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Heavy Metal Contamination in the Buriganga River, Bangladesh: A Review of Ecological Risk and Pollution

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Abstract

The Buriganga River, an essential resource for Dhaka City, Bangladesh, has experienced significant environmental deterioration due to rampant industrialisation, swift urban growth, and insufficient waste management practices. This review consolidates contemporary studies about the origins, dispersion, and ecological consequences of heavy metal contamination in the Buriganga River. Significant heavy metals identified, including Lead (Pb), Cadmium (Cd), Chromium (Cr), Arsenic (As), and Mercury (Hg), predominantly stem from tanneries, dyeing industries, municipal garbage, and untreated sewage. These pollutants not only disturb aquatic ecosystems but also present considerable health hazards to humans via bioaccumulation in fish, vegetables, and potable water. Analytical investigations indicate that heavy metal concentrations in river water, sediments, and biota frequently surpass allowable limits established by the WHO and national guidelines. Prolonged exposure to these contaminants may result in serious health consequences, including renal failure, neurological problems, and malignancies. Ecological indicators, including fish mortality, biodiversity decline, and algal bloom occurrences, underscore the declining health of the river. This research highlights the critical necessity for cohesive management techniques, encompassing source control, enhanced industrial effluent treatment, riverbank restoration, and community involvement in pollution monitoring. It also underscores deficiencies in existing monitoring methods, policy implementation, and data accessibility. Enhancing institutional frameworks and promoting multidisciplinary research are essential for alleviating the dangers of heavy metal contamination and rehabilitating the ecological integrity of the Buriganga River. The results intend to assist policymakers, researchers, and environmental managers in formulating successful remediation and conservation methods.

Keywords: *Environmental Health; Water Quality; Urban Pollution; Human Health Impacts*

Introduction

The Buriganga River, a critical waterway in Dhaka, Bangladesh, has long been a lifeline for domestic use, irrigation, and transportation. Nevertheless, the river has become one of the most polluted in the world because of accelerated urbanisation and industrialisation, with heavy metal contamination posing severe ecological and public health risks (Akbor *et al.,* 2020; Rakib *et al.,* 2024; Uddin & Jeong, 2021). Dhaka, bordered by four main urban rivers: Buriganga, Balu, Shitalakkhay, and Turag (Figure 1), is one of the most populous megacities

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in the world, with a population of nearly 21 million. Buriganga is the watercourse with the most pollution among all others (Nargis *et al.,* 2021). Metals and metalloids are elements that are naturally occurring; while some are essential for biological systems, they can be toxic at high concentrations. The aquatic ecosystems have been the subject of significant concern in recent decades because of the rapid expansion of industrial and urban areas. Heavy metal contamination in the water and sediments of urban rivers is the primary cause of the increasing water security challenges that approximately 80% of the global population currently confronts (Islam *et al.,* 2018). Sediment and water are essential natural resources for human sustenance and serve as primary sinks for a variety of contaminants, making them fundamental components of riverine systems. Haque *et al.* (2022) have identified heavy metals and metalloids (HMs) as the primary environmental concern among these contaminants because of the severe ecological and health consequences they have exhibited over the past decade.

