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RESEARCH PAPER

Distribution, concentration, and risk assessment of trace metals in surface water of Gazipur, Bangladesh

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Abstract

Toxic trace metal (TTM) pollution of surface water in the vicinity of industrial and agricultural areas is a global issue, including Bangladesh. The purpose of this research was to evaluate the contamination levels and ecological risks of TTMs in the surface water of the Gazipur industrial area, a tropical urban region of Bangladesh. Four water samples were analyzed for metals such as Arsenic (As), Selenium (Se), Lead (Pb), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Zinc (Zn), and Mercury (Hg) using Inductively coupled mass spectrometry (ICP-MS). The pollution status and potential ecological risks were assessed using the single-factor pollution index (P_i) and geo-accumulation index (I_g). Results implies that the amount of As, Se, Pb, Cd, Co, Cr, Cu, Mn, Ni, Zn, and Hg were 1.276-12.385, 1.139-5.596, 14.861-81.604, 0.312-3.240, 1.425-22.215, 10.921-92.168, 5.861-184.972, 85.022-843.919, 8.861-91.073, 56.129-860.148 and 0.139-1.400 μgl^{-1}, respectively. The ecological risk assessment, using the single factor pollution index (P_i) and geo-accumulation index (I_g), reveals that Lobondoho Beel consistently exhibits higher pollution levels compared to other sites, with several TTMs exceeding moderate pollution thresholds. The health risks were assessed using the non-carcinogenic Hazard Index (HI) and Incremental Lifetime Cancer Risk (ILCR) by calculating Chronic Daily Intake (CDI). HI values for oral and dermal exposure remain <1, suggesting a low risk, except for Lobondoho Beel. It shows the highest HI (1.81×10^{-3} for oral, 1.36×10^{-5} for dermal) and ILCR for Ni (2.81×10^{-6}) and Cr (1.69×10^{-6}), exceeding the 10^{-6} threshold, indicating cancer risk. Other locations, including Champa Resort Canal, ShorokGhat Bridge, and Shaldha River, show lower pollution and minimal health risks.

1. Introduction

Toxic trace metals are naturally occurring elements with atomic numbers higher than 20 and densities of around 4 gcm^{-3}, significantly higher than water. These are harmful even at low levels (Ahmed *et al.*, 2022; Jomova *et al.*, 2024). Heavy metal poisoning in aquatic systems has gained global attention due to its toxicity, distribution, persistence, and bioaccumulation at tropical levels (Zaynab *et al.*, 2022; Santhosh *et al.*, 2024). Large quantities of trace metals are extracted annually from the earth's crust to fuel economic growth and meet human demands (Avkopashvili *et al.*, 2022). Industrial expansion, mine exhaust, untreated wastewater containing toxic metals, and metal chelates from various industries such as steel, tanneries, batteries, thermal power plants, and sewage waste contribute to aquatic contamination. Additionally, heavy metal-containing fertilizers, pesticides, insecticides, herbicides, coal burning, and wastewater from sewage treatment facilities further pollute aquatic ecosystems (Ukah *et al.*, 2019; Ahmad *et al.*, 2021). This contamination poses significant risks to human health, ecosystems, and biodiversity by altering water composition (Hossain *et al.*, 2022). Monitoring heavy metal concentrations in water, soil, and aquatic life helps determine their presence in these environments, where they are typically low in water but reach higher concentrations in soils, plants, and animals (Hossain *et al.*, 2021a).

Bioaccumulation of trace metals in the body over time can have harmful health effects (Balali-Mood *et al.*, 2021; Sani *et al.*, 2022). Based on dosage and exposure time, certain trace metals can produce teratogenic or mutagenic consequences in humans and animals, while others are carcinogenic. Key toxic trace metals (TTMs) in the environment include As, Se, Pb, Cd, Co, Cr, Cu, Mn, Ni, Zn, and Hg (Ali *et al.*, 2019; Balali-Mood *et al.*,

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Figure 1. Different sampling stations in the Gazipur District, Bangladesh.

2021; Dasharathy *et al.*, 2022). Exposure to these hazardous chemicals can lead to various cancers, making cancer the second leading cause of death globally (Kocarnik, 2022). Cu is essential for respiration, angiogenesis, and neuromodulation (Jacobs *et al.*, 2020). Zn is vital for molecular and cellular biology, with Zn-containing proteins comprising about 10% of the human proteome (Chen *et al.*, 2024), as it is toxic, causing symptoms like diarrhea, vomiting, and death (Hadrup and Ravn-Haren, 2020). Cr has no confirmed essentiality and is not naturally incorporated into proteins (Jomova *et al.*, 2022). Se is essential in small amounts, primarily through selenoproteins (Hariharan and Dharmaraj, 2020). Mn is vital for metabolism and bone growth, but toxic at high levels (Tseng *et al.*, 2025). Cd may be essential at low concentrations but is recognized as toxic (Genchi *et al.*, 2020). Hg has historical medicinal uses and is used as a preservative in vaccines (Zhao *et al.*, 2022). Co is vital as a coenzyme in vitamin B12, with deficiencies leading to pernicious anemia (González-Montaña *et al.*, 2020). Pb is highly toxic, affecting the nervous system and causing anemia, kidney damage, and brain damage with prolonged exposure (Collin *et al.*, 2022; Kumar and Jha, 2024). Ni is present in small amounts in the body, but its essentiality is uncertain, and it is known for causing allergies (Begum *et al*., 2022).

Gazipur district faces significant environmental pollution due to overpopulation, rapid industrialization, and urbanization, like Dhaka city, Bangladesh (Raza *et al*., 2022). Human activities, such as industrialization, poor waste disposal, lack of support and monitoring, and unplanned urbanization, have led to water contamination from TTMs (Hasan *et al*., 2019). As a central industrial hub in Bangladesh, Gazipur hosts numerous factories, including aluminum, textile, pharmaceutical, cosmetics, and more, resulting in widespread water contamination by various chemicals (Wikipedia, 2024). There has been limited study done on surface water contamination by TTM in the Gazipur district, Bangladesh. Thus, the purpose of this study is to close the knowledge gap regarding the evaluation of TTMs in the surface water of that region.

Due to the advancement of science and technologies in elemental analysis at the trace level, ICP-MS is an advanced analytical instrument for analyzing TTMs in surface water due to its high sensitivity, precision, and accuracy (Wilschefski and Baxter, 2019; El Ouaty *et al*., 2022). It can detect metals at very low concentrations (parts per trillion), providing comprehensive multi-element analysis simultaneously. ICP-MS also offers rapid analysis and a wide dynamic range, ensuring reliable detection of both trace and major elements (Laur *et al*., 2020; Clases and Gonzalez de Vega, 2022). This makes it highly effective for monitoring water quality and assessing environmental contamination. Therefore, evaluating the contamination levels of TTMs and their potential ecological risks in the area's surface water using ICP-MS is crucial for accurate TTMs analysis. This research focused on assessing the contamination profile of TTMs, specifically As, Se, Pb, Cd, Co, Cr, Cu, Mn, Ni, Zn, and Hg, in the surface water of the Gazipur district by ICP-MS. Using several pollution indexes, the study also looked at the distribution of TTMs and their ecological risks. Additionally, the assessment of health

Table 1. Sampling information from different place of Gazipur, Bangladesh.

Sampling stations	Latitude	Longitude	Area description
Champa Resort Canal	24.091888	90.404428	Forest area and the canal is used for agricultural cultivation
ShorokGhat Bridge	24.127774	90.376873	The land is used for regular agricultural activities
Shaldha River	24.161726	90.352885	Forest area and the river is used for agricultural cultivation
Lobondoho Beel	24.105212	90.344592	The water from the Beel is used for agricultural cultivation

risks associated with exposure to TTMs was evaluated using CDI, HQ, HI, and ILCR. By monitoring these metals, researchers can identify trends and potential sources of contamination, enabling the development of strategies to mitigate their harmful effects. Comprehending these trends is essential for safeguarding ecosystems and guaranteeing the security of water resources for consumption by humans.

2. Materials and methods

2.1 Description of the study area

In December 2023, four water samples were collected from four distinct areas in the Gazipur, a key district near Dhaka, Bangladesh, located between 23° 50'-24°20' N latitudes and 90°10'-90°40' E longitudes. Bordered by Dhaka, Narayanganj, Mymensingh, Kishoreganj, Narshingdi, and Tangail, it is traversed by the Shitalakshya, Turag, and Balu rivers, which are crucial to the region's hydrology. The Dhaka–Mymensingh Highway divides the district, a hub of industrial, educational, and recreational activities with numerous garment factories, institutions, and parks (Arifeen *et al*., 2021). The various sampling stations are shown in Figure 1.

