb, Cd, and Cr in water as a result of both oral and dermal exposures from all locations of the study area.

Conclusion

Sangu and Matamuhuri rivers are the lifeline of Bandarban's population as well as perennial source of beauty for its waters, streams and beautiful hills of both sides. From the evaluated physical and chemical characteristics of water, it can be concluded that the Sangu and Matamuhuri river were not in good condition. DO value was found less than standard in Sangu river. The EC contents of Sangu and Matamuhuri river were found lower than the standard in all the seasons. Low TDS level was found in both rivers. The variation of turbidity level was found in both the rivers. Low concentration of TSS level was found in water. The chloride content also found less than the standard. Investigation of concentration of heavy metals showed that the Fc and Pb concentrations in water of both the rivers were found somewhat higher than acceptable limit. So, based on these heavy metal concentrations, the water of both Sangu and Matamuhuri river were found not threatened for environmental pollution. Measured water quality index displayed higher rating (WQE>100) indicates unsuitable for drinking purposes in pre-monsoon, monsoon and post-monsoon seasons. Assessment of heavy metal pollution through contaminating factor and PLI revealed low contamination and MPI values were observed 0.055 for Sangu and 0.084 for Matamuhuri river which indicates that both rivers are not polluted yet. Non-carcinogenic and carcinogenic health risks assessment through ingestion and dermal exposure of water were performed with HQ, HI and CR indexes. Results indicated that metal contamination in surface water of Sangu and Matamuhuri river carries no risk for local people presently. However, it is notable that huge agricultural activities beside the river, frequent flash flood and land slide in pre-monsoon and monsoon seasons, heavy soil erosion during heavy rain all resulting from land use land cover change activities, induced water quality deterioration in Sangu and Matamuhuri river. Further studies are required to identify the effect of various types of points and non-point sources of pollution in Sangu and Matamuhuri rivers.

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