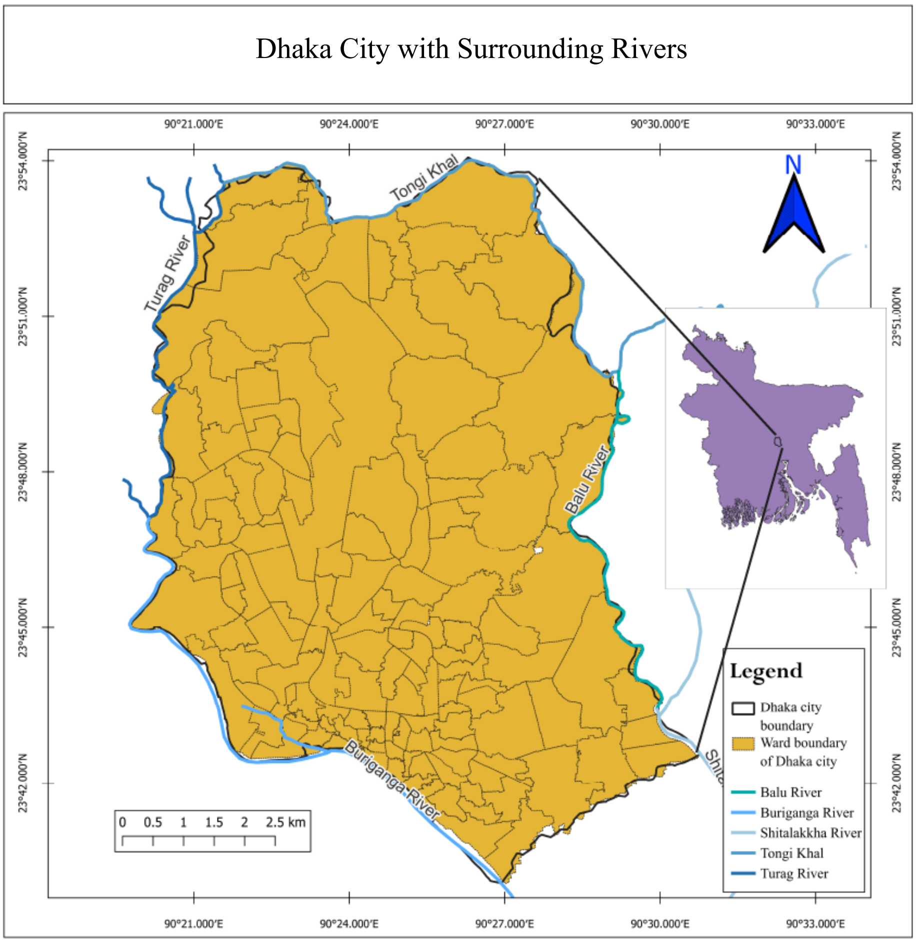

Figure 1: Rivers around Dhaka City.

Heavy metal pollution has a profound effect on human health and riverine ecosystems as a result of its bioaccumulation potential, toxicity, and persistence. Introducing high levels of toxic metals and organic pollutants, depleting dissolved oxygen, and degrading water quality and aquatic life, industrial effluents, particularly from tanneries, metal processing plants, battery manufacturing, and the garment sector, are major contributors (Whitehead *et al.,* 2019).

Tanneries in Hazaribagh release untreated effluents directly into the Buriganga River. Dhaka generates around 4,500 tonnes of solid trash daily, in addition to 20,000 tonnes of tannery waste, 56 million tonnes of textile effluents, and 0.5 million tonnes of sludge annually. The discharge of sewage exacerbates water quality deterioration, endangering the health of approximately 4 million individuals. The risk of Cadmium toxicity, exemplified by Itai-Itai sickness, necessitates immediate regulatory intervention in Bangladesh (Ahmad *et al.,* 2024). In Dhaka, over one-third of home wastewater is untreated, with merely 38% of the population linked to a sewage system. Over time, vigorous human activities, including motorised vessel traffic, infrastructural expansion, encroachment, and the discharge of industrial and sewage waste, have significantly polluted and deteriorated the Buriganga River. The river also gets substantial volumes of food trash, decomposing organic matter, and concerning levels of plastic and polybags (Salman *et al.,* 2018).

Prior research has identified 22 significant industrial discharge locations along the Buriganga River (Figure 2). Dhaka's sewage infrastructure is antiquated and inadequately services a significant portion of the city's northern area. Consequently, city garbage is frequently released straight into adjacent water bodies, ultimately contaminating the Buriganga. Untreated discharges significantly impair water quality and jeopardise the aquatic ecosystem (Alam *et al.,* 2020). Heavy metals, derived from both natural and anthropogenic sources, are significant environmental contaminants that accumulate in soil, water, and sediments, posing substantial dangers to aquatic organisms. Toxic metals such as Chromium, Lead, Cadmium, and Arsenic can affect ecosystems even at minimal amounts. Rivers serve as essential conduits for metal transport, with their dynamics affected by sediment composition and water chemistry (Akbor *et al.,* 2020). Dissolution, sorption, and complexation influence metal mobility and bioavailability. Consequently, heavy metals serve as reliable indicators of aquatic pollution; nevertheless, environmental evaluations must prioritise bioavailable fractions rather than solely total concentrations (Mohiuddin *et al.,* 2011). The Buriganga River exhibits Chromium contamination from tannery effluents, alongside heightened concentrations of nickel, copper, zinc, Lead, Cadmium, and Mercury, signifying several anthropogenic origins. Metal pollution is exacerbated by emissions from Lead-acid and lithium-Cadmium battery utilisation, industrial operations (re-rolling mills, dockyards, cosmetic and electroplating companies), and contributions from landfill leachate, municipal wastewater, and urban runoff (Nargis *et al.,* 2021). Heavy metals present considerable hazards to aquatic ecosystems due to their propensity for bioaccumulation, wherein chemical concentrations in organisms escalate with time above environmental levels. Bioaccumulation transpires when the rates of absorption and storage surpass the rates of metabolism or excretion (Rashid *et al.,* 2012). Heavy metal contamination in freshwater ecosystems is significant due to its toxicity, persistence, and bioaccumulation. Heavy metals provide environmental hazards by substituting critical components in enzymes, so altering biological functioning. Their toxicity is associated with various human health problems, including developmental disorders, miscarriages, cognitive impairments, renal damage, hypertension, and mortality at elevated concentrations. Global heavy metal pollution has surpassed safe thresholds, endangered all living forms, and become a prevention and control issue, an urgent international issue (Barua *et al.,* 2021).

The Buriganga, an urban river, and its environs are significantly contaminated by both point and non-point source pollution. The discharge of untreated effluent from Hazaribag tanneries, textile industries, food industries, home sources, and sewage disposal has significantly contaminated and deteriorated the river's water quality and sediments with heavy metals, resulting in ecological disruption and health risks to humans. Consequently, rigorous monitoring requires comprehension of the existing situation and the proposal of possible corrective measures. This analysis consolidates information from current studies to assess the sources, distribution, and ecological effects of heavy metals in the river's water and sediments, while recommending mitigating options for sustainable management.

