

Heavy Metal Contamination in Major Industrial Zones in Dhaka: A Review of Water and Sediment Quality

Sifat Aysha^{1*}, Suchana Biswas¹, Fairrose Tasnim¹, Atia Zannat Dia¹

Abstract

Heavy metal contamination of groundwater, surface water, and sediments has emerged as one of the most pressing environmental challenges of present time, carrying serious implications for public health, particularly in regions shaped by intensive industrial activities. This review centered on key industrial zones surrounding Dhaka city, where such contamination has been especially severe. Drawing on twenty peer-reviewed studies, it documented concentrations of five heavy metals (Ni, Cr, Cd, Pb, and Fe) across the study areas and evaluated the extent of contamination through comparison with established standards, geospatial mapping, and health risk assessment. Surface water exhibited higher mean concentrations of most heavy metals compared to groundwater, with Ni, Cd, Pb and Fe recording means of 0.28, 0.86, 3.37 and 3.65 mg/l in surface water and 0.073, 0.008, 3.362 and 3.11 mg/l in groundwater respectively, while Cr was the sole exception, with groundwater (1.92 mg/l) exceeding surface water levels (1.01 mg/l). However, heavy metal concentrations, particularly Cr, Pb, and Fe concentrations in both groundwater and surface water exceeded both WHO and ECR standards for safe drinking water. Geospatial analysis displayed higher Cr and Pb levels in Hazaribag groundwater and Dhaleshwari surface water, with Cr averaging 7.6 mg/L and 2.97 mg/L, and Pb averaging 1.2 mg/L and 1.17 mg/L, respectively. Health risk assessments indicated substantial carcinogenic risks from elevated Cr and Pb levels, particularly affecting children, with the highest risks observed in the Hazaribagh and Narayanganj areas. This study underscores the urgent need for stringent pollution control measures and regular monitoring of water quality to mitigate health risks and recommends the implementation of effective water treatment solutions.

Keywords: Heavy metal contamination, Groundwater, Surface water, Geospatial analysis, Health risk assessment, Industrial zone.

1. Introduction

Metallic elements with a density that is comparatively higher than that of water are referred to as heavy metals (Tchounwou et al., 2014). Some are considered

* Corresponding Author email: sifataysha@gmail.com

¹ Department of Environmental Science, Bangladesh University of Professionals (BUP), Dhaka, Bangladesh

DOI: <https://doi.org/10.64494/JFST/v4i1/sa/2026/03/41-66>

essential (Cu, Zn, Fe etc.), and some are considered non-essential (Al, As, Pb etc.) for living organisms (Järup, 2003). The essential trace elements are necessary for our survival; i.e., iron is a constituent of hemoglobin and plays a vital role in transporting oxygen in the human body (Otten et al., 2006).

For daily needs and drinking, 97% of Bangladesh's population depends on groundwater (Hasan et al., 2007). According to the U.N. World Water Development Report 2022, Bangladesh is the sixth-largest estimated annual groundwater withdrawal country in the world. Bangladesh's low-lying topography and geographic location make it extremely vulnerable to the expected effects of climate change, which are expected to have an impact on almost every aspect of socioeconomic life. Of these, the water sector is the most sensitive and vulnerable, and the country's coastal areas are most at risk (Zahid et al., 2018). Fresh drinking water is a severe issue in many parts of Bangladesh because of anthropogenic activities and seawater intrusion having an impact on the surface and groundwater in these areas (Hossain & Shapna, 2025). Bangladesh is a disaster-prone nation that frequently experiences floods, storm surges, tropical cyclones, erosion of riverbanks and coastlines, droughts, and saline water invasion. However, contaminated drinking water is a contributing factor in 80% of all diseases in developing nations (Abedin et al., 2018). Arsenic, iron, salinity, and nitrate issues affect Bangladesh's groundwater for a variety of man-made and natural causes (Tasnim et al., 2025). In Bangladesh's coastal belt, where 45–50 million people live in 19 coastal districts and face severe freshwater scarcity, the supply of sustainable and clean drinking water has become a major concern for the general public (Rahman et al., 2018). Surface water quality is superior to groundwater considering TDS (total dissolved solids), chloride, iron, and arsenic levels, according to comparisons of the water quality indicators with World Health Organization (WHO) and Bangladesh (DoE) regulations.

Although heavy metals are naturally occurring elements found in the earth's crust, anthropogenic activities such as mining and smelting operations, industrial production and utilization, and domestic and agricultural applications of metals and metal-containing compounds account for the majority of environmental contamination and human exposure (Tchounwou et al., 2014). Environmental contamination may arise from the corrosion of metal corrosion, soil erosion of metal ions, heavy metal leaching, re-suspension of sediment, and the evaporation of metals from water sources to soil and groundwater. Additionally, weathering

and volcanic eruptions have been shown to have a serious effect on heavy metal pollution (Briffa et al., 2020). Coal powerplants, metal refineries, nuclear power plants, textiles, plastics, microelectronics, wood preservation, and paper mills are examples of industrial sources (Dey et al., 2021).

The Dhaka Metropolitan Police (DMP) has jurisdiction over an area of 315.98 square kilometers. Dhaka is situated in central Bangladesh on the eastern banks of the Buriganga River (23°42'N 90°22'E). Gazipur, Tangail, Munshiganj, Rajbari, Narayanganj, and Manikganj are the six districts that border the city (BBS, 2022). Despite making up only 3.14% of the DMP area's land use, industries have a disproportionately large environmental impact. The DMP area is home to 1,857 industries, many of which have grown largely unplanned and unregulated, according to RAJUK's Detailed Area Plan (DAP). The districts of Tejgaon, Hazaribagh, Mirpur, Demra, and Kamrangirchar have the highest concentrations of industrial activity.

It is essential to determine the situation of heavy metal contamination around Dhaka, considering public health concerns, environmental impacts, drinking water safety, and long-term socio-economic consequences for affected communities. Heavy metals are well-studied risk factors for major public health problems. For instance, exposure to Cr is can cause cancers, respiratory disorders, DNA damage, immunological issues etc. (Georgaki et al., 2023). Furthermore, aquatic ecosystems are highly vulnerable to pollution from both point and non-point sources, emphasizing the importance of monitoring contaminants in water bodies (Sorker & Khanam, 2022). Heavy metals are environmental pollutants whose direct human health effects can be mirrored by the deteriorating quality of soil, water and air over time (Tchounwou et al., 2014). Due to their ability to bioaccumulate, they may affect entire food chains (BBS, 2022). As a result, environmental monitoring on an ongoing basis is needed. The Buriganga River is a major source of water for individuals, and agriculture in Dhaka. It is located near many industrial activities (Tejgaon, Hazaribagh, Mirpur, Demra, and Kamrangirchar) that pose a potential threat to the future sustainability of the river due to contamination from heavy metals (Faisal et al., 2022). Systematic assessments of the Buriganga River are also necessary for the implementation of environmental regulations and as an inventory of emissions and discharge for enforcement of these regulations to prevent the illegal disposal of hazardous waste. In a city expanding as quickly as

Dhaka, such data also guide more sensible approaches to industrial zoning and land use.

2. Methodology

This study followed a structured approach to identify, screen, and select relevant literature on heavy metal contamination in water and sediment, followed by statistical and spatial analysis of the compiled data.

2.1 Study Area

The study area as shown in figure 1 included Savar, Tongi, Hazaribag, Narayanganj for the assessment of heavy metal concentration in groundwater and Buriganga, Dhaleshwari, Turag, Shitalakhya for the assessment of heavy metal concentration in surface water and sediment. These study areas were selected on the basis of their intense industrial activities, including tanneries, textile mills, and metal processing industries, which render them highly susceptible to heavy metal contamination in both groundwater and surface water.