2.2 Sampling and sample pretreatment

Each sample was collected using sterilized amber plastic bottles (Thermo Scientific, USA, Amber narrow-mouth bottle, HDPE, 500 mL) starting 10-13 cm below the water's surface. The bottles were pre-cleaned with Milli-Q water and ethanol. The samples were transported to the Chemistry Department at the University of Dhaka within 6 hours and stored under appropriate conditions for further analysis. Using GPS on an Android phone, the geographic coordinates of the sampling stations were recorded in Table 1. To preserve the samples, a few drops of pure HNO_3 were added to bring the pH down to about 2.0. They were delivered right away in a cooler box to the lab and kept in a refrigerator at -4°C. The samples were then analyzed to determine the TTMs (Agoro *et al*., 2020).

2.3 Sample preparation for TTMs

First, a 50.0 mL river wastewater sample was measured using a 50.0 mL volumetric flask and transferred to a 100.0 mL beaker. Precisely 3.0 mL of ultra-pure concentrated HNO_3 acid (70%, Sigma-Aldrich, USA) and 1.5 mL of H_2O_2 (35% w/w, Thermo Fisher Scientific, UK) were added to the sample (Asare-Donkor *et al*., 2018). After that, the beaker was placed on a hot plate and the temperature was raised to about 95°C, and heated for about 1 hour until the solution became clear. The contents were transferred to a pre-cleaned 50.0 mL volumetric flask and diluted to the mark with double-distilled water (Rappazzo *et al*., 2019; Agoro *et al*., 2020). The sample was subsequently filtered using Whatman No. 42 filter paper (GE Healthcare UK Limited, Amersham Place, Little Chalfont, Buckinghamshire, HP7 9NA, UK). Double-distilled water was used as a reagent blank and treated in the same manner as the sample (Li *et al*., 2024).

2.4 Quality assurance and quality control

ICP-MS (PerkinElmer, Model: NexION 2000, USA) was used to quantify TTMs. The nebulized material was injected into the ICP-MS system's argon plasma core at a flow rate of roughly 0.35 $mLmin^{-1}$. A quadrupole mass detector was used to measure the m/z ratio of the trace metal ions generated in high-temperature plasma. ICP-multi-element standard solution XIII (Merck, Germany) was used to create standard calibration curves at ppb levels. To prevent contamination, all glassware was cleaned and rinsed with water and ultrapure acid. Using the NexION Setup solution (PerkinElmer, USA), the performance of the ICP-MS apparatus was evaluated before standard calibration. A five-point calibration variance, R^2 >0.9995, was achieved over a range of 1.0-25.0 $ngmL^{-1}$. At least three replicates with a coefficient of variance of 5–8% were carried out to verify the stability of the instrument. The thresholds for detection and quantification were set at three and ten times the noise level, respectively. According to the National Institute of Standards (NIST) standard reference materials SRM 1643f (Trace Elements in Water), the recovery percentage for essential elements ranged from 96 to 103.7%. Procedure blanks, SRM recoveries, and spike recoveries were performed as part of the quality control process, and trace metal concentrations were modified based on examination of recovery and blank samples.

2.5 Ecological risk assessment

The rapid advancement of modern industries has led to significant water pollution, posing severe risks to human health and the environment. This issue stems from the unregulated disposal of waste materials (Zhao *et al*., 2022). To evaluate the target area's pollutant load, several risk assessment parameters are described here.

The single factor pollution index (Pi) method was used to assess the contamination extent from a specific

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pollutant (Karaouzas *et al*., 2021; Ferreira *et al*., 2022). In this study, this technique was applied to evaluate the contamination levels of each pollutant in samples of river water. This method helps identify the most influential contaminant responsible for contamination at every sampling station. For a single pollutant, the pollution index was formulated as follows, Eq.1

$$P_i = \frac{C_i}{S_i} \text{ --------------(1)}$$

Where C_i (μgL^{-1}) is the measured concentration of toxic trace metals, and S_i (μgL^{-1}) is the standard value for the pollutants. A P_i value ≤ 1 indicates minimal pollution, $1 < P_i \leq 2$ signifies low pollution, $2 < P_i \leq 3$ indicates moderate pollution, and $P_i > 3$ corresponds to a high level of pollution (Dey *et al*., 2021; Díaz Rizo *et al*., 2023; Zhao *et al*., 2023).

The contamination level of a sample has been assessed using the geo-accumulation index (I_g) developed by Müller (1969). This index evaluates the degree of contamination with the following formula (Eq. 2):

$$I_g = \log_2\left(\frac{C_n}{1.5C_b}\right) \text{ ---------------(2)}$$

Here, C_n is the measured metal concentration, and C_b signifies the geochemical background concentration, which is the lowest recorded value of each element. Müller's method includes a factor of 1.5 to accommodate potential variations in background values due to lithogenic effects, as specified in Müller's original work. Additionally, the enrichment index introduced by Müller (1981) provides a classification scheme for contamination levels, which is summarized in Table 2 (Birch, 2013).

Table 2. Geo-accumulation index along with its pollution status.

Geo-accumulation index (I_g)	Pollution status
$I_g \leq 0$	Unpolluted
$0 < I_g \leq 1$	Unpolluted to moderately polluted
$1 < I_g \leq 2$	Moderately polluted
$2 < I_g \leq 3$	Moderately to strongly polluted
$3 < I_g \leq 4$	Strongly polluted
$4 < I_g \leq 5$	Strongly polluted
$5 < I_g$	Extremely polluted

2.6 Health risk assessment

2.6.1 Non-carcinogenic analysis

Hazard Quotients (HQ), Hazard Index (HI), and the Incremental Lifetime Cancer Risk (ILCR) were used to approximate the level of TTM contamination. The possible carcinogenic and non-cancer health risks resulting from oral ingestion and dermal absorption of trace metals in the water of Gazipur city's distribution network. The study focused on adults as the target group. The Chronic Daily Intake (CDI) was calculated by the Environmental Protection Agency's (USEPA) Eq. 3 and Eq. 4, respectively, for oral ingestion and dermal absorption pathways.

$$CDI_{oral} = \frac{C \times DI \times ABS \times EF \times ED}{BW \times AT} \text{ ----------------- (3)}$$

$$CDI_{dermal} = \frac{C \times SA \times K_P \times ABS \times ET \times EF \times ED \times CF}{BW \times AT} \text{ -------------- (4)}$$

Table 3 gives the values for calculating CDI through oral ingestion and dermal absorption.

The HQ for each TTM was identified by calculating the ratio of the average daily intake (ADI, mg/kg/day) of the metal from contaminated water to the reference oral dose (R_fD). This assessment considered both the routes of oral and dermal exposure for residents. The cumulative sum of all HQ values provides an estimate of all possible

Table 3. The values for calculating non-carcinogenic human health risk due to oral ingestion and dermal absorption of water.

Parameters	Unit	Oral	Dermal	References
Metal concentration (C)	mg L^{-1}	-	-	
Daily average intake (DI)	L day^{-1}	2.2	-	Mohammadi *et al*., 2019
Skin surface area (SA)	cm^2	-	18000	USEPA, 2004
Permeability coefficient (K_p)	cm/hour	-	Cd, Cr, Mn, As, Hg and Cu = 0.001; Pb = 0.0001, Ni= 0.0002 and Zn= 0.0006	Mohammadi *et al*., 2019; USEPA, 2004
Exposure time (ET)	Hour/event	-	0.58	USEPA, 2004
Exposure frequency (EF)	Days/year	365	350	USEPA, 2004
Exposure duration (ED)	Year	71.8	30	USEPA, 2004; Bangladesh Bureau of Statistics, 2015
Conversion factor (CF)	L cm^{-3}	-	0.001	USEPA, 2004; Bangladesh Bureau of Statistics, 2015
Average body weight (BW)	Kg	60	60	Bangladesh Bureau of Statistics, 2015
Absorption factor (ABS)	-	0.001	0.001	USEPA, 2004
Average time (AT)	day	26207	10500	USEPA, 2004

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Table 4. R_fD ($mgkg^{-1}day^{-1}$) and CSF ($mgkg^{-1}day^{-1}$) for different metal.