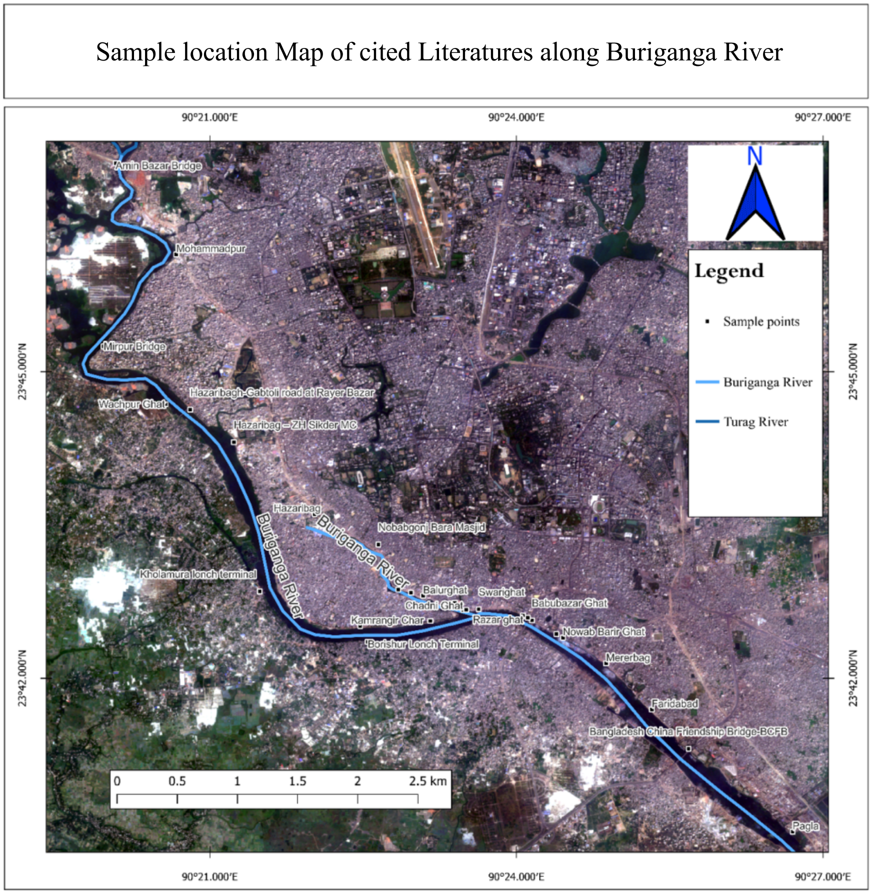

Figure 2: Map of sampling points along the Buriganga River.

Review Methodology

This review article consolidates current scientific literature, governmental records, and environmental assessments to assess the ecological hazards posed by heavy metals in the Buriganga River. The technique is organised into the following principal phases:

Literature Review and Data Acquisition

Peer-reviewed literature from 2010 to 2023 was sourced from Scopus, Web of Science, and Google Scholar, utilising the keywords "Buriganga River," "heavy metals," "ecological risk assessment," "water pollution," "sediment contamination," and "Bangladesh." Government papers (e.g., Department of Environment, Bangladesh) and publications from international agencies (e.g., WHO, U.S. EPA) were also incorporated.

Studies presenting quantitative data on heavy metal concentrations (e.g., Cr, Pb, Cd, As, Hg) in water and sediment evaluations utilising ecological risk indicators (e.g., Geoaccumulation Index, Pollution Load Index, Potential Ecological Risk Index) were included. Studies examining origins, regional and seasonal changes, or health effects were also included. Articles in languages other than English, research with insufficient methodological transparency, or data that was replicated across sources were omitted from the review for practical reasons.

Data Extraction and Classification

Parameters, including heavy metal concentrations (mean/maximum values) in water (mg/L) and sediments (mg/kg), were obtained using reference standards (e.g., WHO, FAO, U.S. EPA sediment guidelines). Geographic sampling sites (e.g., Hazaribagh, Sadarghat) and seasonal data (pre-monsoon versus dry season) from several publications were recorded, along with the extraction of ecological risk indicators (e.g., Igeo, PERI, CF) and their corresponding thresholds. The extracted data were categorised into subject sections: physicochemical features, pollution sources, contamination levels in water and sediment, ecological risk indices, bioaccumulation in biota, and health consequences.

Evaluation of Quality and Verification

Studies were assessed according to sampling methodology (e.g., sample size, grid-based versus random sampling), analytical techniques (e.g., atomic absorption spectroscopy, ICP-MS), and statistical rigour (e.g., application of standard deviation, ANOVA for geographical and temporal comparisons). Inconsistent results (e.g., anomalous metal concentrations) were corroborated with other sources.