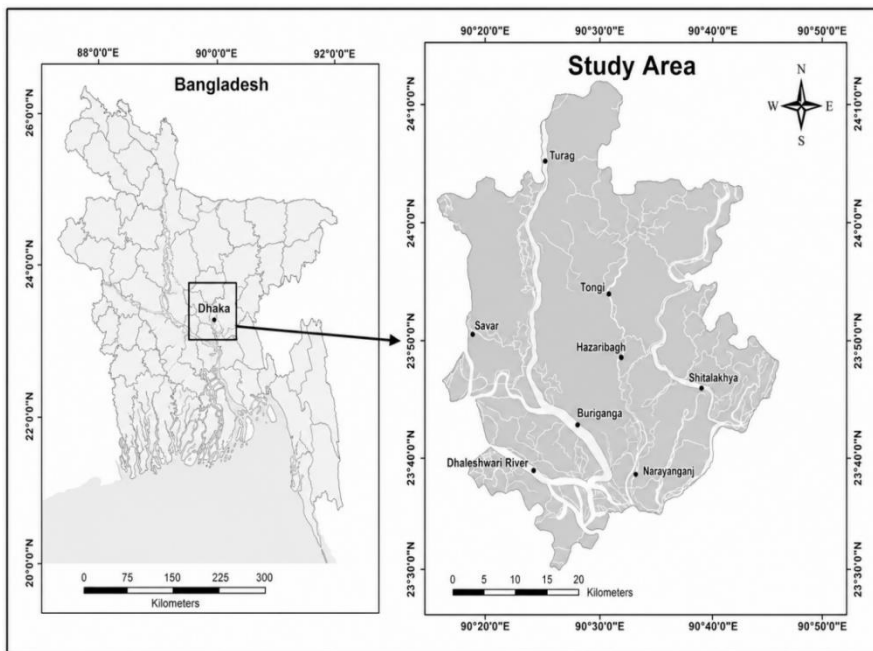


Figure 1: Study area map of Dhaka, Bangladesh, depicting key groundwater sites and surface water and sediment collection rivers covered in this review.

2.2 Data Collection

The concentration data of heavy metals in water sources presented in table 1, 2, and 3 were collected from 20 peer-reviewed articles published in different journals using internet search engines. Other necessary data were collected from different books, articles, websites, and journals. Selected keywords included ‘heavy metal pollution’, ‘trace elements in water’, ‘groundwater pollution’, ‘heavy metal in groundwater’, ‘heavy metal in surface water’, ‘trace elements in Bangladesh water’, ‘heavy metals in Bangladesh water’ etc. in different combinations. The analysis of collected data was done after sorting the concentration of different heavy metals study area-wise using Microsoft Excel 2016 software and was represented by preparing geospatial maps using ArcGIS 10.8.2 software.

2.3 Health Risk Assessment

A conventional method of assessing the potentially harmful effects of exposure to a specific chemical or microbiological agent over a specific amount of time is called a health risk assessment (HRA). USEPA (1989) health scientists have defined the hazard quotient for evaluating health risks arising from trace element toxicity in the following equation after thorough monitoring and data analysis (Bodrud-Doza et al., 2019; Myers et al., 2023; Khandare et al., 2020):

$$HQ = \frac{CDI}{RfD} \quad (1)$$

CDI is the Chronic Daily Intake of trace elements by humans in mg/kg/day and the reference dosage, or the highest allowable limit of a specific trace element in groundwater, is indicated by RfD (mg/kg/day) (USEPA, 1989). In addition, HQ value < 1 indicates the population is not exposed for calculating CDI via oral & Dermal (USEPA, 1989). The equations are:

$$\text{Chronic Daily Intake}_{\text{oral}} = \frac{Cw \times IR \times EF \times ED}{BW \times AT} \quad (2)$$

$$\text{Chronic Daily Intake}_{\text{Dermal}} = \frac{Cw \times SA \times Kp \times ET \times ED \times CF}{BW \times AT} \quad (3)$$

Here, the concentration of trace elements in water is denoted by Cw (mg/l), the skin area available for contact is denoted by SA (cm²), the permeability coefficient is denoted by Kp (cm/hour), the daily average water intake in the area is denoted by DI (L/day), the exposure time is ET (h/event), the annual exposure frequency is denoted by EF (days/year), the exposure period is denoted by ED

(years), the unit conversion factor is CF (L/cm³), the body weight is BW (Kg/person), and the average time is AT (days).

For non-carcinogenic risk assessment, the Hazard Quotients for each element are added up to determine the Hazard Index (HI) (Bodrud-Doza et al., 2019; Myers et al., 2023; Khandare et al., 2020). The equation is:

$$HI=HQ_1+HQ_2+.....+HQ_n \quad (4)$$

If $HQ < 1$, no chronic risk at that site. If $HQ > 1$, indicates a non-carcinogenic health risk. The chronic risk (HI or HQ) is divided into four types: (< 0.1) which denotes negligible risk, (≥ 0.1 to < 1) denotes low risk, (≥ 1 to < 4) and ≥ 4 denotes medium and High risk.

Carcinogenic risk (CR) is calculated by the multiplication of CDI and Slope factor (SF) of cancer by heavy metals (USEPA, 1989). The equation is:

$$CR = CDI \times SF \quad (5)$$

Here, CR stands for cancer risk; SF is the slope factor of contaminants (mg/kg/day).

3. Results and Discussion

This section provides an extensive analysis of the levels of heavy metals in groundwater, surface water, and sediment collected from various industrial sites around Dhaka, Bangladesh. The levels were then compared with WHO (World Health Organization) permissible levels for heavy metals, as well as with ECR (Environmental Conservation Rules) permissible levels for heavy metals in Bangladesh. The article also compares why there were differences in levels of different heavy metals based upon the type and extent of industrial activity in that particular part of Bangladesh.

3.1 Groundwater Analysis

The levels of nickel present in groundwater differed widely among the different study sites. In Tongi, the nickel level (0.0211 ± 0 mg/l) was well below the values specified by the Environmental Conservation Rules 2023 (ECR) and the World Health Organization (WHO) (0.05 mg/l and 0.07 mg/l respectively), as shown in figure 2a and table 1. However, the mean nickel level of Hazaribag on the other hand was much higher than either of these organizations had set, with a value of 0.1568 ± 0.2166 mg/l, as shown in figure 2a and table 1. This is primarily due to

the presence of a number of tanneries and metal manufacturing sectors in Hazaribag which continually release wastewater containing nickel into the surrounding environment. Chromium levels across all sites also varied from 0.0074 to 15.235. Savar had a mean Cr concentration of 0.0133 mg/l, and Tongi had a slightly lower mean Cr concentration of 0.0074 mg/l, as shown in figure 2b and Table 1. Both of these values are well within the ECR and WHO's respectable limit of 0.05 mg/l. Hazaribag, on the other hand, had a mean Cr concentration of 7.6228 mg/l, as shown in figure 2b and table 1, which is far too high. This result was not too surprising, given that the area has had a leather tanning assiduity for a long time and uses a lot of chromium composites in the process. There were also significant differences in the situations of cadmium in groundwater at different spots. Savar had an average Cd concentration of 0.002 mg/l, as shown in figure 2c and table 1, which was lower than the 0.003 mg/l position that both ECR and WHO say is safe. In Tongi, however, the concentration rose to 0.013 mg/l, surpassing the permissible limits, a finding that may reflect the influence of battery manufacturing operations and inadequate industrial waste management in the area. Hazaribag recorded a mean Cd concentration of 0.006 mg/l, as shown in figure 2c and table 1, also above the safety threshold, likely as a consequence of broader industrial waste contamination.