Element	R_fD_{oral}	R_fD_{dermal}	CSF	References
Pb	1.4	0.42	0.0085	Mohammadi *et al.*, 2019; Gnonsoro *et al.*, 2022
Cr	3	0.015	0.5	Mohammadi *et al.*, 2019; Salama, 2019
Cd	0.5	0.005	6.3	Mohammadi *et al.*, 2019; Emmanuel *et al.*, 2022
Zn	300	60	-	Mohammadi *et al.*, 2019
Hg	0.001	0.042	-	Emmanuel *et al.*, 2022; Shipp *et al.*, 2000
Co	0.043	0.0004	-	Tabassum and Singh, 2025; Finley *et al.*, 2012
Mn	0.14	2.2	-	Tabassum and Singh, 2025
Cu	40	12	-	Mohammadi *et al.*, 2019
Ni	20	5.4	0.84	Mohammadi *et al.*, 2019
As	0.0003	0.0008	1.5	Kamunda *et al.*, 2018; Kesari *et al.*, 2012

health risks, represented as the HI. The formula for calculating the HI due to water contamination is given in Eq. 5.

$$HQ = \frac{CDI}{R_fD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

In this case, R_fD and CDI are given in $mgkg^{-1}day^{-1}$. The values of the R_fD and cancer slope factor (CSF) for different metals are listed in Table 4.

HI for several metals separately. The HI for multiple metals was calculated using Eq. 6, as per EPA recommendations for health risk assessment, to evaluate the overall possible non-carcinogenic health consequences resulting from exposure to a mixture of trace metals in water.

$$HI = \Sigma HQ = HQ_{As} + HQ_{Pb} + HQ_{Cd} + HQ_{Co} + HQ_{Cr} + HQ_{Cu} + HQ_{Mn} + HQ_{Ni} + HQ_{Mn} + HQ_{Zn} + HQ_{Hg} \quad \text{--(6)}$$

When the calculated HI is compared to conventional values, residents may experience non-carcinogenic effects when HI >1, but when HI <1, there may be no adverse effects. It is unlikely that the exposed person will suffer from apparent adverse health effects (Mohammadi *et al.*, 2019).

2.6.2 Carcinogenic analysis

The ILCR can be used to predict the possible cancer risk associated with exposure to a certain level of harmful trace metals in drinking water (Emmanuel *et al.*, 2022). The ILCR measures the increased lifetime risk of cancer brought on by ongoing daily exposure to a carcinogenic substance for seventy years (Samaila *et al.*, 2021). Eq.7 is commonly used to calculate lifetime cancer risk (ILCR).

$$ILCR = CDI.CSF \text{ ---------------(7)}$$

The CSF represents the risk resulting from an average lifetime exposure to 1 $mgkg^{-1}day^{-1}$ to a specific carcinogenic chemical. It is contaminant-specific and used to estimate potential cancer risks. The acceptable risk thresholds for carcinogenic exposure are typically set between 10^{-6} and $<10^{-4}$ for single and multiple carcinogenic elements, respectively (Eze *et al.*, 2021).

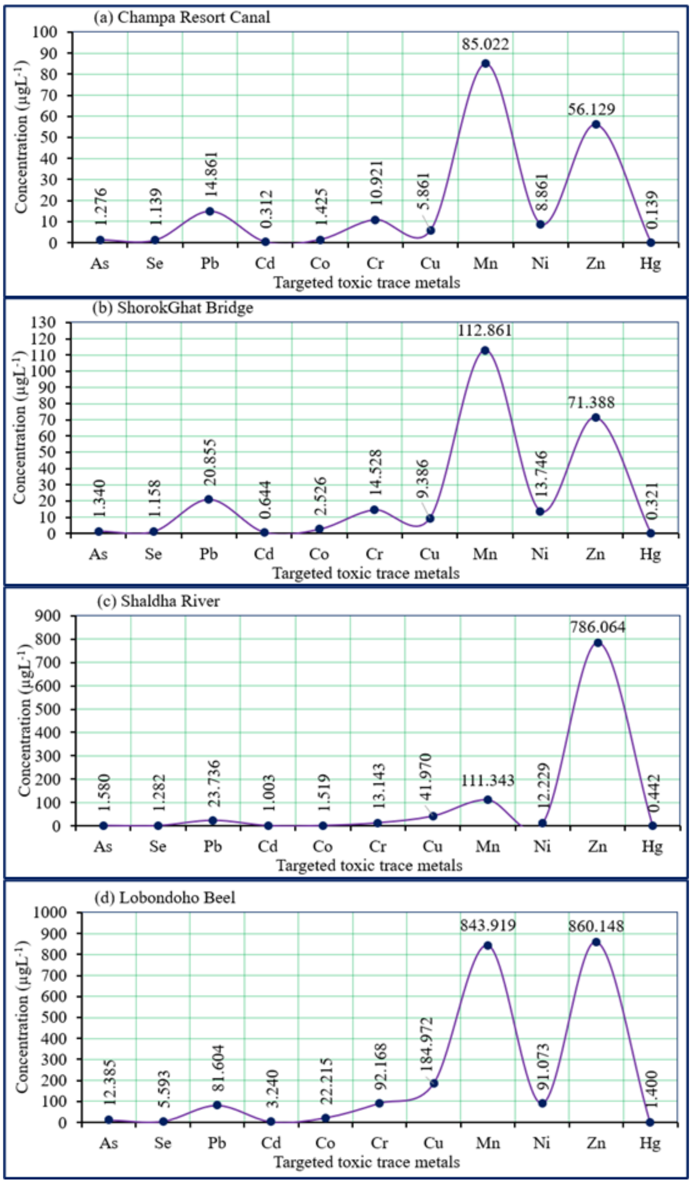

Figure 2. Distribution pattern of the TTMs concentration (μgL^{-1}) in the Gazipur area.

3. Results and discussion

3.1 Trace metal concentration

Water samples (n=4) from four different places of the Gazipur area were analyzed for eleven metals, e.g., As, Se, Pb, Cd, Co, Cr, Cu, Mn, Ni, Zn, and Hg using ICP-MS. Figure 2 presents the amount of various TTMs in water samples from four locations: Champa Resort Canal, ShorokGhat Bridge, Shaldha River, and Lobondoho Beel from Gazipur district. As levels are low across all sites, with the highest at Lobondoho Beel

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(12.385 μgL^{-1}), far below the guideline value of 50 μgL^{-1} (DPHE), indicating minimal contamination. Se concentrations also remain well within the safe limit of 40 μgL^{-1} (WHO, 2004), with Lobondoho Beel showing the highest concentration at 5.593 μgL^{-1}. Pb levels, however, highlight significant ariability; Lobondoho Beel (81.604 μgL^{-1}) exceeds the guideline value of 50 μgL^{-1} (DPHE), indicating severe contamination, while other sites remain below this threshold but still show elevated levels. Cd concentrations are low across all locations, peaking at Lobondoho Beel (3.240 μgL^{-1}) but staying well within the guideline of 10 μgL^{-1} (FAO, 2016). Co also shows significant variation, with Lobondoho Beel (22.215 μgL^{-1}) crossing the guideline value of 10 μgL^{-1} (WHO, 2004), pointing to considerable contamination at this site.

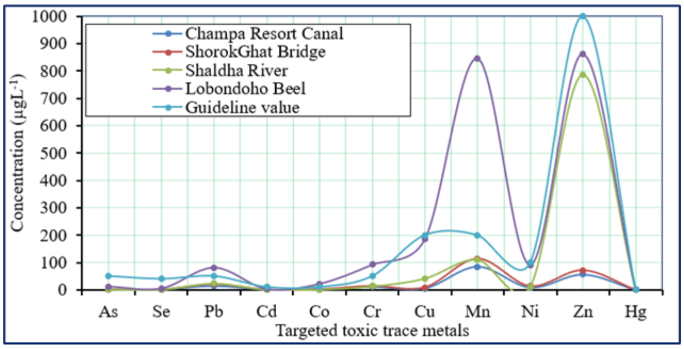

Figure 3. Comparison of Spatial variability of targeted TTMs with guideline values.

