**Research Article****Integrated assessment of physicochemical, microbial, and heavy metal pollution in the shitalakshya river, bangladesh: implications for water quality, ecological and health risks**Md. Masud Rana, Mohammad Abid Hossain, Md. Shahariar Mahmud¹, Abdus Samad^{1*}Rumana Tasmin^{*}, Abul Kalam Azad², and Md Sojib Hasan Noman*Department of Zoology, Jagannath University, Dhaka 1100, Bangladesh***ARTICLE INFO****Article History**

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Keywords: Shitalakshya River, Water quality parameters, Trace metals, Coliform bacteria, Ecological and human health risks.**ABSTRACT**

This study assessed the surface water quality of the river, focusing on physicochemical parameters (pH, DO, EC, TDS, salinity), microbial contamination, and heavy metal pollution, using a combination of water quality indices and ecological risk assessments. Results revealed seasonal fluctuations in water quality, with DO consistently below World Health Organization (WHO) and Environment Conservation Rules (ECR) standards, while TDS and EC frequently approached or exceeded permissible limits. Microbial analysis showed alarmingly high levels of total and faecal coliform counts, far exceeding WHO guidelines. Heavy metal concentrations exceeded permissible limits for Pb, Cd, and As, and Cr contamination was notably high at certain sites. The values of pollution indices, such as the Nemerow Comprehensive Pollution Index, Heavy Metal Pollution Index, Heavy Metal Evaluation Index, and Water Quality Index, indicated that the river was moderately to severely polluted. Ecological risk assessment identified cadmium as the most significant contributor to potential ecological hazards. Arsenic raised non-carcinogenic risk, while Cd showed very high and As, Cr high carcinogenic risks, with children more vulnerable.

Introduction

Sustainable surface water quality is critical for ensuring safe drinking water, supporting fisheries, and maintaining ecosystem health (Rahman et al., 2022). The presence of microbial pathogens and heavy metals in the aquatic environment is severely threatening this water quality, especially during the last few decades (Bhuyan et al., 2019). It has been reported that approximately 2 billion people all over the world use water sources contaminated with faecal matter, resulting in a significant prevalence of waterborne diseases such as cholera, dysentery, and typhoid fever (WHO, 2022). The microbial contaminants in surface water bodies primarily originate from untreated municipal wastewater,

industrial effluents, direct faecal contamination, and leakage from sewage systems (Siddique et al., 2024). Simultaneously, heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), manganese (Mn), and mercury (Hg) are accumulating in aquatic systems due to both geogenic and anthropogenic activities such as unplanned industrialization and urbanization, acute domestic activities, urban runoff, and agricultural production (Hassan et al., 2025). The accumulation of heavy metals in aquatic environments poses adverse impacts on both aquatic ecosystems and human health. Excessive exposure to these pollutants for humans, animals, and other aquatic organisms

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leads to chronic health issues, including cancer, kidney damage, and neurological disorders (Mahmud et al., 2025). The dual threat posed by heavy metal and microbial contamination emphasizes the necessity for integrated water quality monitoring and risk assessment strategies globally.

In developing countries, particularly in Bangladesh, the situation is more worsened due to poor sanitation infrastructure, rapid industrialization and unplanned urbanization (Chowdhury et al., 2024). The urban rivers in Bangladesh are encountering significant level of pollution due to establishment of large number of industries along their bank (DoE, 2024). Among them, the Shitalakshya River has been identified as a major pollution hotspot, which flows through Gazipur and Narayanganj, two major industrial sites in Bangladesh (Al-Razee et al., 2019). Despite this river is a major source of freshwater, fishing, and water-based transportation among the local communities, the river is facing acute pollution due to vast number of industrial establishment, rapid urbanization, and agricultural activities along the river bank (Hasan et al., 2022; Roy et al., 2025). A large number of knitting and dyeing mills, printing units, and chemical industries are situated along the riverbanks, many of which release untreated wastewater directly or indirectly into the river (Hasan et al., 2022). Moreover, excessive use of pesticides and fertilizers in agricultural purposes, untreated urban sewage is regularly discharged into the river that may contain toxic heavy metals and pathogenic microorganisms (Bijekar et al., 2022). Consequently, Department of Environment (DoE) has declared this river as an ecologically critical area since 2009 (Hasan et al., 2022).

The previous studies conducted in this river have mainly assessed physico-chemical parameters (such as pH, DO, EC, salinity, etc.) and heavy metal pollution (such as Hg, Cd, Cu, Cr, Mn, Zn, etc.), however, limited attention has been given to microbial contamination although its direct impacts on human health (Al-Razee et al., 2019; Rahman et al., 2020). Mondal et al., (2024) have reported the

presence of coliform bacteria however, no comprehensive study has been conducted to assess both physico-chemical parameters, heavy metals, and microbial contamination simultaneously. Moreover, spatial and seasonal variation of microbial and heavy metal pollution, along with their ecological and human health risks, is yet to be done. Concerning these important issues, this study explores an integrated assessment of the Shitalakshya River by combining (i) seasonal and spatial variation of physicochemical parameters, microbial indicators, and heavy metal concentrations; (ii) appraisal of the pollution level due to heavy metals using established pollution indices; (iii) assessment of the ecological and human health risks imposed by these heavy metals. By addressing these objectives, this study provide a scientific basis for pollution and risk assessment, policymaking, and the implementation of effective river management strategies in this critical aquatic systems.