Lead concentration in groundwater also followed an uneven distribution across the study areas. Savar recorded a mean Pb concentration of 0.0024 ± 0 mg/l, which remained within the ECR and WHO admissible limit of 0.01 mg/l, while Tongi had a large value of 0.037 ± 0 mg/l, as shown in figure 2d and table 1, surpassing the established thresholds. The most alarming reading, still, came from Hazaribag, where the mean Pb concentration reached 1.205 ± 0 mg/l, as shown in figure 2d and table 1. A value of this magnitude indicated severe impurity, which was most likely caused by the area's inadequate waste operation practices and the accretive discharge of effluents. Savar had a mean Fe concentration of 0.159 ± 0.0325 mg/l, while Tongi had a mean concentration of 0.08 ± 0 mg/l, as shown in figure 2e and table 1.

These values were below the ECR standard of 1 mg/l and within the WHO guideline of 0.3 mg/l, indicating fairly contained impurity at these locales. With a mean Fe concentration of 9.105 ± 0 mg/l, as shown in figure 2e and table 1, Hazaribag once again distinguished itself from the other sites, indicating significant industrial pollution, most likely from metal processing activities.

Table 1: Concentration (mg/l) of heavy metals (Ni, Cr, Cd, Pb, Fe) in groundwater of study areas

Area	Ni (mg/l)	Cr (mg/l)	Cd (mg/l)	Pb (mg/l)	Fe (mg/l)	Reference
Savar	N/A	0.015	0.0022	N/A	0.136	Nesha et al. (2023)
Savar	N/A	0.01152	N/A	0.00239	0.182	Hasan et al. (2022)
Mean (Savar)	N/A	0.0133	0.002	0.0024	0.159	-
SD	N/A	0.0025	0	0	0.0325	-
Tongi	0.0211	0.0074	0.013	0.037	N/A	Sunjida et al. (2016)
Tongi	N/A	N/A	N/A	N/A	0.08	Bakali et al. (2014)
Mean (Tongi)	0.0211	0.0074	0.013	0.037	0.08	-
SD	0	0	0	0	0	-
Hazaribag	0.31	15.235	0.006	1.205	9.105	Akter et al. (2023)
Hazaribag	0.0037	0.0107	N/A	N/A	N/A	Alam et al. (2019)
Mean (Hazaribag)	0.1568	7.6228	0.006	1.205	9.105	-
SD	0.2166	10.7652	0	0	0	-
Narayanganj	N/A	0.0709	0.0067	0.1819	N/A	Rahman et al. (2020)
Narayanganj	0.04	0.015	0.0157	0.228	N/A	Seddique et al. (2004)
Mean (Narayanganj)	0.04	0.04295	0.0112	0.2050	N/A	-
SD	0	0.0395	0.0064	0.0326	N/A	-
Mean (All sites)	0.073	1.92	0.008	0.362	3.11	
SD (All sites)	1.92	3.80	0.005	0.54	5.1889	
ECR 2023	0.05	0.05	0.003	0.01	1	MoEF & CC. (2023)
WHO 2019	0.07	0.05	0.003	0.01	0.3	WHO (2019)

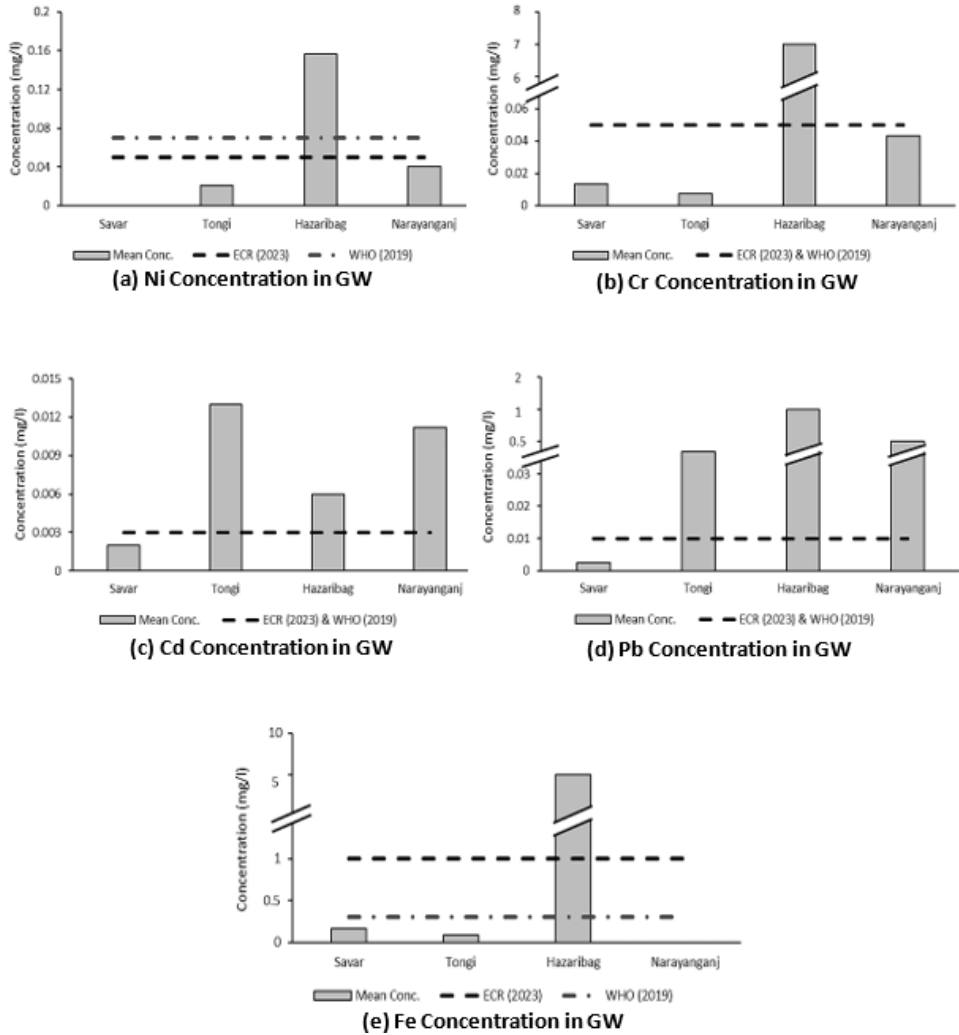


Figure 2: Concentrations of (a) Ni, (b) Cr, (c) Cd, (d) Pb, and (e) Fe in the groundwater of selected study areas. Vertical bars indicate standard values (ECR 2023, WHO 2019) of the concentrations.

3.2 Surface Water Analysis

In surface water samples, nickel concentration levels were found to vary significantly among different sites. For example, in the Buriganga River, nickel concentration levels were found to average 0.439 ± 0.6 mg/l, as shown in figure 3a and table 2, significantly higher than the WHO's 0.07 mg/l guideline level,

though still within the 1 mg/l limit set by the ECR. Similarly, in the Turag River, nickel levels averaged 0.355 ± 0.437 mg/l, as shown in figure 3a and table 2, again exceeding the WHO's guideline level. Such high levels in these two rivers are likely a result of waste dumped into these rivers by electroplating, alloy, and other metalworking industries along their banks.