Cr levels follow a similar pattern, with Lobondoho Beel (92.168 μgL^{-1}) surpassing the safe limit of 50 μgL^{-1} (DPHE), indicating notable contamination, whereas other sites are within the guideline. Cu concentrations are below the guideline value of 200 μgL^{-1} (FAO, 2016) across all sites, but Lobondoho Beel (184.972 μgL^{-1}) shows the highest levels, nearing the threshold. Mn is particularly high at Lobondoho Beel (843.919 μgL^{-1}), though within the guideline of 200 μgL^{-1} (FAO, 2016), indicating significant contamination relative to other sites. Ni levels are elevated at Lobondoho Beel (91.073 μgL^{-1}) but remain within the 100 μgL^{-1} guideline (DPHE), suggesting moderate contamination. Zn concentrations vary greatly, with Lobondoho Beel (860.148 μgL^{-1}) showing the highest levels yet still within the 1000 μgL^{-1} guideline (WHO, 2004). Hg levels are low across all sites, with Lobondoho Beel at 1.400 μgL^{-1}, below the guideline of 2 μgL^{-1} (USEPA 1999). Overall, Lobondoho Beel consistently exhibits the highest concentrations of most trace metals, often exceeding safe limits for Pb, Co, Cr, and Mn, indicating significant contamination and ecological risk. Other sites show varying contamination levels, generally staying within safe limits, with Champa Resort Canal being the least contaminated (Figure 3). This distribution highlights the spatial variability of TTMs and the need for targeted remediation efforts, particularly at Lobondoho Beel. A recent study investigated TTMs in surface soils from industrial areas in Gazipur, Bangladesh. The average concentrations of Cu, Zn, Pb, Cd, and Cr in the soil samples were found to be 36.19, 176.67, 27.95, 0.41, and 29.21 µg/g, respectively, which is much higher than the metals deposited on the soil than in water (Zakir *et al.*, 2015).

Table 5. Comparative studies of TTMs in water with other studies in Bangladesh (μgL^{-1}).

Locations	As	Pb	Cd	Co	Cr	Cu	Ni	Zn	Hg	Se	Mn	References
Gazipur district	4.145	35.264	1.300	6.921	32.690	60.547	31.477	443.432	0.576	2.293	288.286	Present study
Shitalakhya river	10	16	3	-	18	22	14	56	-	-	179	Jolly *et al.*, 2019
Dhaleshwari river	410	1020	1520	-	2590	1010	-	-	-	-	-	Lipy *et al.*, 2021
Dhaleshwari river	-	50	2	-	240	10	20	10	-	-	-	Hasan *et al.*, 2020
Buriganga	-	300	-	-	2850	800	1360	1250	-	-	-	Hossain *et al.*, 2021b
Turag river	-	385	-	-	690	950	890	1840	-	-	-	Hossain *et al.*, 2021b
Korotoa	69	67	7	61	78	-	-	-	-	-	-	Hassan *et al.*, 2024
Halda river	1340	30	32	10	4	3330	-	60	7	-	-	Rakib *et al.*, 2022
Rupsha river	5180	29210	1800		43200	-	-	-	-	-	-	Kubra *et al.*, 2022
Karnaphuli river	34.46	16.83	10.64		86.93	-	-	-	-	-	-	Ali *et al.*, 2016
Reference values												
TRV	150	3	2.2	-	11	9	52	81			6	USEPA, 2000; Jolly *et al.*, 2019; Lipy *et al.*, 2021
WHO	10	10	3	-	5	2000	70	3000	1	-	-	Dey *et al.*, 2021; WHO, 2004.
PEL	17000	91300	3530	-	90000	197000	36000	315000	-	-	-	Jolly *et al.*, 2019
SEL	33000	250000	10000	-	110000	110000	75000	820000	-	-	-	Jolly *et al.*, 2019
TEL	5900	35000	596	-	37300	35700	18000	123000	-	-	-	Jolly *et al.*, 2019

TRV-Toxicity reference value for fresh water, WHO-World Health Organization, PEL: Probable effect level, SEL- Severe effect level, TEL- Threshold effect level

Table 6. Correlation coefficient of the targeted toxic metals in the Gazipur area.

	As	Se	Pb	Cd	Co	Cr	Cu	Mn	Ni	Zn	Hg
As	1.000										
Se	1.000	1.000									
Pb	0.995	0.995	1.000								
Cd	0.982	0.982	0.995	1.000							
Co	0.998	0.998	0.993	0.976	1.000						
Cr	0.999	0.999	0.996	0.981	1.000	1.000					
Cu	0.986	0.986	0.993	0.996	0.977	0.982	1.000				
Mn	1.000	1.000	0.996	0.983	0.999	1.000	0.984	1.000			
Ni	0.999	0.999	0.997	0.983	0.999	1.000	0.983	1.000	1.000		
Zn	0.650	0.654	0.698	0.764	0.616	0.636	0.769	0.644	0.640	1.000	
Hg	0.980	0.980	0.995	1.000	0.976	0.980	0.993	0.982	0.983	0.756	1.000

Correlation is significant at the 0.05 level (2-tailed)

3.2 Comparative study

Table 5 showed that the concentration of As in Gazipur (4.145 μgL^{-1}) is within the WHO limit (10 μgL^{-1}) (WHO, 2004) and below the TRV (150 μgL^{-1}) (USEPA, 2020), indicating a relatively low contamination level. However, Dhaleshwari River (410 μgL^{-1}) (Lipy *et al.*, 2021), Halda River (1340 μgL^{-1}) (Rakib *et al.*, 2022), and Rupsha River (5180 μgL^{-1}) (Kubra *et al.*, 2022) exhibit significantly higher arsenic pollution. The levels of Pb show 35.264 μgL^{-1}, exceeding the WHO guideline (10 μgL^{-1}) (Kubra *et al.*, 2022) but remaining far below highly contaminated sites such as Dhaleshwari (1020 μgL^{-1}) (Lipy *et al.*, 2021) and Rupsha (29210 μgL^{-1}) (Kubra *et al.*, 2022). The Cd concentration in Gazipur (1.3 μgL^{-1}) is below WHO limits (3 μgL^{-1}) (Kubra *et al.*, 2022) but above the TRV (2.2 μgL^{-1}) (Jolly *et al.*, 2019), indicating potential risks. Dhaleshwari (1520 μgL^{-1}) (Lipy *et al.*, 2021) and Rupsha (1800 μgL^{-1}) (Kubra *et al.*, 2022) show excessive contamination. Co levels (6.921 μgL^{-1}) are relatively low, but no comparative data are available for other locations. Cr levels of 32.69 μgL^{-1} significantly exceed the WHO guideline (5 μgL^{-1}) but are much lower than in Dhaleshwari (2590 μgL^{-1}), Buriganga (2850 μgL^{-1}), and Rupsha (43200 μgL^{-1}) (Kubra *et al.*, 2022). The Cu concentration in Gazipur (60.547 μgL^{-1}) remains below the WHO limit (2000 μgL^{-1}) but is higher than in Shitalakhya (22 μgL^{-1}). Halda River (3330 μgL^{-1}) (Rakib *et al.*, 2022) has the highest Cu pollution, indicating industrial effluents' influence. Ni levels (31.477 μgL^{-1}) are exceeding the WHO guideline (70 μgL^{-1}) (WHO, 2004) but remain far below PEL (315000 μgL^{-1}) (Jolly *et al.*, 2019), Dhaleshwari and Buriganga show significantly higher Ni pollution, indicating industrial sources. Zn levels of 443.432 μgL^{-1} are higher than Shitalakhya (179 μgL^{-1}) (Jolly *et al.*, 2019), but far below the WHO limit (3000 μgL^{-1}) (WHO, 2004). Hg concentration (0.576 μgL^{-1}) is below the WHO limit (1 μgL^{-1}) (WHO, 2004) but still poses potential risks, especially since Hg contamination is highly toxic even at low concentrations. The Se concentration in Gazipur (2.293 μgL^{-1}) is below the TRV (6 μgL^{-1}) (Jolly *et al.*, 2019), indicating minimal contamination. Gazipur records Mn levels of 288.286 μgL^{-1}, much lower than in Shitalakhya (179 μgL^{-1}) (Lipy *et al.*, 2021) but still requiring attention as excessive Mn exposure can lead to neurological disorders.

The study indicates that Pb, Cr, and Cd levels exceed WHO guidelines, posing potential health risks in Gazipur. Compared to other rivers, Dhaleshwari, Rupsha, and Buriganga exhibit extreme contamination, necessitating urgent remediation.