Method and Materials

Study area

This study was conducted along the Shitalakshya River bank in Narayanganj District, Bangladesh (Fig. 1). The main hotspot area under the Kanchpur Bridge in Senpara was selected as Site A (23.703886°N, 90.518486°E), where numerous anthropogenic activities take place, particularly on both sides of the bridge. Site B (23.689582°N, 90.526242°E) was located at Kutubpur Ghat. Site C (23.710012°N, 90.510670°E) was chosen on the opposite riverbank of Site A, where many buildings and construction material manufacturing units are located. Site D (23.692478°N, 90.522481°E) was selected at the riverbank near the Partex Group pulp and paper mills in Siddhirganj Ghat, which is situated directly across from Kutubpur Ghat. The distance between Site A and Site B was approximately 1 km, and the distance from Site B to Site D was less than 1 km. Site C was located over 1 km from Site D.

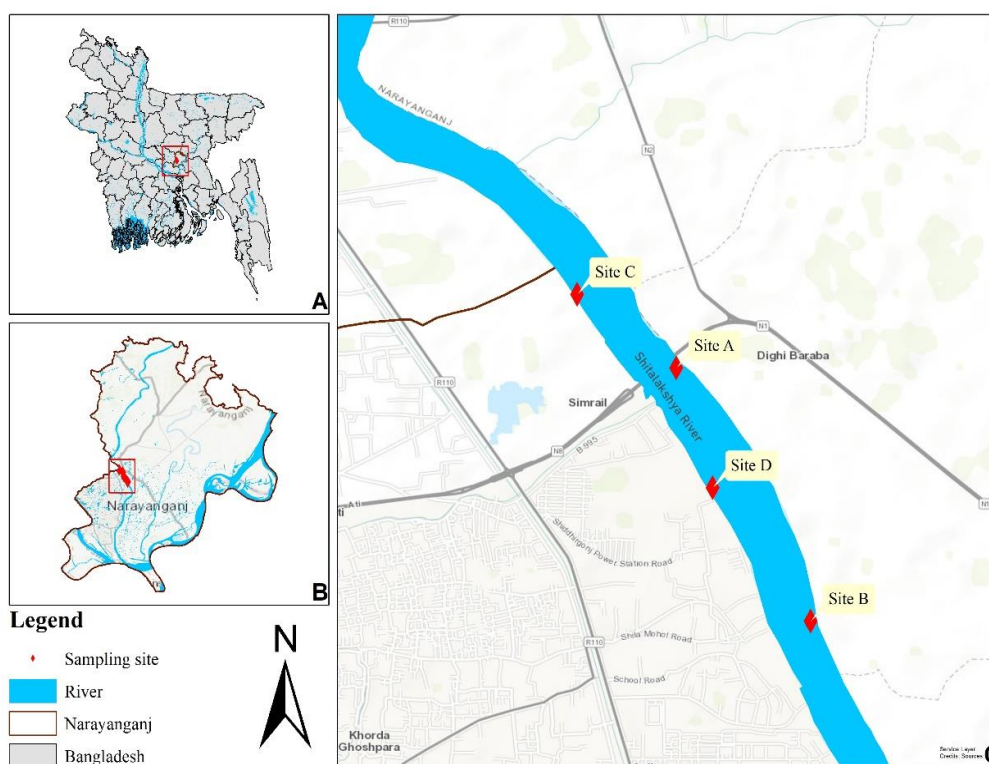


Fig. 1. Sampling sites of Shitalakshya River, Narayanganj, Bangladesh.

Sample collection

A total of 12 water samples were collected from the preselected locations along the Shitalakshya River using 250 mL autoclaved high-density polyethylene (HDPE) bottles. At each sampling site, three independent replicate samples were collected during each sampling campaign to ensure analytical reliability and capture local variability. Sample collection was carried out from January to October 2022, spanning the three major seasons of Bangladesh (pre-monsoon, monsoon, and post-monsoon). This seasonal design was adopted to capture temporal variations in water quality associated with changes in river discharge, rainfall, and pollutant loading. The selected sampling sites represent distinct environmental settings, including industrial discharge zones, urban-influenced areas, and comparatively less disturbed locations, thereby ensuring a representative assessment of spatial variability in pollution. Before sampling, the equipment was thoroughly rinsed with

deionized water, and sample bottles were treated with 5% HNO₃ acid overnight to prevent contamination (APHA, 2015). Samples were taken from 10–20 cm below the water surface to avoid floating contaminants. After collection, the samples were immediately transported to the laboratory and stored in an icebox (4°C) for further analysis.

Sample Analysis

Analysis of physicochemical parameters

Physicochemical parameters such as pH, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), and salinity were analyzed using a digital multiparameter meter (Hanna, Romania). pH was measured with Model HI2002-02 equipped with sensor HI1170. Dissolved oxygen (DO) concentrations were measured using the HI2040 model paired with the HI764080 sensor. Total dissolved solids (TDS) and electrical conductivity

(EC) were determined with an EC meter (Model HI2030) equipped with the HI763100 sensor. Salinity and TDS values were calculated using the device's built-in conversion factor.