Analytical Framework

The subsequent ecological risk indices were considered in the development of the analytical framework for the review article: Geoaccumulation Index (Igeo): Evaluated sediment contamination levels in comparison to baseline values. Pollution Load Index (PLI): Assessed the aggregate metal contamination in sediments. Potential Ecological Risk Index (PERI): Risks quantified utilising toxicity coefficients for metals (e.g., Cd = 30, Hg = 40). Nemerow Pollution Index (NPI): Categorises water quality according to multi-metal thresholds. Hazard Quotient (HQ) and Hazard Index (HI): Assessed non-carcinogenic risks through oral and dermal exposure routes. Incremental Lifetime Cancer Risk (ILCR): Assessed carcinogenic risks associated with metals such as Arsenic (As) and Chromium (Cr^{6+}).

The review revealed multiple limitations, such as variability in sampling protocols and detection thresholds among studies, a lack of long-term monitoring data to evaluate temporal pollution trends, and a paucity of studies focusing on emerging contaminants (e.g., rare earth elements) or the synergistic effects of metal mixtures. This review article does not include data directly from previously published review studies. All information provided is sourced from actual research articles to guarantee the authenticity and originality of the work.

Physicochemical Properties of River Water

According to reports from different studies, Table 1 shows the seasonal fluctuations in the physico-chemical properties of the water in the Buriganga River. The Buriganga River's pH ranged from 6.5 to 8.47, with Sadarghat, Jhauchor, Bosilla, and Sluicegate having the lowest pH (Rahman *et al.*, 2014) and Hazaribag having the highest (Fatema *et al.,* 2012). This variance was most likely caused by industrial discharges of salts, chemicals, and garbage. Lower pH increases metal mobility and bioavailability, while higher pH affects metal solubility (Islam *et al.,* 2021). When assessing a river's ability to buffer against acidic inputs from rainfall or wastewater, alkalinity assessment is essential. Higher alkalinity typically translates into higher pH levels, according to research showing a positive association between the two variables. Alkalinity and pH were both greater in the summer than in the winter. The total alkalinity of the Buriganga River varied between 55 and 295 mg/L, with the summertime peak near Mirpur Bridge being 295 mg/L. Salinity from solid waste and industrial effluents was the cause of the electrical conductivity (EC), which peaked at Babubazar Ghat and ranged from 121.6 to 2456 µS cm^{-1} (Saifullah *et al.,* 2012).

During the wet season, dissolved oxygen (DO) levels were constantly higher, reaching a peak of 6.9 mg/L at Babubazar Ghat. In the dry season, however, they dropped to 0.0 mg/L at Mirpur Bridge (Ahammed *et al.,* 2017; Salman *et al.,* 2018). Since the Environmental Quality Standard (ECR) calls for a minimum of 5 mg/L, none of the measured DO levels complied. Since DO is essential for maintaining aquatic life and supporting biochemical activities, low quantities suggest the Buriganga River is experiencing ecological degradation and is on the verge of biological collapse (Mottalib *et al.,* 2017). The Buriganga River's Biochemical Oxygen Demand (BOD) levels peaked at 76.60 mg/L (Ahammed *et al.,* 2017) near the Mirpur Bridge in the winter and fell to 8.0 mg/L at the same location in the monsoon (Salman *et al.,* 2018). These values were noticeably higher during the dry season. A high BOD is a sign of significant microbial activity and organic pollution, which causes the river's oxygen content to drop significantly. The dry season saw a noticeably higher level of Chemical Oxygen Demand (COD), which measures the amount of oxygen needed to oxidise organic and certain inorganic materials. COD peaked at 602.76 mg/L at Sadarghat during the dry season, while it was 26 mg/L at Mirpur Bridge during the monsoon. These results indicate a high load of organic pollutants in the river, as they greatly surpass the UNECE criterion of ≤3 mg/L (Islam *et al.,* 2021).

Table 1: Water quality parameters at different locations of the Buriganga River

Seasons	Key water parameters									References
	pH	EC (µS/cm)	TDS (mg/L)	TSS (mg/L)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	Chloride (mg/L)	Total Alkalinity (mg/L)	
Summer	7.52	1130	566	72	0.0	21	59	119	295	**Salman *et al.*, 2018**
Monsoon	6.91	230	99	16	3.7	8	26	14	55	
Winter	7.50	739	374	37	0.0	11	30	49	147	
Summer	8.47	315.26	-	-	1.01	-	-	-	-	**Fatema *et al.*, 2012**
Winter	7.49	121.6	124	10.90	1.04	76.60	104.8	-	-	**Ahammed *et al.*, 2017**
Summer	7.95	888	497	36.10	0.0	25.20	64.0	-	-	
Summer	7.23	655	46.66	605	2.56	41.33	602.76	-	-	**Islam *et al.*, 2021**
Summer	6.05	-	424	129	3.45	49.35	126	60.56	-	**Rahman *et al.*, 2014**
Monsoon	7.16	-	168	84.75	4.69	35.95	90	47.34	-	
Winter	6.05	-	1015	158.25	2.39	68.36	139	82.49	-	
Winter	6.99	1190	587	216	3.05	88.25	218	-	270	**Akbor *et al.*, 2017**
Winter	7.3	2456	-	-	4.2	28.2	-	-	-	**Saifullah *et al.*, 2012**
Monsoon	7.0	1620	-	-	6.3	29.6	-	-	-	
Summer	7.60	1200	-	-	-	50	200	-	-	**Mottalib *et al.*, 2017**