3.3 Ecological risk assessment

The Pearson correlation coefficients among various TTMs (As, Se, Pb, Cd, Co, Cr, Cu, Mn, Ni, Zn, and Hg) in surface water from the Gazipur area reveal strong positive correlations (values close to 1) for most elements, indicating they often coexist or share similar sources (Table 6). In addition, they are highly correlated, suggesting a common contamination source or behavior in that region. Zn shows lower correlations with other elements, especially with Cd, Co, and Cr, suggesting different contamination sources or behaviors. Hg also shows strong correlations with most elements except Zn, indicating its distinct interaction or source in that environment.

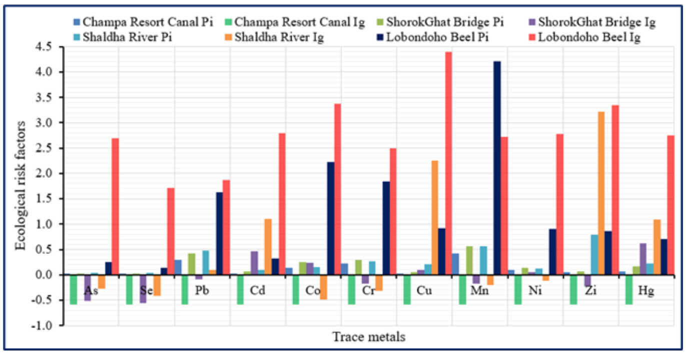

Figure 4. Ecological pollution status of targeted TTMs in the surface water of Gazipur district.

The ecological pollution status of TTMs in the surface water of Gazipur district is assessed using P_i and I_g indices (Figure 4). For As, all sites exhibit minimal

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pollution ($P_i \leq 1$) with Champa Resort Canal, ShorokGhat Bridge, and Shaldha River being unpolluted ($I_g < 0$), while Lobondoho Beel is moderately to strongly polluted ($I_g = 2.694$). Se also shows minimal pollution at all sites ($P_i \leq 1$), with Lobondoho Beel being moderately polluted ($I_g = 1.711$) and other sites remaining unpolluted to moderately polluted ($I_g < 1$). Pb ranges from minimal pollution at Champa Resort Canal (P_i =0.297) to high pollution at Lobondoho Beel (P_i = 1.632), with corresponding pollution status ranging from unpolluted to moderately polluted across sites. Cd presents minimal to low pollution levels ($Pi \leq 1$), with Lobondoho Beel exhibiting a moderately to strongly polluted status ($I_g = 2.791$).

Cobalt shows minimal to moderate pollution ($P_i \leq 2$) with strong pollution at Lobondoho Beel ($P_i = 2.222$, I_g = 3.378). Cr ranges from minimal to moderate pollution ($P_i \leq 2$), with Lobondoho Beel exhibiting moderately to strongly polluted status ($I_g = 2.492$). Cu shows minimal to low pollution ($P_i \leq 2$) except at Shaldha River and Lobondoho Beel, which exhibit strongly polluted status (I_g = 2.255 and 4.395, respectively). Mn displays low pollution at Champa Resort Canal and Shaldha River (P_i < 1) and high pollution at Lobondoho Beel ($P_i = 4.220$), indicating moderately to strongly polluted status. Ni shows minimal pollution at all sites ($P_i \leq 1$) except Lobondoho Beel, which is moderately polluted (P_i = 0.911, $I_g = 2.777$). Zn has minimal pollution levels at most sites, with Shaldha River and Lobondoho Beel showing strong pollution (I_g = 3.223 and 3.353, respectively). Hg indicates minimal pollution at most sites ($P_i \leq 1$), with Lobondoho Beel being moderately polluted ($P_i = 0.700$, $I_g = 2.747$). Overall, Lobondoho Beel consistently exhibits higher levels of pollution compared to other sites, with several TTMs exceeding moderate pollution thresholds, highlighting significant ecological risk in this area.

3.4 Health risk assessment

3.4.1 Non-carcinogenic analysis

The non-carcinogenic risks (HI) of all the toxic trace metals through oral and dermal exposure routes

Table 7. CDI and HQ values for oral and dermal exposure of TTMs.

Metals	CDI		HQ		Sampling station
	Oral	Dermal	Oral	Dermal	
As	4.68×10^{-8}	2.22×10^{-10}	1.56×10^{-4}	2.78×10^{-7}	Champa Resort Canal
	4.91×10^{-8}	2.33×10^{-10}	1.64×10^{-4}	2.91×10^{-7}	ShorokGhat Bridge
	5.79×10^{-8}	2.75×10^{-10}	1.93×10^{-4}	3.44×10^{-7}	Shaldha River
	4.54×10^{-7}	2.15×10^{-9}	1.51×10^{-3}	2.69×10^{-6}	Lobondoho Beel
Pb	5.45×10^{-7}	2.59×10^{-10}	3.89×10^{-7}	6.16×10^{-10}	Champa Resort Canal
	7.65×10^{-7}	3.63×10^{-10}	5.46×10^{-7}	8.64×10^{-10}	ShorokGhat Bridge
	8.70×10^{-7}	4.13×10^{-10}	6.22×10^{-7}	9.83×10^{-10}	Shaldha River
	2.99×10^{-6}	1.42×10^{-9}	2.14×10^{-6}	3.38×10^{-9}	Lobondoho Beel
Cd	1.14×10^{-8}	5.43×10^{-11}	2.29×10^{-8}	1.09×10^{-8}	Champa Resort Canal
	2.36×10^{-8}	1.12×10^{-10}	4.72×10^{-8}	2.24×10^{-8}	ShorokGhat Bridge
	3.68×10^{-8}	1.75×10^{-10}	7.36×10^{-8}	3.49×10^{-8}	Shaldha River
	1.19×10^{-7}	5.64×10^{-10}	2.38×10^{-7}	1.13×10^{-7}	Lobondoho Beel
Co	4.00×10^{-7}	1.90×10^{-9}	1.33×10^{-7}	1.27×10^{-7}	Champa Resort Canal
	5.33×10^{-7}	2.53×10^{-9}	1.78×10^{-7}	1.69×10^{-7}	ShorokGhat Bridge
	4.82×10^{-7}	2.29×10^{-9}	1.61×10^{-7}	1.52×10^{-7}	Shaldha River
	3.38×10^{-6}	1.60×10^{-8}	1.13×10^{-6}	1.07×10^{-6}	Lobondoho Beel
Cr	4.00×10^{-7}	1.90×10^{-9}	1.33×10^{-7}	1.27×10^{-7}	Champa Resort Canal
	5.33×10^{-7}	2.53×10^{-9}	1.78×10^{-7}	1.69×10^{-7}	ShorokGhat Bridge
	4.82×10^{-7}	2.29×10^{-9}	1.61×10^{-7}	1.52×10^{-7}	Shaldha River
	3.38×10^{-6}	1.60×10^{-8}	1.13×10^{-6}	1.07×10^{-6}	Lobondoho Beel
Cu	2.15×10^{-7}	1.02×10^{-9}	5.37×10^{-9}	8.50×10^{-11}	Champa Resort Canal
	3.44×10^{-7}	1.63×10^{-9}	8.60×10^{-9}	1.36×10^{-10}	ShorokGhat Bridge
	1.54×10^{-6}	7.30×10^{-9}	3.85×10^{-8}	6.09×10^{-10}	Shaldha River
	6.78×10^{-6}	3.22×10^{-8}	1.70×10^{-7}	2.68×10^{-9}	Lobondoho Beel
Mn	3.12×10^{-6}	1.48×10^{-8}	2.23×10^{-5}	6.72×10^{-9}	Champa Resort Canal
	4.14×10^{-6}	1.96×10^{-8}	2.96×10^{-5}	8.93×10^{-9}	ShorokGhat Bridge
	4.08×10^{-6}	1.94×10^{-8}	2.92×10^{-5}	8.81×10^{-9}	Shaldha River
	3.09×10^{-5}	1.47×10^{-7}	2.21×10^{-4}	6.67×10^{-8}	Lobondoho Beel
Ni	3.25×10^{-7}	3.08×10^{-10}	1.62×10^{-8}	5.71×10^{-11}	Champa Resort Canal
	5.04×10^{-7}	4.78×10^{-10}	2.52×10^{-8}	8.86×10^{-11}	ShorokGhat Bridge
	4.48×10^{-7}	4.26×10^{-10}	2.24×10^{-8}	7.88×10^{-11}	Shaldha River
	3.34×10^{-6}	3.17×10^{-9}	1.67×10^{-7}	5.87×10^{-10}	Lobondoho Beel
Zn	2.06×10^{-6}	5.86×10^{-9}	6.86×10^{-9}	9.77×10^{-11}	Champa Resort Canal
	2.62×10^{-6}	7.45×10^{-9}	8.73×10^{-9}	1.24×10^{-10}	ShorokGhat Bridge
	2.88×10^{-5}	8.21×10^{-8}	9.61×10^{-8}	1.37×10^{-9}	Shaldha River
	3.15×10^{-5}	8.98×10^{-8}	1.05×10^{-7}	1.50×10^{-9}	Lobondoho Beel
Hg	5.10×10^{-9}	2.42×10^{-11}	5.10×10^{-6}	5.76×10^{-10}	Champa Resort Canal
	1.18×10^{-8}	5.59×10^{-11}	1.18×10^{-5}	1.33×10^{-9}	ShorokGhat Bridge
	1.62×10^{-8}	7.69×10^{-11}	1.62×10^{-5}	1.83×10^{-9}	Shaldha River
	5.13×10^{-8}	2.44×10^{-10}	5.13×10^{-5}	5.80×10^{-9}	Lobondoho Beel