Microbiological analysis

A standard plate count method, modified with MacConkey agar (Himedia, UK, MH081), was used for the Total Coliform Count (TCC) test. The Total fecal coliform count (TFCC) test was carried out with a modified standard plate count method, employing mFC agar (Himedia, UK, M1122) (Baird et al., 2017). In summary, sample water was exposed to a 10-fold series of dilutions, including 10^{-1} , 10^{-2} , and 10^{-3} . After that, 0.1 mL of each diluted water sample was spread onto an individual MacConkey agar plate according to the standard spreading procedure and incubated for 18–24 hours at 37°C (Baird et al., 2017). A digital colony counter (J-2, China) was used to count bacterial colonies, and results were expressed as TCC and TFCC in Colony-Forming Unit per milliliter (CFU/mL). Among the tested dilutions, the 10^{-2} dilution was selected for final calculation as it yielded countable colonies (30–300), and CFU/mL values were calculated accordingly using the following formula (Collins et al., 1984):

$$\begin{aligned} & \text{Total TC (CFU mL}^{-1}\text{)} \\ &= \frac{\text{Total colonies observed} \times \text{dilution factor}}{\text{Plated water volume}} \end{aligned}$$

Analysis of trace metals

For trace metal analysis, water samples were collected in a beaker and acidified with 1 mL of 65% HNO₃ using a micropipette. The solution was filtered through a 0.45 μm Whatman filter paper, and 10 mL was transferred to a sample bottle for metal analysis (APHA, 2005). Trace metals such as Pb, Cr, Cd, and Mn were quantified using Flame Atomic Absorption Spectrometry (AA-7000, Shimadzu, Japan) following EPA Method 3005A

(USEPA, 1992). The concentrations of As and Hg were determined using hydride vapour generation and cold vapour techniques. All trace metal analyses were conducted at the Bangladesh Council of Scientific and Industrial Research (BCSIR) laboratory.

Water pollution assessment

The pollution level in the surface water of Shitalakshya River due to synergistic effects of multiple trace metals was assessed using multiple pollution indices presented in Table 1.

Quality control and quality assurance

Analytical grade reagents and standards (Merck, Fluka, 1000 ppm stock solutions) were used throughout the study. Calibration was performed using multi-point standard curves with $R^2 \geq 0.995$, prepared fresh for each analysis. The limits of detection (LOD) and limits of quantification (LOQ) for each metal were determined based on three and ten times the standard deviation of procedural blanks, respectively, ensuring the sensitivity and reliability of measurements at low concentrations. To ensure precision and monitor contamination, reagent blanks and duplicate samples were analyzed regularly. Recovery rates from spiked samples were maintained within 90–110%, and relative standard deviations (RSD) were kept below 10%. Certified Reference Materials (CRMs) were employed where applicable to validate results. All glassware was acid-washed, and acid blanks were subtracted to account for background levels. Procedures adhered strictly to BCSIR laboratory protocols following EPA Method 3050A.

Statistical analysis

Descriptive statistics (mean values), data organization, processing, and interpretation were calculated using Microsoft Excel 2013. Sampling sites were mapped using ArcGIS 10.2.2 (ESRI, USA).

Table 1. Water quality and pollution indices with interpretation.

Index	Formula	Interpretation (Pollution level)	Reference
Contamination Factor (CF)	$CF = \frac{C_m}{C_{background}} \quad [4]$ <p>C_m = Metal concentration in water $C_{background}$ = Baseline metal concentration</p>	Low (CF < 1); Moderate (1 < CF < 3); Significant (3 < CF < 6); Severe (CF ≥ 6)	El-Amier et al. (2017); Su et al. (2022)
Ecological risk index	$E_r^i = T_r \times CF \quad [5]$ <p>Ecological Risk (E_r^i) Contamination factor (C_f) [The toxicity factor (T_r): Pb = 5; Cr = 2; Cd = 30; Mn = 1; As = 10; Hg = 40]</p>	PERI < 150: Minimal risk 150 ≤ PERI < 300: Moderate risk PERI ≥ 300: High risk	Hakanson (1980)
Water Quality Index (WQI)	$WQI = \frac{\sum(Q_n \times W_h)}{\sum W_h} \quad [6]$ <p>Quality Rating, $Q_n = (V_n - V_{id}) / (S_n - V_{id}) \times 100$ Unit Weight, $W_h = \frac{k}{S_n}$ Proportionality constant, $k = \frac{1}{\sum(\frac{1}{S_n})}$ V_n: Measured water quality value V_{id}: Ideal value in pure water (usually 0) S_n: Acceptable standard limit for the parameter</p>	WQI = 0-25 (Excellent) WQI = 26-50 (Good) WQI = 51-75 (Poor) WQI = 76-100 (Very poor)	Suchi et al. (2024)
Chronic Daily intake (CDI)	$CDI_{ingestion} = (EC \times IR \times EF \times ED) / (BW \times AT) \quad [7]$ $CDI_{dermal} = (EC \times SA \times AF \times ABS \times ET \times EF \times ED \times CF) / (BW \times AT) \quad [8]$ <p>EC = Metal concentration (mgL⁻¹); IR = Ingestion rate (2.5 L/day); SA = Skin surface area (18000 cm²); AF = Skin adherence factor (0.07 mg/cm²); ABS = Dermal absorption fraction (0.001); ET = Exposure time (0.6 h/day); EF = 365 days/year; ED = 70 years; CF = Conversion factor (0.000001 L/cm³); BW = 70 kg; AT = Averaging time (25550 days)</p>		Islam et al. (2014)