Table 2: Concentration (mg/l) of heavy metals (Ni, Cr, Cd, Pb, Fe) in surface water of study areas

Area	Season	Ni (mg/l)	Cr (mg/l)	Cd (mg/l)	Pb (mg/l)	Fe (mg/l)	Reference
Buriganga	Winter	1.360	2.85	N/A	0.3	14.01	Hossain et al. (2021)
	Summer	0.740	1.13	N/A	0.24	10.61	
Buriganga	Pre-monsoon	0.036	0.019	N/A	0.075	1.34	Islam et al. (2015)
	Monsoon	0.017	0.012	N/A	0.049	0.74	
	Post-monsoon	0.041	0.048	N/A	0.112	1.79	
Mean (Buriganga)		0.439	0.8118	N/A	0.1552	5.698	
SD		0.600	1.236	N/A	0.109	6.166	
Dhaleshwari	Monsoon	N/A	2.59	1.52	1.02	N/A	Lipy et al. (2021)
	Winter	N/A	3.35	1.89	1.32	N/A	
Mean (Dhaleshwari)		N/A	2.97	1.705	1.17	N/A	
SD		0.000	0.537	0.262	0.212	N/A	
Turag		N/A	0.05	0.0025	0.08	N/A	Aktar et al. (2017)
Turag		0.370	0.33	0.0119	N/A	N/A	Ahmed et al. (2016)

Turag	Winter	0.890	0.69	N/A	0.385	8.41	Hossain et al. (2021)
	Summer	1.040	0.53	N/A	0.255	5.58	
Turag	Pre-monsoon	0.019	0.04	N/A	0.069	3.05	Islam et al. (2015)
	Monsoon	0.017	0.031	N/A	0.033	2.1	
	Post-monsoon	0.021	0.103	N/A	0.08	2.52	
Turag		0.131	0.0558	0.0143	0.0146	2.606	Sarkar et al. (2016)
Mean (Turag)		0.355	0.2287	0.0096	0.1309	4.0443	
SD		0.437	0.268	0.002	0.148	2.473	
Shitalakhya	Pre-monsoon	0.031	0.047	N/A	0.045	1.41	Islam et al. (2015)
	Monsoon	0.022	0.034	N/A	0.009	0.53	
	Post-monsoon	0.034	0.061	N/A	0.01	1.73	
Mean (Shitalakhya)		0.029	0.0473	N/A	0.0213	1.2233	
SD		0.006	0.009	N/A	0.025	0.622	
Mean (All sites)		0.28	1.01	0.86	0.37	3.65	
SD (All sites)		0.2167	1.3446	1.1988	0.5369	2.2623	
ECR 2023		1.0	0.5	2.0	0.1	3.0	MoEF&CC. (2023)
WHO 2019		0.07	0.05	0.003	0.01	0.3	

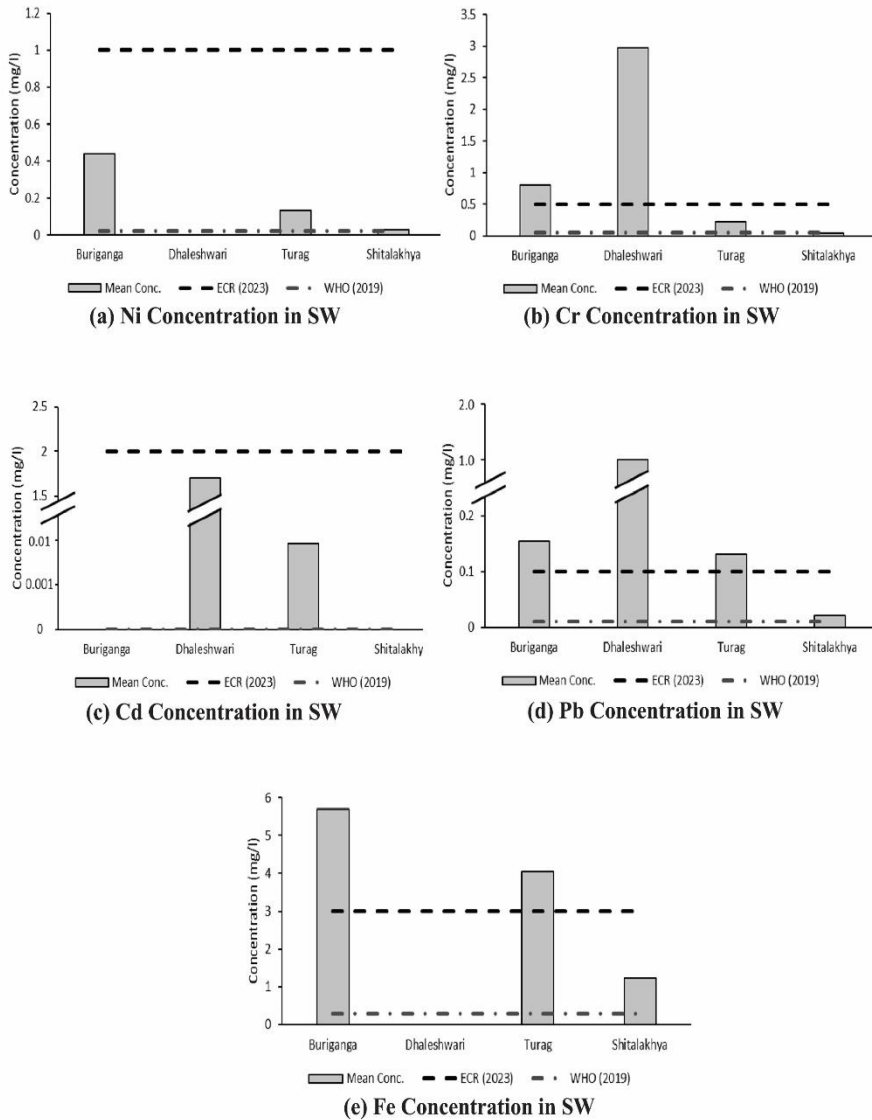


Figure 3: Concentrations of (a) Ni, (b) Cr, (c) Cd, (d) Pb, and (e) Fe in the surface water of selected study areas. Vertical bars indicate standard values (ECR 2023, WHO 2019) of the concentrations