The Buriganga River's total suspended solids (TSS) concentration varied from 16 mg/L to 605 mg/L, with Pagla recording the highest level in March. Especially during the dry season, these levels are higher than the 25 mg/L USEPA standard. High TSS damages aquatic plants and animals by increasing turbidity, obstructing light penetration, interfering with photosynthesis, and lowering dissolved oxygen levels. Because suspended particles absorb more heat, high TSS also raises the temperature of the surface water. The Buriganga River's Total Dissolved Solids (TDS) levels varied from 99 to 1015 mg/L, with Mirpur Bridge recording the highest level during the winter. During the dry season, TDS concentrations were higher than the 500 mg/L USEPA allowable limit. According to Salman *et al*. (2018), TDS indicates the presence of dissolved minerals and ions such as metals, phosphates, nitrates, ammonia, and sulphates.

Heavy Metal Concentrations and Sources

Research indicates that water contains more than WHO/FAO safety standards for Mn, Zn, Se, and Pb (Ahmed *et al.,* 2016; Uddin & Jeong, 2021). According to the Nemerow Index (NI), 86% of samples indicate moderate to high contamination, making the river "severely polluted" (Akbor *et al.,* 2020).

Table 2 presents the concentrations of the ten metals in the water samples collected during summer, monsoon, and winter. This study examined multiple articles and identified 10 elements, noting that trace amounts of metals such as iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) are essential for biological functions in humans and aquatic organisms; however, increased concentrations may result in toxicity and ecological disturbance. The review study noted Cr levels ranging from (0.020±0.065) mg/l to (0.757(1.1297) mg/l. It was frequently noted that metal concentration was elevated in winter compared to the monsoon, perhaps because of decreased water movement that promotes metal accumulation. These changes may also be influenced by the river's flow dynamics and the existence of industrial and sewage discharge sites. Primary sources of increased Chromium levels at various locations in Dhaka comprise industrial discharge, notably from tanneries, municipal wastewater, domestic refuse, and urban runoff. Lead is a poisonous, carcinogenic agent that presents significant hazards to human health, especially by impairing the nervous system. Lead concentration was measured at a minimum of 0.0039 (0.0006) mg/l by Das *et al.* in 2011 during summer and a maximum of 1.470 (0.405) mg/l by Nargis *et al.* in 2021 during winter, with the range remaining between these values. Cadmium and its derivatives are highly toxic, with exposure associated with cancer and detrimental effects on the cardiovascular, renal, digestive, neurological, reproductive, and respiratory systems. Cadmium (Cd) concentration measured ranged from 0.00011 (±0.0005) mg/l to 0.010 (±0.006) mg/l. Copper was detected at a concentration of 0.460 (0.0331) mg/l in Sadarghat port along the Buriganga River, as reported by Akbor *et al.*, 2020, representing the highest recorded figure for this element. Zinc is a vital trace element that is integral to numerous physiological and metabolic processes in various organisms. This investigation found Zinc (Zn) values varying from 0.0071 mg/l to 1.043 mg/l. Iron in water may derive from natural geological formations, industrial discharges, and household garbage. Exceeding iron levels of 10 µg/g may lead to increased pulse rate, blood clotting, hypertension, and weariness. The concentration of Fe in Buriganga river water ranged from 0.74 mg/l to 3.614 (0.591) mg/l. In general, dry seasons demonstrate elevated metal concentrations owing to less water flow, hence increasing toxicity risks (Uddin & Jeong, 2021), while concentrations are lower during the monsoon period. Such changes may also be affected by the river's hydrodynamics and its closeness to industrial areas and sewage discharge points.

The contamination of the Buriganga arises from both industrial and domestic effluents. Traditionally located in Hazaribagh, tanneries released untreated effluents comprising Chromium (Cr), Lead (Pb), Cadmium (Cd), and copper (Cu) directly into the river (Hossain, 2025; Uddin & Jeong, 2021). Notwithstanding the relocation initiatives to Savar in 2022, lingering pollution endures because of insufficient wastewater treatment (Hossain, 2025). The textile and pharmaceutical industries emit zinc (Zn), nickel (Ni), and Arsenic (As) during dyeing and chemical procedures (Real *et al.,* 2019; Sahen *et al.,* 2025). Urban sewage and inadequate waste management intensify contamination, adding elements such as Mercury (Hg) and silver (Ag) (Akbor *et al.,* 2020; Rakib *et al.,* 2024). Significant contributors to heightened element concentrations at multiple sites in Dhaka are industrial effluents, particularly from leather tanning operations, municipal wastewater, household garbage, and urban surface runoff.