Index	Formula	Interpretation (Pollution level)	Reference
Target Hazard Quotient (THQ)	$THQ = CDI / RfD$ [9] EDI = Estimated Daily Intake (EDI) RfD = Reference dose of the heavy metal (mg/kg/day) [RfD: Pb = 0.0014; Cr = 0.003; Cd = 0.0005; Mn = 0.02; As = 0.0003; Hg = 0.0003]	THQ < 1 = no significant risk THQ ≥ 1 = there may be potential health risks from exposure to that particular metal	Javed and Usmani, (2016); Mahmud et al. (2025)
The Hazard Index (HI)	$HI = \sum THQ$ [10]	HI < 0.1: Negligible; 0.1 - <1: Low; 1 - <4: Medium; ≥ 4: Very High Risk.	ATSDR (2007)
Target Cancer Risk (CR)	Cancer risk = CDI × SF [11] [Slope Factor (SF): Pb = 0.0085; Cr = 0.5; Cd = 15; As = 1.5]	Acceptable risk range: $10^{-6} - 10^{-4}$	USEPA (2020)

Results and Discussion

Physico-chemical parameters

Physico-chemical parameters determine the water quality of surface water, indicating its suitability for ecological health, domestic uses, and sustainable water resource management (de Oliveira et al., 2025). This study evaluated physicochemical parameters among various sampling sites of the Shitalakhya River and demonstrated the corresponding seasonal variation in Table S1. The pH value showed a wide variation among the sampling sites and the three seasons, where the highest value was recorded to be 8.15 in winter, followed by 7.23 and 6.42 in summer and monsoon, respectively. The average pH value was 7.28, within the acceptable limits suggested by WHO (2022) and ECR (2023) and consistent with the preceding studies by Chowdhury et al. (2021) and Islam et al. (2015) in the same river. The average dissolved oxygen (DO) level was found to 3.62 mgL^{-1} , with Site A having the lowest value of 2.82 mgL^{-1} during winter, while the highest value was recorded to 4.17 mgL^{-1} during the monsoon period. Notably, DO levels at all the sampling sites and seasons remained consistently below the WHO (2022) and ECR (2023) recommended limits. This reflects degraded water quality, with the potential to cause adverse consequences for aquatic species and human health. The low DO

levels in the Shitalakhya River were also recorded by Majed and Islam (2022) and Islam et al. (2021). These low levels of DO might be attributed to various industrial activities near the Shitalakhya River that produce effluents containing biodegradable organic substances (Mahmud et al., 2025). The average Total Dissolved Solids (TDS) concentration in the Shitalakshya River was 366.79 mg L^{-1} , well below the WHO (2022) and ECR (2023) guideline values. Seasonal variations were notable, with the highest TDS value of 853 mgL^{-1} recorded during the summer at Site A1, and the lowest value of 43.4 mgL^{-1} observed during the monsoon season at the same site. The mean TDS values for summer, monsoon, and winter were 638.91 mgL^{-1} , 89.30 mgL^{-1} , and 372.16 mgL^{-1} , respectively. The mean Electrical Conductivity (EC) value in the Shitalakshya River was $731.43 \text{ }\mu\text{S/cm}$, which also remained within the WHO (2022) and ECR (2023) standards. The mean EC values for summer, monsoon, and winter were $1283.5 \text{ }\mu\text{S/cm}$, $173.54 \text{ }\mu\text{S/cm}$, and $737.25 \text{ }\mu\text{S/cm}$, respectively. The low TDS and EC levels during the monsoon can be attributed to dilution from increased rainfall and runoff, whereas higher values in summer and winter are likely due to reduced flow and higher concentrations of dissolved substances (Yasmin et al.,

2023). The average salinity value across all seasons in the Shitalakshya River was 316.82 mgL⁻¹. During the summer, salinity was recorded at 600.34 mg L⁻¹ across the four study sites. In contrast, the monsoon season showed the lowest salinity of 65.57 mgL⁻¹, likely due to substantial rainfall during this period, which dilutes river water and reduces ion concentrations (Pillsbury, 1981).

Total coliform count and fecal coliform count

Total coliform count (TCC) and fecal coliform counts (TFCC) are widely used microbial indicators of water quality, where elevated levels reflect contamination by fecal matter and related pathogens, posing significant risks to human health and aquatic ecosystems (Veras et al., 2025). The mean TCC of the four sampling sites in the Shitalakshya River was 5.5×10^4 CFU/mL during winter and 3.83×10^3 CFU/mL in summer (Table 2). Colony morphology revealed the presence of both lactose-fermenting (pink) and non-lactose-fermenting (colorless) coliform bacteria. The average TFCC was recorded as 6.3×10^4 CFU/mL in winter, decreasing markedly to 1.43×10^3 CFU/mL during summer. Both lactose-fermenting (blue) and non-lactose-fermenting (grey) fecal coliform colonies were observed, confirming substantial fecal contamination. Both TCC and TFCC were significantly higher in winter than in summer, indicating seasonal variability. This reduction during the summer and monsoon is likely attributable to dilution effects and increased river discharge (Yasmin et al., 2023). Site-specific analysis showed that Site B consistently exhibited the highest coliform counts, suggesting persistent pollution inputs, most likely from untreated domestic sewage originating from adjacent densely populated areas (Pant et al., 2023). Site A showed relatively stable TCC values but a noticeable decline in TFCC, while Site C recorded comparatively lower bacterial loads in both seasons, possibly due to reduced waste discharge and its proximity to a less disturbed riverbank (Yasmin et al., 2023).