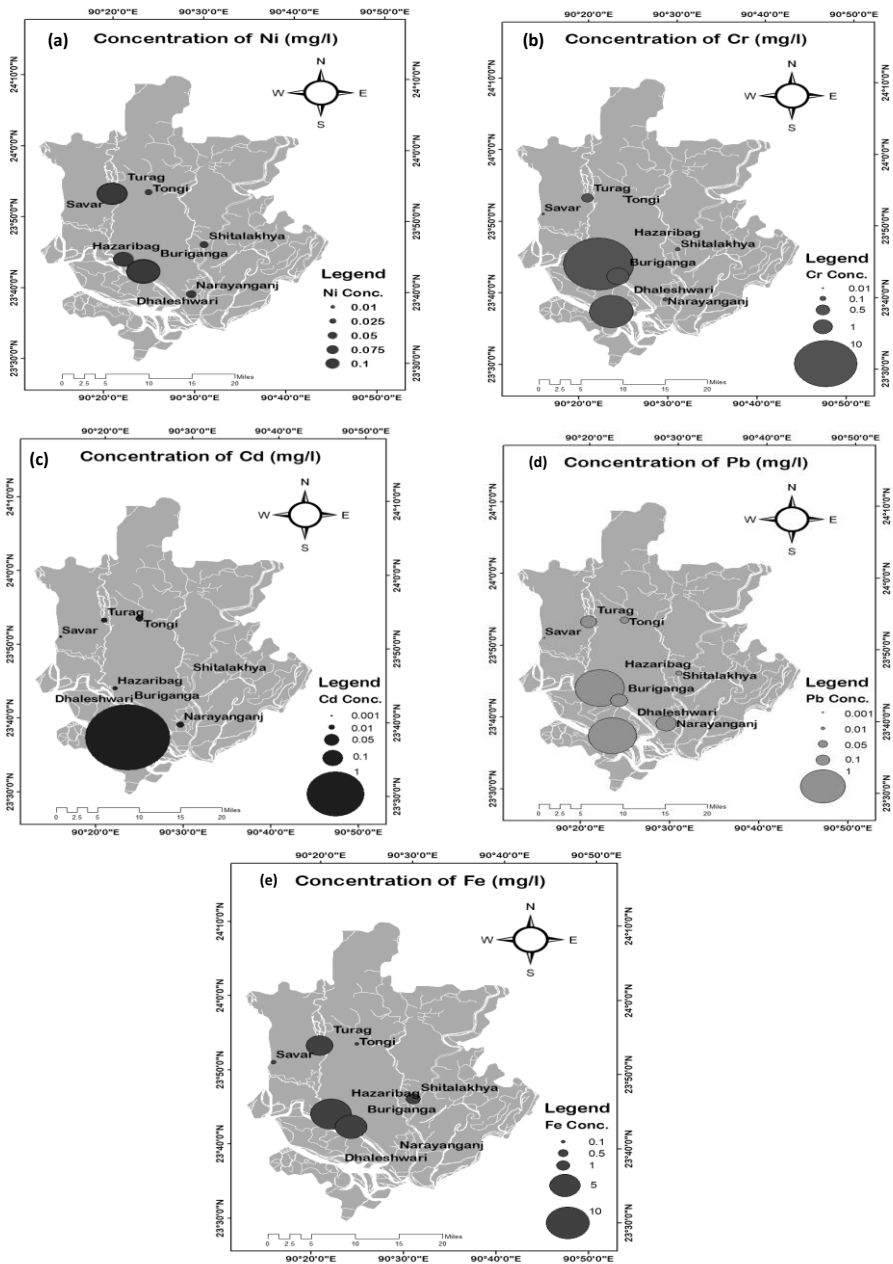


Figure 4: Concentration map of (a) Ni, (b) Cr, (c) Cd, (d) Pb, and (e) Fe in the groundwater and surface water of selected study areas

It was found that all the rivers had high chromium levels in their surface water samples. The Dhaleshwari River had a higher average chromium level of 2.97 ± 0.537 mg/l, illustrated in figure 3b and table 2, whereas the average Cr level in the Buriganga River surface water samples was found to be 0.8118 ± 1.236 mg/l, presented in figure 3b and table 2, which exceeded the WHO and ECR limits of 0.05 mg/l. The tanneries and textile industries use chromium in their processes, causing high levels of chromium in these rivers. High levels of pollution were also found in the rivers in terms of cadmium in their surface water samples. The mean concentration of Cd in the Dhaleshwari River water was 1.705 ± 0.262 mg/l, depicted in figure 3c and table 2, which is much higher than the WHO recommendation of 0.003 mg/l and very close to the limit set by the ECR, which is 2 mg/l. The high levels of Cd were probably due to discharges from battery factories, electroplating industries, and improper disposal of industrial wastes.

Both rivers had high concentrations of lead, which is extremely hazardous, in the surface water. Similarly, the Buriganga River had high concentrations of lead at 0.1552 ± 0.109 mg/l, shown in figure 3d and table 2, whereas the Dhaleshwari River had a mean Pb concentration of 1.17 ± 0.212 mg/l, presented in figure 3d and table 2, which is much higher than the WHO and ECR permissible limit of 0.01 mg/l. This may be due to the leftover leaded gasoline, urban runoff, paint factories, and battery factories. Surface water iron concentrations were just as alarming. For the Buriganga River, the mean Fe concentration of 5.698 ± 6.166 mg/l, shown in figure 3e and table 2, exceeded the ECR requirement of 3 mg/l as well as the WHO guideline of 0.3 mg/l. For the Turag River, the mean Fe concentration of 4.0443 ± 2.473 mg/l, presented in figure 3e and table 2, also exceeded the ECR requirement as well as the WHO guideline. This again points to corrosion of old infrastructure as well as to industrial activities involving the processing of metals.

From geospatial analysis in figure 4, higher concentrations of the metals were noticed in the northern parts of Dhaka city including Hazaribag groundwater, and Dhaleshwari, Buriganga surface water respectively.

3.3 Sediment Analysis

Table 3: Concentration (mg/l) of heavy metals (Ni, Cr, Cd, Pb, Fe) in sediments of study area

Area	Season	Ni (mg/Kg)	Cr (mg/Kg)	Cd (mg/Kg)	Pb (mg/Kg)	Fe (mg/kg)	Reference
Buriganga	Winter	34.06	111.6	N/A	18.33	4689.5	Hossain et al. (2021)
	Summer	31.18	99.7	N/A	15.01	4620.1	
Buriganga	Summer	21.04	22.47	0.281	110.6	N/A	Akbor et al. (2020)
	Winter	19.71	21.22	0.269	107.8	N/A	
Mean (Buriganga)		26.49	63.75	0.275	62.93	4659.3	
SD		7.186	48.635	0.009	53.45	49.073	
Dhaleshwari	Monsoon	N/A	96.02	1.56	23.69	N/A	Lipy et al. (2021)
	Winter	N/A	118.4	1.67	26	N/A	
Mean (Dhaleshwari)		N/A	107.2	1.615	24.84	N/A	
SD		N/A	15.80	0.078	1.633	N/A	
Turag		155.4	178	0.8	18.3	N/A	Mohiuddin et al. (2016)
Turag		35.3	127.1	0.115	26.35	12721.3	Sarkar et al. (2016)
Turag	Summer	54.14	67.77	N/A	30.23	4212.9	Hossain et al. (2021)
	Winter	57.71	71.81	N/A	31.6	4252.1	
Mean (Turag)		75.63	111.2	0.458	26.62	7062.1	
SD		54.08	52.13	0.485	5.976	4901.1	
Shitalakhya		N/A	38.39	0.64	13.16	N/A	Kabir et al. (2020)
Shitalakhya		N/A	74.82	N/A	N/A	38697.3	Islam et al. (2016)
Shitalakhya		29.09	10.15	0.43	24.66	N/A	(Rahman et al. 2020)
Mean (Shitalakhya)		29.09	41.12	0.535	18.91	38697.3	
SD		0	31.33	0.149	8.14	0	
Mean (All sites)		43.74	80.80	0.721	33.33	20139.6	

SD (All sites)		27.65	32.94	0.615	21.66	18215.6	
SD		0	32.42	0.149	8.132	0	
TRV (TEL)		18	37	0.6	35	N/A	

Nickel showed considerable variation at the regional level among the heavy metals. The mean concentration of Ni in the Turag River sediment was 75.637 ± 54.076 mg/kg, which was over three times higher than that of the Buriganga River at 26.499 ± 7.1856 mg/kg, presented in table 3. The concentration of both rivers was well above the Toxicity Reference Value (TRV) threshold for nickel, which stands at approximately 18 mg/kg. This raised considerable concerns regarding the health of the aquatic ecosystem. In light of the presence of numerous metal processing and electroplating industries along the routes of these rivers, the level of pollution at these sites was not surprising. The level of chromium in the rivers was slightly different. While the mean concentration of Cr in the Turag River was 111.16 ± 52.127 mg/kg and in the Dhaleshwari river was 107.19 ± 15.803 mg/kg, shown in table 3, well above the TRV threshold of approximately 37 mg/kg. These riverbanks are also home to tanneries and textile dyeing plants, which are known to generate chromium waste and seem to affect the sediment loading in the Turag River significantly. The Dhaleshwari River had the worst sediment cadmium pollution level among the three rivers, with a mean Cd value of 1.615 ± 0.0778 mg/kg, presented in table 3, more than twice the TRV value of 0.6 mg/kg. Cadmium accumulation in these river systems was mainly attributed to electroplating processes, battery manufacturing, and the routine disposal of untreated industrial waste.

In addition, all the rivers under investigation had noticeable higher lead amounts present in the sediments. The TRV of 35 mg/kg was highly exceeded by the mean Pb concentration of the Buriganga River, which was 62.934 ± 53.452 mg/kg, shown in table 3, and the mean Pb concentration of the Turag River, which was 26.619 ± 5.9757 mg/kg, presented in table 3. This is because the Buriganga River had a significantly higher mean Pb concentration, indicating more severe contamination, possibly due to the continuous discharges from the paint and battery production industries. Hence, there are reasons to be concerned about the aquatic life in both of the above locations. Among all the elements under study in the present article, the concentration of iron in the sediments of the water bodies is the highest. The concentration of Fe in the Shitalakhya River is 38697.3 ± 0 mg/kg on average, shown in table 3, suggesting the presence of a discernible industrial imprint in the riverbed.