for adult residents were determined (Figure 5) using CDI and HQ values of metals (Table 7)

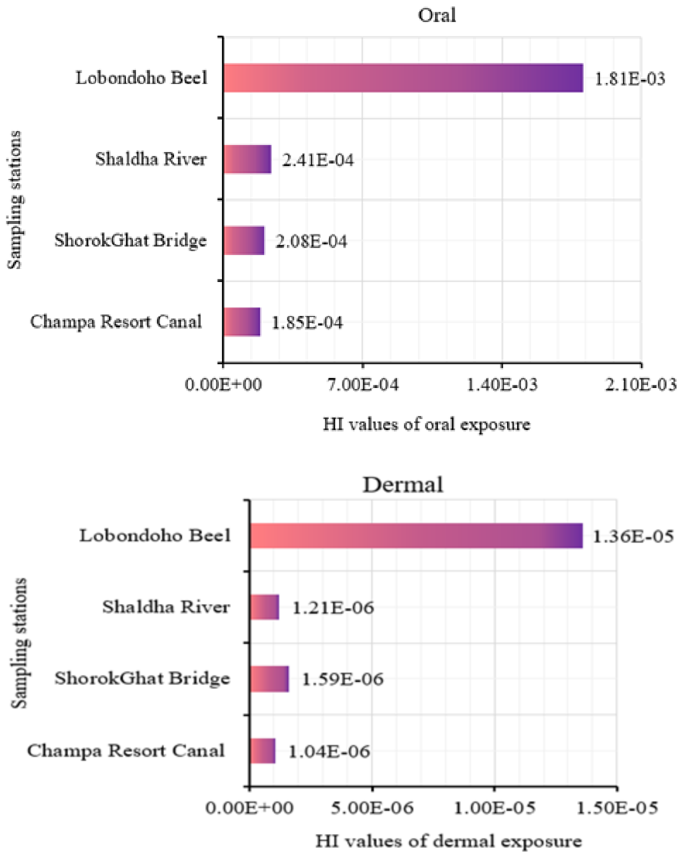

Figure 5. HI values of oral and dermal intake of TTMs.

The analysis of chronic daily intake (CDI) and hazard quotients (HQ) for oral and dermal exposure to TTMs across various sampling stations in Gazipur, Bangladesh, highlights significant variations in contamination levels. Among all locations, Lobondoho Beel exhibits the highest CDI and HQ values for multiple trace metals, indicating greater exposure risk. The CDI for As ranges from 4.68×10^{-8} to 4.54×10^{-7} mgkg^{-1}day^{-1}, with Lobondoho Beel showing the highest values. Though the HQ values remain below 1, suggesting a low risk of non-carcinogenic effects. Pb contamination is notably high at Lobondoho Beel (CDI: 2.99×10^{-6} oral, HQ: 2.14×10^{-6} oral) compared to other sites, indicating localized pollution sources. Cd, Co, and Cr also exhibit elevated levels at Lobondoho Beel, with oral CDI values reaching 1.19×10^{-7}, 3.38×10^{-6}, and 3.38×10^{-6} mgkg^{-1}day^{-1}, respectively.

In contrast, Cu and Zn contamination are moderate. Mn shows significantly high CDI values at Lobondoho Beel (3.09×10^{-5} oral, HQ: 2.21×10^{-4} oral). Ni and Hg also indicate higher contamination at this location. In contrast, Champa Resort Canal, ShorokGhat Bridge, and Shaldha River show relatively lower CDI and HQ values, indicating minimal to moderate exposure risks.

The Hazard Index (HI) values are categorized into oral and dermal exposure pathways (Figure 5), providing insight into potential non-carcinogenic health effects. Among the sampling locations, Lobondoho Beel exhibits the highest HI values (1.81×10^{-3} for oral and 1.36×10^{-5} for dermal), indicating relatively greater exposure risks. In comparison, Shaldha River (2.41×10^{-4} oral, 1.21×10^{-6} dermal), ShorokGhat Bridge (2.08×10^{-4} oral, 1.59×10^{-6} dermal), and Champa Resort Canal (1.85×10^{-4} oral, 1.04×10^{-6} dermal) show considerably lower HI values, suggesting minimal health concerns.

According to standard guidelines, non-carcinogenic health effects may arise when HI >1, whereas HI <1 suggests no significant health risks. Since all measured HI values in this study are well below 1, the likelihood of adverse health impacts due to TTM exposure in these areas is minimal. However, Lobondoho Beel has relatively elevated HI values compared to other sites.

3.4.2 Carcinogenic analysis

Table 8 presents an ILCR analysis for oral and dermal exposure of TTMs (As, Pb, Cd, Cr, and Ni) at different sampling stations. The lifetime risk of acquiring cancer as a result of exposure to various TTMs is shown by the ILCR values. Among the locations, Lobondoho Beel exhibits the highest ILCR values for both oral and dermal exposure, with Ni (2.81×10^{-6}) and Cr (1.69×10^{-6}) surpassing the 10^{-6} threshold, suggesting a potential cancer risk that requires further assessment. In contrast, Shaldha Rivershows moderate ILCR values, particularly for Cd (2.32×10^{-7} oral) and Ni (3.77×10^{-7} oral), but still within acceptable limits. ShorokGhat Bridge and Champa Resort Canal exhibit the lowest ILCR values, with all contaminants remaining below the 10^{-6} threshold, indicating negligible cancer risk.

Table 8. The ILCR values of carcinogenic health risks associated with oral and dermal exposure to the surface water of the study area.

Sampling stations	As		Pb		Cd		Cr		Ni	
	Oral	Dermal	Oral	Dermal	Oral	Dermal	Oral	Dermal	Oral	Dermal
Champa Resort Canal	7.02×10^{-8}	3.33×10^{-10}	4.63×10^{-9}	2.20×10^{-12}	7.21×10^{-8}	3.42×10^{-10}	2.00×10^{-7}	7.79×10^{-8}	2.73×10^{-7}	2.59×10^{-10}
ShorokGhat Bridge	7.37×10^{-8}	3.50×10^{-10}	6.50×10^{-9}	3.08×10^{-12}	1.49×10^{-7}	7.06×10^{-10}	2.66×10^{-7}	1.04×10^{-7}	4.23×10^{-7}	4.02×10^{-10}
Shaldha River	8.69×10^{-8}	4.12×10^{-10}	7.40×10^{-9}	3.51×10^{-12}	2.32×10^{-7}	1.10×10^{-9}	2.41×10^{-7}	9.38×10^{-8}	3.77×10^{-7}	3.57×10^{-10}
Lobondoho Beel	6.81×10^{-7}	3.23×10^{-9}	2.54×10^{-8}	1.21×10^{-11}	7.48×10^{-7}	3.55×10^{-9}	1.69×10^{-6}	6.58×10^{-7}	2.81×10^{-6}	2.66×10^{-9}

Additionally, oral exposure contributes significantly more to ILCR than dermal exposure, highlighting oral as the primary risk pathway. Based on standard guidelines, an ILCR above 10^{-4} indicates significant risk, while values between 10^{-6} and 10^{-4} suggest moderate concern. Given these findings, Lobondoho Beel requires immediate monitoring and potential mitigation measures, while other locations should continue regular assessments to ensure public health safety.