According to World Health Organization guidelines, fecal coliforms or *Escherichia coli* should be absent in 100 mL of drinking water, and surface waters should

not exceed 100 CFU per 100 mL (WHO, 2022). The coliform levels observed in this study far exceeded these limits, indicating that the river water is unsuitable for drinking and direct domestic use without treatment. However, the suitability for agricultural or recreational purposes requires further assessment using additional water quality criteria. Comparable contamination levels have been reported for other major rivers in Bangladesh, including the Buriganga and Dhaleshwari rivers (Saha et al., 2009; Real et al., 2017). Similar trends have also been documented in heavily polluted rivers across South Asia, including the Ganga and Sutlej (Iqbal et al., 2022; Chatterjee et al., 2025). These findings underscore the continued discharge of untreated sewage and waste as major contributors to microbial pollution, posing serious risks to public health and aquatic ecosystems.

Distribution of trace metals

Trace metal contamination of surface water is a major environmental concern worldwide due to the non-biodegradable nature, persistence, and toxicity of metals even at low concentrations (Mishra et al., 2019). In the present study, the Shitalakshya River exhibited mean concentrations of Pb (0.030 mgL⁻¹), Cr (0.0398 mgL⁻¹), Cd (0.0043 mgL⁻¹), Mn (0.0336 mgL⁻¹), As (0.014 mgL⁻¹), and Hg (0.001 mgL⁻¹), following the descending order of Cr > Mn > Pb > As > Cd > Hg (Table 3). The average Pb concentration exceeded the WHO (2022) guideline for drinking water, although it remained within national standards (ECR, 2023), indicating potential chronic health risks, particularly neurodevelopmental impairment in children (WHO, 2022; Hossain et al., 2021). Cr showed pronounced spatial variability, with concentrations at Sites B and C exceeding both WHO (2022) and ECR (2023) limits, likely due to industrial effluents and domestic wastewater discharges observed at these locations (Islam et al., 2021).

Although Cr levels were lower than those reported for heavily polluted rivers such as the Buriganga, Turag, and Dhaleshwari rivers, evidence suggests a gradual temporal increase in the Shitalakshya River,

Table 2. Total and fecal coliform bacteria count in surface water from four sites in the Shitalakshya River.

Site/ River	Unit	Total coliforms		Fecal coliforms		Reference
		Winter	Summer	Winter	Summer	
A	CFU/mL	3.9×10^4	3.3×10^3	3.3×10^4	8.0×10^2	
B	CFU/mL	9.4×10^4	4.6×10^3	13.4×10^4	2.7×10^3	
C	CFU/mL	1.8×10^4	1.1×10^3	0.2×10^4	1.0×10^2	
D	CFU/mL	4.9×10^4	6.3×10^3	8.4×10^4	2.1×10^3	
Shitalakshya River (Mean)	CFU/mL	5.5×10^4	3.83×10^3	6.33×10^4	1.43×10^3	Present study
Buriganga river	CFU/mL	1.2×10^5		3.5×10^4		Saha et al. (2009)
Dhaleshwari river	CFU/mL	1.38×10^{23}		6×10^{13}		Real et al. (2017)
Obohia river, Nigeria	CFU/mL	23.66×10^6		NA		Onuotu et al. (2025)
Rispana River, India	MPN/100 mL	~2419.6		NA		Pant et al. (2023)
Ganga river, India	MPN/100 mL	~84,000-121,000		~25,000-55,000		Chatterjee et al. (2025)
Oda River, Ghana	MPN/100 mL	~168.33		~147.67		Anoyege and Alatinga (2025)
Sutlej River, Pakistan	CFU/100 mL	NA		~77,000		Iqbal et al. (2022)
Nakdong River, South korea	CFU/100 mL	~173		~22		Seo et al. (2019)

NA- Not Available

WHO (2017) drinking water standard: 0 CFU/100 mL (Coliforms)

WHO (2017) bathing water guideline: ≤ 100 CFU/100 mL (fecal coliforms)

highlighting the need for continuous monitoring (Ahmad et al., 2010; Arefin and Rahman, 2016; Kabir et al., 2020). Cd concentrations exceeded WHO permissible limits and, despite being lower than levels reported for other major Bangladeshi rivers, remain ecotoxicologically significant due to their

cumulative toxicity and severe impacts on aquatic organisms and human health (Islam et al., 2021). Manganese concentrations complied with WHO and ECR guidelines but were higher than those reported

for relatively less contaminated rivers, with elevated levels at Site C likely linked to nearby industrial activities; moreover, climate-induced changes in redox conditions may further increase Mn bioavailability in the future (Bhuiyan et al., 2015). The mean arsenic concentration exceeded the WHO drinking water guideline and was consistent with previous reports from the same river, indicating persistent contamination (Jolly et al., 2018). Mercury was detected at low but uniform concentrations across

all sites, remaining within guideline values; however, its presence likely reflects anthropogenic inputs such as fossil fuel combustion and urban runoff (Majed et al., 2022). Overall, the findings indicate significant trace metal contamination of the Shitalakshya River,

accumulation in aquatic systems. The present study is limited to water-phase analysis; therefore, future research incorporating sediment characterization is recommended to better understand pollutant persistence and source dynamics.