3.4 Health Risk Assessment

Significant differences were observed in the levels of risk due to cancer-causing and non-cancerous agents among the populations of the studied areas, depending on the age group and the route of exposure and the sources of water. Children (0-10 years) were found to have higher noncarcinogenic risk than adults for all the areas and routes of exposure. At the Hazaribagh area, the HQ and HI values for the children due to oral exposure to groundwater found in this study were extremely high, i.e., 192.82, shown in table 4. However, the values for adults were lower, i.e., up to 90.903, presented in table 4. This was true for all areas of study as well, indicating that children were more physiologically vulnerable to the effects of heavy metal contamination of water. Among the routes of exposure to contamination that were considered, the route of ingestion was more important than that of dermal contact.

Table 4: Non-carcinogenic risk for groundwater and surface water among children and adults

Area	Fe	Pb	Cr	Ni	Cd	Hazard Index (HI)	Chronic Risk according to USEPA (1999)
GW Area	HQ Oral Adult					HI	
Savar	0.01666	N/A	0.13933	N/A	0.12571	0.30048	Low
Tongi	0.00838	0.29071	0.07752	0.03316	0.81714	1.22691	Medium
Hazaribagh	0.95386	9.46786	79.8579	0.2464	0.37714	90.9031	High
Narayangonj	N/A	1.61071	0.44995	0.06286	0.704	2.82752	Medium
GW Area	HQ Oral Child					HI	
Savar	0.03533	0.03983	0.29555	N/A	0.26667	0.63739	Low
Tongi	0.01778	0.61667	0.16444	0.07033	1.73333	2.60256	Medium
Hazaribagh	2.02333	20.0833	169.395	0.52267	0.8	192.824	High
Narayangonj	N/A	3.41666	0.95444	0.13333	1.49333	5.99778	High
GW Area	HQ Dermal Adult					HI	
Savar	0.00051	0.00008	0.00253	N/A	0.05721	0.06031	Negligible
Tongi	0.00025	0.00126	0.00141	0.00011	0.37183	0.37487	Low
Hazaribagh	0.02893	0.04103	1.45355	0.00083	0.17161	1.69597	Medium
Narayangonj	N/A	0.00698	0.00819	0.00021	0.32035	0.33573	Low

GW Area	HQ Dermal Child					HI	
Savar	0.00149	0.00024	0.00748	N/A	0.16877	0.17798	Low
Tongi	0.00075	0.00371	0.00416	0.00033	1.09699	1.10594	Medium
Hazaribagh	0.08537	0.12105	4.28826	0.00245	0.50630	5.00343	High
Narayangonj	N/A	0.02059	0.02416	0.00062	0.94507	0.99048	Low
SW River	HQ Oral Adult					HI	
Buriganga	0.59693	1.21942	8.50457	0.68986	0	11.0108	High
Dhaleshwari	0	9.19286	31.1142	0	107.171	147.479	High
Turag	0.42369	1.02850	2.39590	0.55786	0.60342	5.00938	High
Shitalakhya	0.12816	0.16736	0.49552	0.04557	0	0.83660	Low
SW River	HQ Oral Child					HI	
Buriganga	1.266222	1.219429	18.04	1.463333	0	21.9889	High
Dhaleshwari	0	9.192857	66	0	227.333	302.526	High
Turag	0.89873	1.02850	5.08222	1.18333	1.28	9.47279	High
Shitalakhya	0.27184	0.16736	1.05111	0.09667	0	1.58698	Medium
SW River	HQ Dermal Adult					HI	
Buriganga	0.01810	0.00529	0.15479	0.00232	0	0.18051	Low
Dhaleshwari	0	0.03984	0.56633	0	48.7677	49.3739	High
Turag	0.01285	0.00446	0.04361	0.00188	0.27459	0.33739	Low
Shitalakhya	0.00389	0.00072	0.00902	0.00015	0	0.01379	Low
SW River	HQ Dermal Oral					HI	
Buriganga	0.05342	0.01559	0.45668	0.00686	0	0.53256	Low
Dhaleshwari	0	0.11753	1.67079	0	143.874	145.662	High
Turag	0.03792	0.01315	0.12866	0.00555	0.81008	0.99536	Low
Shitalakhya	0.01147	0.00214	0.02661	0.00045	0	0.04067	Low

In Savar, the HI values for the ingestion of groundwater as a route of exposure to contamination were recorded as follows: adults had values of 0.300483, shown in table 4, while children had values of 0.637389, presented in table 4. The values for dermal contact were substantially lower at 0.060328, shown in table 4, and 0.17798, presented in table 4, respectively. This was true across all locations under investigation, which only serves to affirm that the risk posed by the ingestion of contaminated water was far more significant compared to that posed by skin contact with water. In addition to that, the non-carcinogenic risks associated with surface water contamination were generally higher compared to groundwater contamination within the entire area of investigation. In terms of HI

values, the Dhaleshwari River recorded extremely high values for both adult and child populations, with values of 147.4786 and 302.5262, respectively, as a consequence of oral exposure, shown in table 4. These values were significantly higher compared to groundwater contamination sites. This can only be explained by the fact that surface waters are directly affected by the discharge of industrial wastes and urban runoff, which was less pronounced in groundwater.

Table 5: Cancer risk for groundwater and surface water among children and adults

Area	Cancer Risk (CR)		Cancer risk according to USEPA (1999)	
GW Area	Cd			
	Adult	Child	Adult	Child
Savar	2.38857E-08	5.06667E-08	Very low	Very low
Tongi	1.55257E-07	3.29333E-07	Very low	Very low
Hazaribagh	7.16571E-08	0.000000152	Very low	Very low
Narayangonj	1.3376E-07	2.83733E-07	Very low	Very low
GW Area	Pb			
	Adult	Child	Adult	Child
Savar	6.76029E-07	0.000001434	Very low	Very low
Tongi	1.04657E-05	0.0000222	Medium	Medium
Hazaribagh	0.000340843	0.000723	High	High
Narayangonj	5.79857E-05	0.000123	Medium	High
GW Area	Cr			
	Adult	Child	Adult	Child
Savar	0.000209	0.000443333	High	High
Tongi	0.000116286	0.000246667	High	High
Hazaribagh	0.119786857	0.254093333	Very High	Very High
Narayangonj	0.000674929	0.001431667	High	Very High
SW River	Cd			
	Adult	Child	Adult	Child
Buriganga	0	0	N/A	N/A
Dhaleshwari	2.03626E-05	4.31933E-05	Medium	Medium
Turag	1.14651E-07	2.432E-07	Very Low	Very Low
Shitalakhya	0	0	N/A	N/A

SW River	Pb			
	Adult	Child	Adult	Child
Buriganga	4.38994E-05	0.00009312	Medium	Medium
Dhaleshwari	0.000330943	0.000702	High	High
Turag	0.000037026	0.00007854	Medium	Medium
Shitalakhya	6.02486E-06	0.00001278	Low	Medium
SW River	Cr			
	Adult	Child	Adult	Child
Buriganga	0.012756857	0.02706	Very High	Very High
Dhaleshwari	0.046671429	0.099	Very High	Very High
Turag	0.003593857	0.007623333	Very High	Very High
Shitalakhya	0.000743286	0.001576667	Medium	Very High

Similarly alarming differences were noted in the results of carcinogenic risk assessment conducted over the areas under study. The risk of cancer associated with chromium exposure through surface water was particularly alarming, with values as high as 0.04667 in the Dhaleshwari River water intended for adult populations and as high as 0.099 for children as shown in table 5. For groundwater, the highest cancer risk observed was for Cr for all the locations as presented in Table 5. Furthermore, in groundwater, the highest values of carcinogenic risk were recorded in the Hazaribagh area, though these values were lower than those recorded for surface water samples, also mostly for Cr. This only goes to emphasize the extent of carcinogenic contamination of river water. In addition, dermal exposure can be associated with a lower risk of carcinogenicity compared to oral ingestion but was certainly not insignificant. In the Dhaleshwari River water intended for consumption, the values of dermal HI were recorded as high as 49.373, mainly due to nickel exposure. The health risk assessment further showed that children were more susceptible to health risks resulting from water contamination, both cancer-causing and non-cancerous in nature. It was also seen that the major mode of exposure was oral ingestion, thus making water safety and quality central to any health response. Most importantly, it was revealed that surface water is more dangerous compared to groundwater in terms of heavy metal contamination.