Table 2: Concentration of heavy metals in water from various locations of the Buriganga River

Seasons	Concentration of Heavy Metals (mg/l)										References
	Cr	**Mn**	**Fe**	**Ni**	**Cu**	**Zn**	**Cd**	**Hg**	**Pb**	**As**	
Monsoon	0.757±1.1297	0.598±0.0536	3.614±0.591	0.7958±0.521	0.0126±0.009	BDL	0.0041±0.000	BDL	0.0430±0.020	-	**Nargis *et al.*, 2021**
Winter	BDL	1.287±1.04	BDL	0.7958±0.521	0.1703±0.521	0.3912±134.82	BDL	0.102±0.016	1.470±0.405	-	
Summer	0.556	-	2.83	-	-	0.90	0.008	0.0022	0.0606	-	**Mottalib *et al.*, 2017**
Summer	-	0.0555	-	-	0.0063	0.0187	0.0132	-	0.0028	0.0020	**Mokaddes, *et al.*, 2012**
Winter	0.068±0.004	-	-	-	0.0239±0.0027	0.120±0.01132	0.00095±0.000	-	0.0132±0.00214	-	**Billah *et al.*, 2022**
Summer	0.306	-	1.32	0.036	0.084	1.043	0.033	0.017	0.075	-	**Rahman *et al.*, 2014**
Monsoon	0.08	-	0.74	0.017	0.036	0.337	0.010	0.010	0.052	-	
Winter	0.468	-	1.79	0.047	0.219	0.858	0.052	0.050	0.111	-	
Monsoon	0.0903±0.0203	-	-	0.0027±0.0007	0.00069±0.0000	0.0071±0.001	0.0015±0.0013	-	0.00805±0.0037	0.00325±0.00239	**Das *et al.*, 2011**
Winter	0.293±0.239	-	-	0.0057±0.0046	BDL	0.018±0.0088	0.00237±0.0003	-	0.00859±0.0025	0.00353±0.0007	
Summer	0.251±0.020	-	-	0.0023±0.0009	BDL	0.015±0.00646	0.00011±0.0005	-	0.0039±0.0006	0.0023±0.00032	
Winter	0.0277±0.0176	0.238±0.199	-	0.0222±0.0141	0.026±0.159	0.0651±0.048	0.00127±0.0083	-	0.0299±0.0051	0.0165±0.0085	**Bashar *et al.*, 2023**
Summer	0.057±0.0119	-	-	0.07±0.0164	0.460±0.0331	0.670±0.0777	0.005±0.00084	0.036±0.0023	0.114±0.353	BDL	**Akbor *et al.*, 2020**
Winter	0.045±0.0936	-	-	0.062±0.0145	0.428±0.0308	0.125±0.0145	0.005±0.00084	0.025±0.0015	0.085±0.0264	BDL	
Winter	0.029±0.070	0.811±0.589	1.814±0.410	0.811±0.589	0.029±0.070	1.036±0.569	0.010±0.006	0.013±0.00	0.011±0.019	-	**Fahad *et al.,***

Seasons	Concentration of Heavy Metals (mg/l)										References
	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Hg	Pb	As	
Summer	0.020±0.065	0.764±0.800	1.434±0.299	0.764±0.800	0.020±0.065	0.954±0.156	0.021±0.008	0.010±0.00	BDL	-	**2024**
Rainy	BDL	0.725±0.000	0.860±0.398	0.725±0.000	BDL	0.564±0.000	BDL	0.014±0.00	0.025±0.007	-	

*Abbreviations: BDL indicates below the detection limits

Heavy Metal Concentrations in Sediments

The total amounts of heavy metals in sediments are displayed in Table 3. In recent years, heavy metal pollution in aquatic ecosystems has elicited significant concerns due to its persistence, non-biodegradable characteristics, prolonged lifespan, and propensity to bioaccumulate in diverse aquatic creatures. Sediments serve as repositories for metals, with average amounts of Cd (7.7 mg/kg), Pb (731 mg/kg), and Cr (297 mg/kg) significantly beyond U.S. EPA limits (Islam *et al.,* 2018).

Chromium (Cr) values in the sediment samples varied from 21 to 243 mg/kg (Table 3), with the maximum quantity seen at the Kholamura launch terminal. Elevated Chromium levels were continuously detected at multiple locations along the Buriganga River, especially within its tributaries, but a decreasing trend was reported at downstream sites (Mohiuddin *et al.,* 2010). The increased levels are presumably due to the direct release of untreated waste from the leather tanning industry. These results exceed established pollution levels, signifying considerable contamination. Chromium is widely utilised in leather tanning and the manufacturing of dyes, mordants, and textile pigments. Anthropogenic contributions of Chromium to surface waters may stem from municipal wastewater, laundry detergents, road runoff (including tire and brake wear), paints, and radiator corrosion. The principal source of Chromium contamination in the Buriganga River is associated with effluents from the tanning sector (Mohiuddin *et al.,* 2015).