Table 3. Concentration of heavy metal (mgL⁻¹) of the Shitalakshya river compared to national and international standards and other studies from worldwide.

River / Standard Limit	Pb	Cr	Cd	Mn	As	Hg
WHO (2022)	0.01	0.05	0.003	0.05	0.01	0.006
ECR (2023)	0.01	0.05	0.003	0.40	0.05	0.001
Shitalakshya River (Present study)	0.03	0.0398	0.0043	0.0336	0.014	0.001
Shitalakshya river (Jolly et al. 2018)	0.016	0.018	0.003	0.179	0.01	–
Shitalakshya River (Kabir et al. 2020)	0.0041	–	0.0028	0.1694	–	–
Turag River (Arefin & Rahman, 2016)	–	0.3337	0.0119	–	–	–
Buriganga river (Bhuiyan et al., 2015)	0.119	0.114	–	0.157	–	–
Buriganga river (Ahmad et al. 2010)	0.0653	0.5673	0.0097	–	–	–
Karnaphuli river (Ali et al., 2016)	0.0168	0.086	0.0104	–	0.0336	–
Meghna river (Islam et al. 2020)	0.034	0.032	0.001	0.018	0.011	–
Brahmaputra River Basin (Islam et al. 2020)	0.031	0.025	0.002	0.137	0.005	–
Gomti river (Ahmed et al. 2021)	0.053	–	0.006	0.03	0.022	0.122
Pardo River, Brazil (Alves et al. 2014)	0.003	0.008	–	0.035	–	–
Çoruh river basin, Turkey (Bilgin et al. 2016)	0.014	0.007	–	0.091	–	–

particularly with Pb, Cd, and As, posing long-term ecological and public health risks and underscoring the urgency for pollution control measures and systematic water quality surveillance. It is important to note that sediment analysis provides a more stable and long-term assessment of heavy metal

Water quality assessment

The Water Quality Index (WQI) was primarily utilized to assess the overall condition of the water, based on six selected heavy metals. The average WQI value across the sampling sites was 133.1, with individual site values ranging from

130.91 to 137.2. As shown in Fig. 2, all sites are classified as having very poor water quality, exceeding the defined threshold level. Site C exhibited the highest WQI value, indicating comparatively greater pollution load, which may be attributed to its proximity to industrial discharge zones. In contrast, Site D showed relatively lower values, suggesting comparatively reduced contamination. The elevated WQI across all sites reflects the cumulative impact of heavy metals, particularly Pb, Cd, and As, on overall water quality. Given these findings, the water from the Shitalakshya River is unsuitable for domestic use, irrigation, or industrial purposes, due to the potential toxic effects of heavy metals on human health, agricultural productivity, and aquatic ecosystems. It is strongly recommended to minimize the discharge of metal-containing waste from nearby industries and factories, alongside implementing regular monitoring of trace metal concentrations in water used by local communities. However, this finding is significantly lower than the WQI value reported by Suchi et al. (2024) in the Turag River.

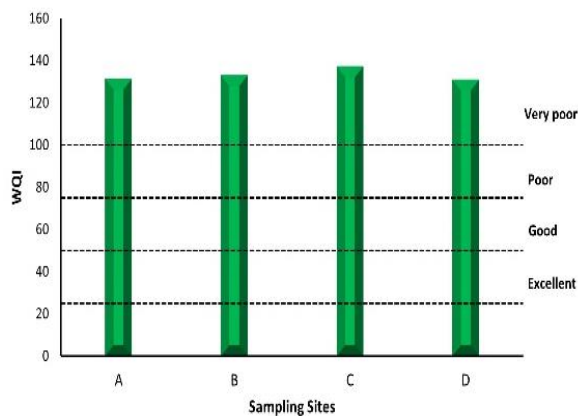
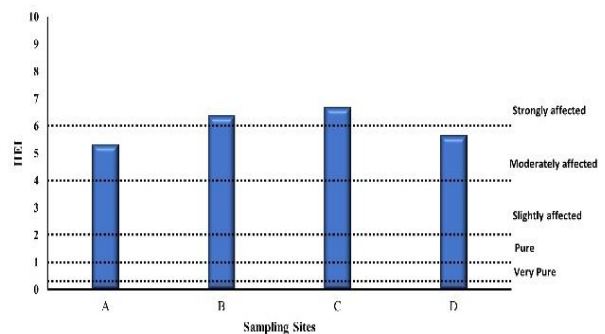
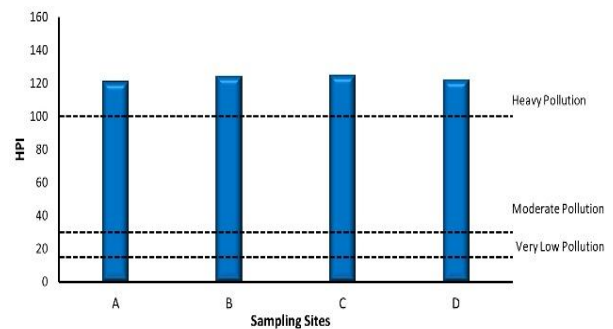


Fig. 2. Water Quality Index among the four sites of Shitalakshya River.