Conclusion

The study conducted in the Gazipur district, Bangladesh, using ICP-MS analysis, revealed significant contamination of toxic trace metals (TTMs) in surface water, particularly around industrial and agricultural areas. The concentrations of metals such as Pb, Co, Cr, and Mn exceeded safe limits at Lobondoho Beel, indicating substantial pollution and ecological risk. In contrast, Champa Resort Canal, ShorokGhat Bridge, and Shaldha River generally showed lower contamination levels, with some metals remaining within acceptable limits. Ecological risk assessments using pollution indices (P_i and I_g) confirmed varying degrees of pollution across sites, with Lobondoho Beel consistently presenting the highest ecological risk due to elevated metal concentrations. The health risk assessment of TTMs indicates potential concerns for both non-carcinogenic and carcinogenic effects. While the HI values for oral and dermal exposure remain below the threshold of 1, suggesting minimal immediate health risks, Lobondoho Beel exhibits the highest HI values, indicating a relatively higher risk. The ILCR analysis shows that Ni and Cr levels exceed the 10^{-6} threshold, suggesting a potential carcinogenic risk. Comparisons with other rivers and reference values highlight elevated contamination levels, with some metals surpassing WHO and USEPA limits. These findings highlight the critical need for effective monitoring and remediation measures to protect both environmental health and public well-being in the aquatic ecosystems of the Gazipur district.

Conflict of interests

The authors state that none of their personal relationships or conflicting financial interests might have influenced the work described in this study.

References

Agoro, M.A., Adeniji, A.O., Adefisoye, M.A. and Okoh, O.O. (2020). Heavy metals in wastewater and sewage sludge from selected municipal treatment plants in Eastern Cape province, South Africa. *Water* (Switzerland), 12(10), 2746. https://doi.org/10.3390/w12102746

Ahmad, W., Alharthy, R.D., Zubair, M., Ahmed, M., Hameed, A. and Rafique, S. (2021). Toxic and heavy metals contamination assessment in soil and water to evaluate human health risk. *Scientific Report,* 11, Article number 17006. https://doi.org/10.1038/s41598-021-94616-4

Ahmed, S.F., Kumar, P.S., Rozbu, M.R., Chowdhury, A.T., Nuzhat, S., Rafa, N., Mahlia, T.M.I., Ong, H.C. and Mofijur, M. (2022). Heavy metal toxicity, sources, and remediation techniques for contaminated water and soil. *Environmental Technology and Innovation,* 25, 102114. https://doi.org/10.1016/j.eti.2021.102114

Ali, H., Khan, E. and Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry,* Volume 2019, Article ID 6730305. https://doi.org/10.1155/2019/6730305

Ali, M.M., Ali, M.L., Islam, M.S. and Rahman, M.Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring and Management,* 5, 27–35. https://doi.org/10.1016/j.enmm.2016.01.002

Arifeen, H.M., Phoungthong, K., Mostafaeipour, A., Yuangyai, N., Yuangyai, C., Techato, K. and Jutidamrongphan, W. (2021). Determine the land-use land -cover changes, urban expansion and their driving factors for sustainable development in gazipur Bangladesh. *Atmosphere (Basel),* 12, 1353. https://doi.org/10.3390/atmos12101353

Asare-Donkor, N.K., Ofosu, J.O. and Adimado, A.A. (2018). Hydrochemical characteristics of surface water and ecological risk assessment of sediments from settlements within the Birim River basin in Ghana. *Environmental Systems Research,* 7, Article Number 9. https://doi.org/10.1186/s40068-018-0113-1

Avkopashvili, M., Avkopashvili, G., Avkopashvili, I., Asanidze, L., Matchavariani, L., Gongadze, A. and Gakhokidze, R. (2022). Mining-Related metal pollution and ecological risk factors in South-Eastern Georgia. *Sustainability*, 14(9), 5621. https://doi.org/10.3390/su14095621

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M.R. and Sadeghi, M. (2021). Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. *Frontiers in Pharmacology.* 12, 643972. https://doi.org/10.3389/fphar.2021.643972

Bangladesh Bureau of Statistics. (2015). Health and Morbidity Status Survey-2014, Government of the People's Republic of Bangladesh.

Begum, W., Rai, S., Banerjee, S., Bhattacharjee, S., Mondal, M.H., Bhattarai, A. and Saha, B. (2022). A comprehensive review on the sources, essentiality and toxicological profile of nickel. *RSC Advances,* 12, 9139–9153. https://doi.org/10.1039/d2ra00378c

Birch, G. (2013). Use of Sedimentary-Metal Indicators in Assessment of Estuarine System Health, *Treatise on Geomorphology*, 14, 282-291. https://doi.org/10.1016/B978-0-12-374739-6.00392-4

Chen, B., Yu, P., Chan, W.N., Xie, F., Zhang, Y., Liang, L., Leung, K.T., Lo, K.W., Yu, J., Tse, G.M.K., Kang, W. and To, K.F. (2024). Cellular zinc metabolism and zinc signaling: from biological functions to diseases and therapeutic targets. *Signal Transduction and Targeted Therapy,* 9, 6. https://doi.org/10.1038/s41392-023-01679-y

Clases, D. and Gonzalez de Vega, R. (2022). Facets of ICP-MS and their potential in the medical sciences—Part 1: fundamentals, stand-alone and hyphenated techniques. *Analytical and Bioanalytical Chemistry,* 414, 7337–7361. https://doi.org/10.1007/s00216-022-04259-1

Collin, M.S., Venkatraman, S.K., Vijayakumar, N., Kanimozhi, V., Arbaaz, S.M., Stacey, R.G.S., Anusha, J., Choudhary, R., Lvov, V., Tovar, G.I., Senatov, F., Koppala, S. and Swamiappan, S. (2022). Bioaccumulation of lead (Pb) and its effects on human. *Journal of Hazardous Materials Advances,* 7, 100094. https://doi.org/10.1016/j.hazadv.2022.100094

Dasharathy, S., Arjunan, S., Maliyur Basavaraju, A., Murugasen, V., Ramachandran, S., Keshav, R. and Murugan, R. (2022). Mutagenic, Carcinogenic, and Teratogenic Effect of Heavy Metals. *Evidence-based Complementary and Alternative Medicne,* Volume 2022, Article ID 8011953. https://doi.org/10.1155/2022/8011953

Dey, M., Akter, A., Islam, S., Chandra Dey, S., Choudhury, T.R., Fatema, K.J. and Begum, B.A. (2021). Assessment of contamination level, pollution risk and source apportionment of heavy metals in the Halda River water, Bangladesh. *Heliyon,* 7, e08625. https://doi.org/10.1016/j.heliyon.2021.e08625

Díaz Rizo, O., Casanova Díaz, A.O., Torres Ramos, A.G. and Ramos López, D. (2023). Heavy metals concentration, pollution indexes, and health risk assessment of urban road dust in the historical center of Havana, Cuba. *Environmental Monitoring Assessment,* 195, 349. https://doi.org/10.1007/s10661-022-10875-2

DPHE, Department of public health engineering, Bangladesh standard, Government of the peoples republic of Bangladesh. Retrieved from https://wqtrms.dphe.gov.bd/

El Ouaty, O., El M'rini, A., Nachite, D., Marrocchino, E., Marin, E. and Rodella, I. (2022). Assessment of the heavy metal sources and concentrations in the Nador Lagoon sediment, Northeast-Morocco. *Ocean and Coastal Management,* 216, 105900. https://doi.org/10.1016/J.OCECOAMAN.2021.105900

Emmanuel, U.C., Chukwudi, M.I., Monday, S.S. and Anthony, A.I. (2022). Human health risk assessment of heavy metals in drinking water sources in three senatorial districts of Anambra State, Nigeria. *Toxicology Reports,* 9, 869–875. https://doi.org/10.1016/j.toxrep.2022.04.011

Eze, V., Ndife, C. and Muogbo, M. (2021). Carcinogenic and Non-carcinogenic Health Risk Assessment of Heavy Metals in Njaba River, Imo State, Nigeria. *Brazilian Journal of Analytical Chemistry,* 8, 57–70. https://doi.org/10.30744/brjac.2179-3425.ar-05-2021

FAO. (2016). Shaw, J. Milk: The Mammary Gland and Its Secretion; Food and Agriculture Organization (FAO) of The United Nations: Rome, Italy, 2016; p. 89.