Lead (Pb) concentrations in sediments varied from 31 to 110.34 mg/kg, with the maximum concentration recorded at Sadarghat port during winter and at Kholamura Lonch terminal in the dry season (Table 3). Cadmium (Cd) concentrations ranged from 0.281 to 6.1 mg/kg. The peak concentration was documented by Islam *et al.* (2018), whereas the minimum was noted by Akbor *et al.* (2020) near Sadarghat port. Nickel (Ni) values in sediments varied from 19 to 287.65 mg/kg. Nearly all recorded values surpassed allowable environmental thresholds, highlighting the pressing necessity for remedial initiatives. Zinc (Zn) is a crucial and plentiful transition metal required for primary productivity, and its lack can adversely affect ecosystem functionality. In the sediments of the Buriganga River, zinc values varied from 16.6 to 502.3 mg/kg. Zinc is extensively utilised in die-casting, coatings, rubber fabrication, and alloy production. Saha *et al.* (2011) identified the greatest concentration of zinc (Zn) at Wachpur Ghat in the winter season. Sediments exhibit severe pollution (Igeo > 5) for Ag, Pb, and Cd, signifying significant anthropogenic impact (Akbor *et al.,* 2020; Islam *et al.,* 2018).

Table 3: Concentration of heavy metals in sediments from various locations of the Buriganga River

Seasons	Concentration of Heavy Metals (mg/kg)										References
	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Hg	Pb	As	
Winter	148	-	-	68	133	-	6.1	-	48	20	**Islam *et al.,* 2018**
Summer	129	-	-	61	109	-	4.8	-	43	16	
Winter	173	403.6	1298.9	153	344	48.1	1.0	-	31	-	**Mohiuddin *et al.*, 2015**
Summer	243	-	-	81	92	27.9	4.1	-	82	0.013	**Mohiuddin *et al.*, 2011**
Winter	187	-	-	91	55	16.6	4.2	-	110	0.012	
Summer	218.39	-	-	147.06	23.18	-	3.87	-	77.13	-	**Ahmad *et al.,* 2010**
Monsoon	203.17	-	-	199.28	21.75	-	3.26	-	64.71	-	
Winter	155.01	-	-	287.65	32.54	-	3.11	-	69.78	-	
Winter	101.2	-	-	-	184.4	502.3	0.8	-	79.8	-	**Saha *et al.,* 2011**
Summer	22.471	-	-	21.043	168.95	222.3	0.281	0.625	110.64	2.15	**Akbor *et al.,* 2020**
Winter	21.217	-	-	19.713	159.06	208.77	0.269	0.606	107.75	2.02	
Winter	105.51	-	-	26.10	203.86	251.85	-	-	71.11	-	**Sikder et al., 2016**

Ecological Risk Assessment

The ecological risk assessment of the Buriganga River in Bangladesh underlines significant pollution from industrial and household sources. Heavy metals such as Cadmium, Lead, and Chromium surpass ecological safety thresholds, presenting significant hazards to aquatic organisms and human health. Approximately 71% of sediment samples exhibited a Pollution Load Index (PLI) exceeding 1, indicating a trend of increasing degradation (Akbor *et al.,* 2020; Islam *et al.,* 2018). Cadmium and Mercury presented the greatest dangers (Potential Ecological Risk Index (PERI) >600), with 86% of locations categorised as moderately to very hazardous (Akbor *et al.,* 2020; Islam *et al.,* 2018). Cadmium (CF=61) and Lead (CF=24) predominated sediment pollution, associated with tannery and industrial effluents (Islam *et al.,* 2018; Rakib *et al.,* 2024).

Ahmed *et al.* (2016) and Uddin & Jeong (2021) indicated that fish species such as Labeo rohita bioaccumulate manganese (Mn), Lead (Pb), and Arsenic (As), beyond safety thresholds and presenting carcinogenic hazards (e.g., Target Cancer Risk for As = 1.2×10^{-3}). Metals in irrigation water permeate crops, with rice and spinach exhibiting Cadmium and Lead concentrations that jeopardise food safety (Sahen *et al.,* 2025; Uddin & Jeong, 2021).

Human Health Implications

The ecological hazards of the Buriganga River directly affect human health, especially because of increased concentrations of heavy metals in the water. These toxins infiltrate the food chain via aquatic organisms, presenting hazards including carcinogenicity, organ damage, and developmental toxicity. Prolonged exposure, particularly via the ingestion of contaminated fish and water, poses a threat to at-risk populations (Rahman *et al.,* 2021). Hazard Index (HI) values exceeding 1 signify cumulative health risks from Mn, Pb, and Cd, impacting renal, neurological, and skeletal systems (Ahmed *et al.,* 2016; Real *et al.,* 2019). Arsenic and nickel in aquatic environments and ichthyic species are associated with increased cancer risks (TR $>1\times10^{-4}$) (Ahmed *et al.,* 2016; Uddin & Jeong, 2021).

Heavy metals, including Cadmium (Cd), Arsenic (As), Lead (Pb), Mercury (Hg), and Chromium (Cr), are extremely poisonous and pose considerable hazards to human health and the environment. Although trace metals such as zinc (Zn), copper (Cu), and nickel (Ni) are vital in minimal quantities, excessive exposure interferes with biological systems.

In metropolitan environments, heavy metals infiltrate the human body via dermal contact, inhalation, and ingestion, with a particular impact on children. They pollute food, water, and air, resulting in acute, chronic, and sub-chronic health problems, including neurotoxicity, cancer, and developmental disorders.