4. Conclusion

This study concluded that the heavy metal contamination of the groundwater as well as the surface water of the industrial areas of Dhaka is a critical public health concern. Geospatial analysis indicated that the groundwater of Hazaribag, as well as the surface water of the Dhaleshwari River, were the most critical areas of contamination, which came up as pollution hotspots in the study area.

Among the metals studied, Cr, Pb, and Fe consistently exhibited the highest concentrations across most of the study areas relative to the other metals investigated. Furthermore, health risk assessment following USEPA (1989) protocols revealed significant health concerns associated with heavy metal contamination, with carcinogenic risks due to Cr and Pb found to be particularly critical for children aged 0–10 years. This study thus strongly recommends strengthening water quality management and pollution control strategies in the industrial zones of Dhaka, with immediate attention from policymakers and relevant stakeholders. In severely contaminated areas, rapid remediation measures such as phytoremediation and targeted dredging should be prioritized to mitigate heavy metal pollution. The proper installation, operation, and maintenance of Effluent Treatment Plants (ETPs) across all industrial facilities must be ensured, alongside regular monitoring and strict enforcement of wastewater discharge standards. Furthermore, this study underscores the necessity of implementing integrated water treatment and monitoring frameworks to safeguard public access to safe drinking water. Establishing a centralized real-time water quality monitoring network, promoting cleaner production technologies in industrial sectors, and raising community awareness regarding the health risks of heavy metal contamination are also strongly encouraged as complementary long-term measures.

Acknowledgments

The authors declare that no additional individuals or organizations contributed to this review paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All data underlying the results are available as part of the article and no additional data are required.

Funding

This research received no external funding.

AI Declaration

During the preparation of this work, the authors used ChatGPT to improve the grammar and readability of the manuscript. The authors reviewed and edited the concentration as needed and take full responsibility for the final published version.

References

- Abedin, M. A., Collins, A. E., Habiba, U., & Shaw, R. (2018). Climate change, water scarcity, and health adaptation in southwestern coastal Bangladesh. *International Journal of Disaster Risk Science*, 10(1), 28–42. <https://doi.org/10.1007/s13753-018-0211-8>
- Ahmed, K., Rahman, A., Sarkar, M., Islam, J., Jahan, I., Moniruzzaman, M., Saha, B., & Bhounmik, N. (2016). Assessment on the level of contamination of Turag River at Tongi area in Dhaka. *Bangladesh Journal of Scientific and Industrial Research*, 51(3), 193–202. <https://doi.org/10.3329/bjsir.v51i3.29431>
- Akbor, Md. A., Rahman, Md. M., Bodrud-Doza, Md., Haque, Md. M., Siddique, Md. A. B., Ahsan, Md. A., Bondad, S. E. C., & Uddin, Md. K. (2020). Metal pollution in water and sediment of the Buriganga River, Bangladesh: an ecological risk perspective. *Desalination and Water Treatment*, 193, 284–301. <https://doi.org/10.5004/dwt.2020.25805>
- Aktar, P., & Moonajilin, M. S. (2017). Assessment of Water Quality Status of Turag River Due to Industrial Effluent. *International Journal of Engineering and Information Systems*, 1(6), 105–118. <https://hal.archives-ouvertes.fr/hal-01580938>
- Akter, A., Hossain, M., Khan, R. A., & Faiz, M. A. (2023). Effects of Tanning on Seasonal Variation in the Physiochemical Quality of Surface and Groundwater and Including an Analysis of Trace Metals in Hazaribagh. *International Journal of Environmental Impacts*, 6(2), 73–79. <https://doi.org/10.18280/ije.060203>
- Alam, M. S., Han, B., Al-Mizan, & Pichtel, J. (2019). Assessment of soil and groundwater contamination at a former Tannery district in Dhaka, Bangladesh. *Environmental Geochemistry and Health*, 42(7), 1905–1920. <https://doi.org/10.1007/s10653-019-00457-6>
- Bakali, B., Mia, Md. Y., & Zakir H. M. (2014). Water Quality Evaluation of Tongi Area in Bangladesh: An Impact of Industrialization. *Journal of Chemical, Biological and Physical Sciences*, 4(2), 1735–1752.
- BBS. (2022). Bangladesh Bureau of Statistics. <https://bbs.gov.bd/>. [Access Date: 20 June 2026]

- Bodrud-Doza, M., Islam, S.M.D.-U., Hasan, Md.T., Alam, F., Haque, Md.M., Rakib, M.A., Asad, Md.A., Rahman, M.A. (2019). Groundwater pollution by trace metals and human health risk assessment in central west part of Bangladesh. *Groundwater for Sustainable Development* 9, 100219. <https://doi.org/10.1016/j.gsd.2019.100219>
- Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, 6(9), Article e04691. <https://doi.org/10.1016/j.heliyon.2020.e04691>
- Dey, M., Akter, A., Islam, S., Chandra Dey, S., Choudhury, T. R., Fatema, K. J., & Begum, B. A. (2021). Assessment of contamination level, pollution risk and source apportionment of heavy metals in the Halda River water, Bangladesh. *Heliyon*, 7(12), Article e08625. <https://doi.org/10.1016/j.heliyon.2021.e08625>
- Faisal, A.-A., Rahman, M. M., & Haque, S. (2022). Retrieving spatial variation of aerosol level over urban mixed land surfaces using Landsat imageries: Degree of air pollution in Dhaka Metropolitan Area. *Physics and Chemistry of the Earth, Parts A/B/C*, 126, Article 103074. <https://doi.org/10.1016/j.pce.2021.103074>
- Georgaki, M.-N., Charalambous, M., Kazakis, N., Talias, M.A., Georgakis, C., Papamitsou, T., Mytilaki, C. (2023). Chromium in water and carcinogenic human health risk. *Environments* 10, 33. <https://doi.org/10.3390/environments.10020033>
- Hasan, M., Islam, M. A., Alam, M. J., Rahman, M., & Hasan, M. A. (2022). Hydrogeochemical characterization and quality assessment of groundwater resource in Savar — an industrialized zone of Bangladesh. *Environmental Monitoring and Assessment*, 194(8). <https://doi.org/10.1007/s10661-022-10137-1>
- Hasan, M. A., Ahmed, K. M., Sracek, O., Bhattacharya, P., Brömssen, M. V., Broms, S., Fogelström, J., Mazumder, M. L., & Jacks, G. (2007). Arsenic in Shallow Groundwater of Bangladesh: Investigations from Three Different Physiographic Settings. *Hydrogeology Journal*, 15, 1507-1522. <https://doi.org/10.1007/s10040-007-0203-z>
- Hossain, M. L., & Shapna, K. J. (2025). Drinking water management: Challenges and adaptive strategies in salinization-affected coastal communities of Bangladesh. *Cleaner Water*, 4, Article 100171. <https://doi.org/10.1016/j.clwat.2025.100171>