Level of pollution assessment

To evaluate the pollution intensity across the Shitalakshya River, the Nemerow Comprehensive

Pollution Index (NCPI), Heavy Metal Pollution Index (HPI), and Heavy Metal Evaluation Index (HEI) were applied. The average NCPI across all sites was 1.15, classifying the water quality as moderately polluted (Fig. 3). Site C recorded the highest NCPI of 1.32, while Site D recorded the lowest of 1.06. Compared to previous studies, the NCPI value observed in the present study is notably higher than that of the Ganges River (Haque et al., 2020), yet lower than the levels reported for the Buriganga and Turag Rivers (Akbor et al., 2020; Suchi et al., 2024). The average HPI in this study was 123.48, exceeding the standard threshold of 100 at all sampling sites (Fig. 3). This indicates high metal pollution across the river, and the finding is also consistent with HEI, where the mean value was calculated to be 6.02. The HPI and HEI values reported in our study are higher than those previously reported in the Ganges and Halda rivers (Haque et al., 2020; Kamal et al., 2024). However, in contrast, Sultana et al. (2024) reported even higher HPI and HEI values for the same river as well as for the Buriganga, Turag, Rupsha, and Karnaphuli rivers.



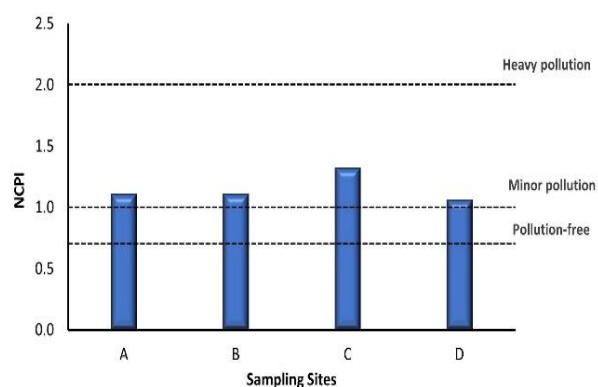


Fig. 3. Assessment of Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI), and Nemerow Comprehensive Pollution Index (NCPI) across four sampling sites of the Shitalakshya River.

Assessment of ecological risk

The presence of excessive toxic chemicals in aquatic environments can lead to ecological imbalance, which can be assessed using the method introduced by Hakanson et al. (1980). The ecological threat posed by trace metals was assessed using the Ecological Risk Index (Er), as illustrated in Fig. 4. The findings highlight which metals contribute most significantly to ecological degradation. The mean Er value was 53.55, with the highest recorded value for Cd (177.69) and the lowest for Mn (0.34). The ascending order of Er values for the metals was Mn < Cr < Hg < As < Pb < Cd, indicating that cadmium (Cd) posed the elevated ecological risk among the analysed elements. The dominance of cadmium (Cd) in ecological risk is likely associated with industrial effluents, particularly from textile, dyeing, and chemical industries located along the riverbanks. The comparatively lower contribution of Mn and Cr suggests either lower input or reduced bioavailability of these metals in the studied area (Mahmud et al., 2025; Hassan et al., 2026). The ecological risk recorded in this research is significantly lower than that reported for the Dhaleshwari and Turag Rivers (Islam et al., 2021; Suchi et al., 2024). Overall, the elevated ecological risk, driven predominantly by cadmium, suggests a potential threat to aquatic species through chronic toxicity, bioaccumulation, and disruption of

physiological and reproductive processes, which may ultimately compromise ecosystem stability and biodiversity in the Shitalakshya River.

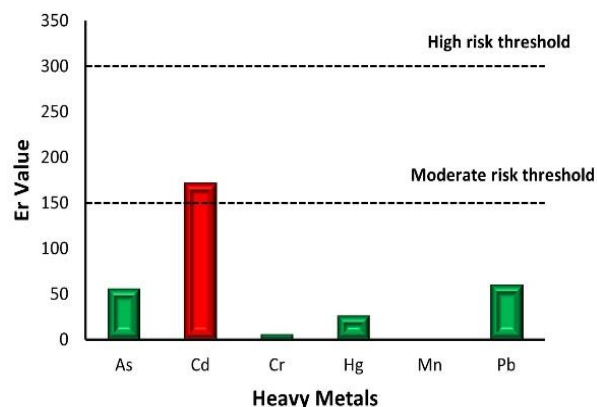


Fig. 4. Ecological risk of individual metals in the Shitalakshya River.