Lead (Pb) is a prevalent and very harmful environmental contaminant. It usually enters the body through ingestion or inhalation and is carried in the bloodstream in multiple chemical forms, harming essential organs like the heart, liver, kidneys, and brain. Lead hinders haemoglobin production, interferes with enzyme functions, and induces neurological harm, particularly in youngsters, potentially resulting in diminished IQ, developmental setbacks, and psychosis (Barua *et al.,* 2021).

Nickel (Ni), Copper (Cu), and Zinc (Zn) are vital elements, yet they become detrimental when excessively absorbed from environmental sources. Copper and nickel have been linked to tumorigenesis and potential carcinogenicity. Despite Zn being regarded as largely non-toxic, excessive use can disrupt nutrient absorption and adversely affect growth and reproductive health (Haque *et al.,* 2022).

Chromium (Cr), especially in its hexavalent state (Cr VI), is a significant carcinogen. Mercury (Hg) possesses no recognised advantageous biological role in humans and is highly poisonous in all its forms. Inorganic Mercury exposure can Lead to gastrointestinal problems, spontaneous abortion, and congenital anomalies. Organic compounds, including methylmercury, exhibit neurotoxicity and may Lead to symptoms such as erethism, gingivitis, neurological deterioration, and central nervous system (CNS) impairment (Barua *et al.,* 2021).

Arsenic (As), similar to Lead (Pb) and Mercury (Hg), is extremely hazardous and carcinogenic across all oxidation states. Prolonged Arsenic exposure impairs insulin functionality, enzymatic activity, and ATP synthesis. It is associated with several health issues and presents a significant risk when consumed in excessive amounts (Pasha *et al.,* 2023).

While Cu, Zn, and Ni are vital metals, excessive consumption may Lead to tumours, reproductive complications, and growth deficiencies. These findings underscore the imperative to regulate heavy metal contamination to protect public health.

Impact of Heavy Metals on Soil Microbial Biomass and the Environment

Soil microbial biomass is a significant indicator of pollution. Although modest quantities of heavy metals may promote microbial development, elevated amounts markedly diminish microbial biomass and enzymatic activity. Heavy metal exposure impairs soil biological processes, modifies microbial populations, diminishes fertility, and alters species diversity, particularly impacting fungi. These metals may infiltrate the food chain, resulting in prolonged ecological harm (Barua *et al.,* 2021).

In contrast to organic contaminants, heavy metals do not undergo natural degradation and instead accumulate in soils, rivers, and marine sediments. They are readily translocated between environmental compartments and represent a significant danger to aquatic environments by infiltrating the food web and adversely affecting aquatic organisms.

Mitigation Strategies and Policy Recommendations

Addressing ecological hazards in the Buriganga River necessitates a multifaceted approach. Essential recommendations encompass the enforcement of stringent industrial waste management regulations, the establishment of centralised effluent treatment facilities, and the promotion of environmentally sustainable technologies (Rahman *et al.,* 2021). Industries must have mandated effluent treatment facilities (ETPs) and adhere to compliance (Hossain, 2025; Rakib *et al.,* 2024), while residents should be educated on the hazards of utilising dirty water and encouraged to adopt safer agricultural techniques (Uddin & Jeong, 2021). Urban development must incorporate sustainable wastewater systems, and regulatory frameworks should promote compliance through penalties and subsidies. Dredging and phytoremediation are necessary to diminish metal bioavailability (Rakib *et al.,* 2024; Sahen *et al.,* 2025). Broaden research on seasonal metal fluxes and trophic transfer processes (Rakib *et al.,* 2024; Sahen *et al.,* 2025). Ultimately, cooperation among government, industry, and communities is essential for sustained success. These methods can rehabilitate ecological integrity and protect public health.

Conclusion

This study's findings indicate that the Buriganga River is undergoing considerable environmental stress from the release of untreated industrial effluents, municipal sewage, and urban runoff. Seasonal variations exacerbate pollution levels, especially in the dry season when diminished water flow results in the concentration of pollutants. Physicochemical characteristics, including significantly low dissolved oxygen, heightened BOD and COD values, and increased electrical conductivity, indicate poor water quality and ecological degradation. The concentration of heavy metals, such as Chromium, Lead, Cadmium, and iron, in water and sediment samples surpasses international safety thresholds, presenting significant health hazards to adjacent communities via bioaccumulation and environmental exposure. These harmful components also interfere with soil microbial activity, biodiversity, and the overall functioning of ecosystems. The enduring and non-biodegradable characteristics of heavy metals pose a significant threat to the long-term viability of the Buriganga River. Prompt and synchronised actions are crucial, encompassing rigorous regulation of industrial effluents, efficient wastewater treatment, consistent monitoring, and ecological restoration projects.

The ecological problem of the Buriganga River highlights the pressing necessity for comprehensive management. Although initiatives such as tannery relocation signify advancement, the rigorous implementation of rules, technical innovations, and public involvement are essential for mitigating heavy metal pollution. Future initiatives must emphasise transdisciplinary research and regional collaboration to protect this essential ecosystem and its reliant communities.

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