- Hossain, M. N., Rahaman, A., Hasan, Md. J., Uddin, Md. M., Khatun, N., & Shamsuddin, S. Md. (2021). Comparative seasonal assessment of pollution and health risks associated with heavy metals in water, sediment and Fish of Buriganga and Turag River in Dhaka City, Bangladesh. *SN Applied Sciences*, 3(4). <https://doi.org/10.1007/s42452-021-04464-0>
- Islam, S. M. D.-U., & Azam, G. (2015). Seasonal variation of physicochemical and toxic properties in three major rivers; Shitalakhya, Buriganga and Turag around Dhaka city, Bangladesh. *Journal of Biodiversity and Environmental Sciences*, 7(3), 120–131.
- Islam, D.U., Amir, M., Tanjena Rume, & Mohinuzzaman, M. (2016). Assessing Heavy Metal Contamination in the Bottom Sediments of Shitalakhya River, Bangladesh; Using Pollution Evaluation Indices and Geo-spatial Analysis. *Pollution*, 2(3), 299–312. <https://doi.org/10.7508/pj.2016.03.005>
- Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin*, 68(1), 167–182. <https://doi.org/10.1093/bmb/ldg032>
- Kabir, Md. H., Islam, Md. S., Hoq, Md. E., Tusher, T. R., & Islam, Md. S. (2020). Appraisal of heavy metal contamination in sediments of the Shitalakhya River in Bangladesh using pollution indices, geo-spatial, and multivariate statistical analysis. *Arabian Journal of Geosciences*, 13(21). <https://doi.org/10.1007/s12517-020-06072-5>
- Khandare, A.L., Validandi, V., Rajendran, A., Singh, T.G., Thingnganing, L., Kurella, S., Nagaraju, R., Dheeravath, S., Vaddi, N., Kommu, S., Maddela, Y. (2020). Health risk assessment of heavy metals and strontium in groundwater used for drinking and cooking in 58 villages of Prakasam district, Andhra Pradesh, India. *Environmental Geochemistry and Health* 42, 3675–3701. <https://doi.org/10.1007/s10653-020-00596-1>
- Lipy, E. P., Hakim, M., Mohanta, L. C., Islam, D., Lyzu, C., Roy, D. C., Jahan, I., Akhter, S., Raknuzzaman, M., & Abu Sayed, Md. (2021). Assessment of Heavy Metal Concentration in Water, Sediment and Common Fish Species of Dhaleshwari River in Bangladesh and their Health Implications. *Biological Trace Element Research*, 199(11), 4295–4307. <https://doi.org/10.1007/s12011-020-02552-7>

- Merrill, R. D., Labrique, A. B., Shamim, A. A., Schulze, K., Christian, P., Merrill, R. K., & West Jr, K. P. (2010). Elevated and variable groundwater iron in rural northwestern Bangladesh. *Journal of water and health*, 8(4), 818-825. <https://doi.org/10.2166/wh.2010.144>
- Mohammadi, A. A., Zarei, A., Majidi, S., Ghaderpoury, A., Hashempour, Y., Saghi, M. H., Alinejad, A., Yousefi, M., Hosseingholizadeh, N., & Ghaderpoori, M. (2019). Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. *MethodsX*, 6, 1642–1651. <https://doi.org/10.1016/j.mex.2019.07.017>
- MoEF&CC. (2023). *Environment Conservation Rules, 2023*. Government of the People's Republic of Bangladesh
- Mohiuddin, K., Islam, M., Basak, S., Abdullah, H., & Ahmed, I. (2016). Status of heavy metal in sediments of the Turag River in Bangladesh. *Progressive Agriculture*, 27(2), 78–85. <https://doi.org/10.3329/pa.v27i2.29315>
- Myers, R.A., Gyimah, E., Gbemadu, K., Osei, B., Akoto, O. (2023). Appraising groundwater quality and the associated health risks of heavy metal contamination at Suame magazine. *Scientific African* 21, Article e01794. <https://doi.org/10.1016/j.sciaf.2023.e01794>
- Nesha, M., Fardous, Z., Islam, H., Pinkey, P. D., Rahman, Md. A., & Alamgir, M. (2023). Investigation of Some Physicochemical Parameters and Heavy Metals for Monitoring the Groundwater Quality of Savar Upazila of Dhaka, Bangladesh. *Environment and Natural Resources Journal*, 21(3), 1–13. <https://doi.org/10.32526/ennrj/21/202200264>
- Otten, J. J., Hellwig, J.P., & Meyers. L. D. (2006). The essential guide to nutrient requirements. In DRI, *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*. (pp. 328–39). Washington, D.C: National Academies Press.
- Rahman, K., Barua, S., Ahammad, F., & Akramul Alam, Md. (2020). Assessment of pollution and sources of heavy metals in the sediments of the Shitalakhya river, Bangladesh. *International Journal of Advanced Geosciences*, 8(1), Article 89. <https://doi.org/10.14419/ijag.v8i1.30789>
- Rahman, M. A. T. M. T., Paul, M., Bhoumik, N., Hassan, M., Alam, Md. K., & Aktar, Z. (2020). Heavy metal pollution assessment in the groundwater of the Meghna Ghat industrial area, Bangladesh, by using water pollution indices approach. *Applied Water Science*, 10(8). <https://doi.org/10.1007/s13201-020-01266-4>

- Rahman, M. F., Mahmud, M. J., Sadmani, A. A., Chowdhury, A. I., Anderson, W. B., Bodruzzaman, A. B., & Huq, S. (2020). Previously unrecognized potential threat to children from manganese in groundwater in rohingya refugee camps in Cox's Bazar, Bangladesh. *Chemosphere*, 266, 129128. <https://doi.org/10.1016/j.chemosphere.2020.129128>
- Rahman, M., Khan, M. R., Ahmed, K. M., Zahid, A., & Siddique, M. A. M. (2018). An assessment of nitrate concentration in the groundwater of the central coastal region of Bangladesh. *Journal of NOAMI*, 35(1-2), 107-116.
- Rahman, M. a. T. M. T., Majumder, R. K., Rahman, S. H., & Halim, M. A. (2010). Sources of deep groundwater salinity in the southwestern zone of Bangladesh. *Environmental Earth Sciences*, 63(2), 363–373. <https://doi.org/10.1007/s12665-010-0707-z>
- Rahman, M. M., Bodrud-Doza, M., Siddiqua, M. T., Zahid, A., & Islam, A. R. M. T. (2020). Spatiotemporal distribution of fluoride in drinking water and associated probabilistic human health risk appraisal in the coastal region, Bangladesh. *The Science of the Total Environment*, 724, 138316. <https://doi.org/10.1016/j.scitotenv.2020.138316>
- Sarkar, M., Islam, J. B., & Akter, S. (2016). Pollution and ecological risk assessment for the environmentally impacted Turag River, Bangladesh. *Journal of Materials and Environmental Science*, 7(7), 2295–2304.
- Seddique, A. A., Ahmed, K. M., Shamsudduha, M., Aziz, Z., & Hoque, M. (2004). Heavy Metal Pollution in Groundwater in and around Narayanganj Town, Bangladesh. *Bangladesh Journal of Geology*, 23, 1–12.
- Sorker, R., & Khanam, S. (2022). Phthalate esters (PAEs): Emerging organic pollutant in aquatic ecosystems. *Journal of FST*, 1(1), 161–187.
- Sunjida, S. B., Rahman, I., Yesmine, S., & Islam, R. (2016). Assessing the Quality of Household and Drinking Water in Tongi Industrial Zone of Bangladesh and Its Toxicological Impact on Healthy Sprague Dawley Rats. *Journal of Applied Pharmacy*, 8(3). <https://doi.org/10.21065/1920-4159.1000224>
- Tasnim, F., Hasan, M., Sakib, Md.N., Zahid, A., Rahman, M., Islam, Md.S., Muktadir, M.G., 2025. An assessment of the spatial and temporal distribution of nitrate and trace element concentrations in groundwater in coastal districts of Bangladesh. *The Science of the Total Environment* 970,178988. <https://doi.org/10.1016/j.scitotenv.2025.178988>