Health Risk Assessment

Non-carcinogenic risk assessment

The assessment of the target hazard quotient (THQ) and hazard index (HI) provides a quantitative framework for evaluating potential non-carcinogenic health risks associated with human exposure to trace metals in surface water through ingestion and dermal contact pathways (Mahmud et al., 2025). The THQ values presented in Table S2 indicate the potential non-carcinogenic health risks from exposure to various metals for both children and adults. In this study, all metals except arsenic (As) showed THQ values below 1 for both groups, whereas the values of Pb, Cr, Cd, Mn, and Hg are within acceptable limits and unlikely to pose significant health risks. However, arsenic exhibited THQ values of 1.82 for children and 1.67 for adults, both exceeding the threshold of 1. This indicates a notable non-carcinogenic health risk from As, with children being slightly more vulnerable than adults. The cumulative THQ values represent the Hazard Index (HI), which reflects the overall potential health risk. The HI values were 3.7 for adults and 3.3 for children, which exceeds the threshold limit, indicating potential health risk for the surface water of Shitalakshya River (Fig. 5). The elevated hazard index (HI) is primarily driven by arsenic (As), which

showed the highest contribution to non-carcinogenic risk. The higher HI values for adults compared to children are associated with differences in exposure parameters, although both groups exceed safe thresholds, indicating potential long-term health risks.

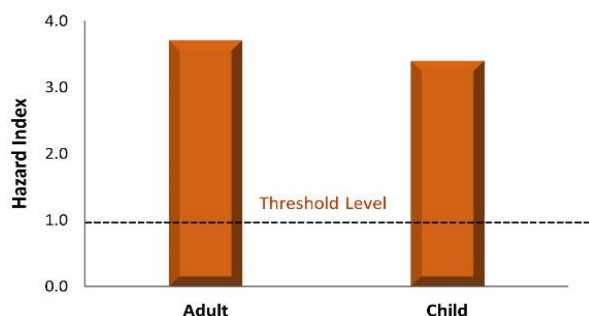


Fig. 5. Hazard Index (HI) values for adults and children exposed to Shitalakshya River.

Carcinogenic Risk Assessment

Carcinogenic risk (CR) assessment is a widely applied approach to estimate the probability of cancer development in humans resulting from long-term exposure to carcinogenic trace metals through contaminated surface water via ingestion and dermal contact pathways (Shetty et al., 2024). The carcinogenic risk for adults and children is represented in Table S3. The findings showed that Cd was found to pose the most severe concern, with significant carcinogenic risks exceeding the threshold value of 1×10^{-4} for both adults (0.0023) and children (0.0025), classified as very high risk. Moreover, As and Cr also exhibited higher risks for both adults (0.00075 and 0.00071, respectively) and children (0.000819 and 0.00077, respectively). In contrast, Pb presented a comparatively lower risk, remaining within the acceptable range for both adults (9.11×10^{-6}) and children (9.9×10^{-6}). Notably, children consistently showed slightly higher risk values than adults across all metals, highlighting their greater vulnerability to carcinogenic effects of heavy metal exposure. Overall, both non-carcinogenic and carcinogenic risk assessments indicate that prolonged exposure to water from the Shitalakshya River may pose significant health risks, particularly due to As and Cd contamination, with children being more susceptible than adults, underscoring the urgent need for risk-

based water management, pollution control, and public health protection measures.

Conclusion

This study provides an integrated evaluation of the surface water quality of the Shitalakshya River, revealing substantial degradation driven by physicochemical imbalance, microbial contamination, and trace metal pollution. Across all seasons and sampling sites, multiple parameters exceeded national and international guideline values, indicating persistent anthropogenic pressure. Persistently low DO levels, together with elevated TDS, EC, and salinity, especially during the dry season, indicate organic pollution and reduced dilution capacity. Microbial analyses showed extremely high total and fecal coliform counts, rendering the river water unsuitable for drinking and direct domestic use without appropriate treatment. Trace metal assessment identified Pb, Cd, As, and Cr as major contaminants, with industrial zones exhibiting pronounced chromium enrichment. Pollution indices classified the river as moderately to severely polluted, while ecological risk assessment highlighted Cd as the dominant ecological threat. Human health risk analysis revealed significant non-carcinogenic risk from arsenic and carcinogenic risk primarily associated with cadmium, with children being more vulnerable than adults. These findings underscore the urgent need for stricter pollution control and continuous monitoring of microbial and heavy metal contamination to reduce exposure risks for local communities relying on this river.

CRedit authorship contribution statement

Md. Masud Rana: Writing – original draft, Investigation, Formal analysis, Data curation; Mohammad Abid Hossain: Writing – original draft, Software, Methodology, Formal analysis; Md. Shahariar Mahmud: Writing – original draft, review & editing; Abdus Samad: Conceptualization, Writing – review & editing, Supervision, Resources; Rumana Tasmin: Writing – review & editing, Supervision, Investigation, Visualization, Resources; Abul Kalam Azad: Microbiological Analysis, Writing – review &

editing, Resources; Md Sojib Hasan Noman: Sample collection, Formal analysis.

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Authors contribution

All authors have reviewed, comprehended, and adhered to the guidelines outlined in the "Ethical Responsibilities of Authors" section as specified in the Instructions for Authors.

Conflict of interest

The authors declare that they have no financial or personal conflicts of interest that might be perceived as influencing the research presented in this study.

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