Ferreira, S.L.C., da Silva, J.B., dos Santos, I.F., de Oliveira, O.M.C., Cerda, V. and Queiroz, A.F.S. (2022). Use of pollution indices and ecological risk in the assessment of contamination from chemical elements in soils and sediments – Practical aspects. *Trends in Environmental Analytical Chemistry,* 35, e00169. https://doi.org/10.1016/J.TEAC.2022.E00169

Finley, B.L., Monnot, A.D., Paustenbach, D.J. and Gaffney, S.H. (2012). Derivation of a chronic oral reference dose for cobalt. *Regulatory Toxicology and Pharmacology,* 64, 491–503. https://doi.org/10.1016/J.YRTPH.2012.08.022

Genchi, G., Sinicropi, M.S., Lauria, G., Carocci, A. and Catalano, A. (2020). The effects of cadmium toxicity. *International Journal of Environmental Research and Public Health*, 17(11), 3782. https://doi.org/10.3390/ijerph17113782

Gnonsoro, U.P., Ake Assi, Y.E.D., Sangare, N.S., Kouakou, Y.U. and Trokourey, A. (2022). Health Risk Assessment of Heavy Metals (Pb, Cd, Hg) in Hydroalcoholic Gels of Abidjan, Côte d'Ivoire. *Biological Trace Element Research,* 200, 2510–2518. https://doi.org/10.1007/s12011-021-02822-y

González-Montaña, J.R., Escalera-Valente, F., Alonso, A.J., Lomillos, J.M., Robles, R. and Alonso, M.E. (2020). Relationship between vitamin b12 and cobalt metabolism in domestic ruminant: An update. *Animals,* 10, 1855. https://doi.org/10.3390/ani10101855

Hadrup, N. and Ravn-Haren, G. (2020). Acute human toxicity and mortality after selenium ingestion: *A review. Journal of Trace Elements in Medicine and Biology,* 58, 126435. https://doi.org/10.1016/j.jtemb.2019.126435

Hariharan, S. and Dharmaraj, S. (2020). Selenium and selenoproteins: it's role in regulation of inflammation. *Inflammopharmacology,* 28, 667–695. https://doi.org/10.1007/s10787-020-00690-x.

Hasan, M.K., Shahriar, A. and Jim, K.U. (2019). Water pollution in Bangladesh and its impact on public health. *Heliyon,* 5, e02145. https://doi.org/10.1016/j.heliyon.2019.e02145

Hasan, M.M., Ahmed, M.S., Adnan, R. and Shafiquzzaman, M. (2020). Water quality indices to assess the spatiotemporal variations of Dhaleshwari river in central Bangladesh. *Environmental and Sustainability Indicators,* 8, 100068. https://doi.org/10.1016/j.indic.2020.100068

Hassan, K.M.T., Ferdoushi, Z., Rana, M.M. and Alam, M.S (2024). Assessing the Seasonal Variability of Water Quality and Heavy Metals Concentration in Sediment, Water, and Fish Muscles of Korotoa River in Bangladesh. *Aquaculture Research,* Volume 2024, Article ID 5343363. https://doi.org/10.1155/2024/5343363

Hossain, M.B., Runu, U.H., Sarker, M.M., Hossain, M.K. and Parvin, A. (2021a). Vertical distribution and contamination assessment of heavy metals in sediment cores of ship breaking area of Bangladesh. *Environmental*

RESEARCH PAPER

Geochemistry and Health, 43, 4235–4249. https://doi.org/10.1007/s10653-021-00919-w

Hossain, M.B., Tanjin, F., Rahman, M.S., Yu, J., Akhter, S., Noman, M.A. and Sun, J. (2022). Metals Bioaccumulation in 15 Commonly Consumed Fishes from the Lower Meghna River and Adjacent Areas of Bangladesh and Associated Human Health Hazards. *Toxics,* 10(3), 139. https://doi.org/10.3390/toxics10030139

Hossain, M.N., Rahaman, A., Hasan, M.J., Uddin, M.M., Khatun, N. and Shamsuddin, S.M. (2021b). 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,* Volume 3, Article Number 509. https://doi.org/10.1007/s42452-021-04464-0

Jacobs, A., Renaudin, G., Forestier, C., Nedelec, J.M. and Descamps, S. (2020). Biological properties of copper-doped biomaterials for orthopedic applications: A review of antibacterial, angiogenic and osteogenic aspects. *Acta Biomaterialia,* 117, 21–39. https://doi.org/10.1016/j.actbio.2020.09.044

Jolly, Y.N., Rana, S,. Akter, S., Kabir, J., Rahman, M.S., Rahman, M.M. and Sultana, M.S. (2019). Appraisal of metal pollution in the aquatic environment of shitalakhya river, bangladesh and its ecological risk assessment. *Journal of Nature Science and Sustainable Technology,* 12(4), 289-313. Retrieved from https://www.researchgate.net/publication/354340755_APPRAISAL_OF_METAL_POLLUTION_IN_THE_AQUATIC_ENVIRONMENT_OF_SHITALAKHYA_RIVER_BANGLADESH_AND_ITS_ECOLOGICAL_RISK_ASSESSMENT

Jomova, K., Alomar, S.Y., Nepovimova, E., Kuca, K. and Valko, M. (2024). Heavy metals: toxicity and human health effects. *Archives of Toxicology*, 99(1), 153-209. https://doi.org/10.1007/s00204-024-03903-2

Jomova, K., Makova, M., Alomar, S.Y., Alwasel, S.H., Nepovimova, E., Kuca, K., Rhodes, C.J. and Valko, M. (2022). Essential metals in health and disease. *Chemico-Biological Interactions,* 367, 110173. https://doi.org/10.1016/j.cbi.2022.110173

Kamunda, C., Mathuthu, M. and Madhuku M. (2018). Potential human risk of dissolved heavy metals in gold mine waters of Gauteng Province, South Africa. *Journal of Toxicology and Environmental Health Sciences,* 10, 56–63. https://doi.org/10.5897/jtehs2018.0422

Karaouzas, I., Kapetanaki, N., Mentzafou, A., Kanellopoulos, T.D. and Skoulikidis, N. (2021). Heavy metal contamination status in Greek surface waters: A review with application and evaluation of pollution indices. *Chemosphere,* 263, 128192. https://doi.org/10.1016/j.chemosphere.2020.128192

Kesari, V.P., Kumar, A. and Khan, P.K. (2012). Genotoxic potential of arsenic at its reference dose. Ecotoxicology and *Environmental Safety,* 80, 126–131. https://doi.org/10.1016/j.ecoenv.2012.02.018

Kocarnik, J.M., Compton, K., Dean, F.E., Fu, W., Gaw, B.L., Harvey, J.D., Henrikson, H.J., Lu, D., Pennini, A., Xu, R., Ababneh, E., Abbasi-Kangevari, M., Abbastabar, H., Abd-Elsalam, S.M., Abdoli, A., Abedi, A., Abidi, H., Abolhassani, H., Adedeji, I.A. and Force, L.M. (2022). Cancer incidence, mortality, years of life lost, years lived with disability, and Disability-Adjusted Life Years for 29 cancer groups from 2010 to 2019. *JAMA Oncology*, 8(3), 420. https://doi.org/10.1001/jamaoncol.2021.6987

Kubra, K., Mondol, A.H., Ali, M.M., Palash, M.A.U., Islam, M.S., Ahmed, A.S.S., Masuda, M.A., Islam, A.R.M.T., Bhuyan, M.S., Rahman, M.Z. and Rahman, M.M. (2022). Pollution level of trace metals (As, Pb, Cr and Cd) in the sediment of Rupsha River, Bangladesh: Assessment of ecological and human health risks. *Frontiers in Environmental Science,* 10, 778544. https://doi.org/10.3389/fenvs.2022.778544

Kumar, N. and Jha, A.K. (2024). Lead Toxicity Mitigation : Sustainable Nexus Approaches. Environmental Contamination Remediation and Management, Springer. https://doi.org/10.1007/978-3-031-46146-0

Laur, N., Kinscherf, R., Pomytkin, K., Kaiser, L., Knes, O. and Deigner, H.P. (2020). ICP-MS trace element analysis in serum and whole blood. *PLoS One,* 15, e0233357. https://doi.org/10.1371/journal.pone.0233357

Li, L., Wu, F., Liu, Y., He, T., Lin, J., Zhang, W., Li, R., Chen, H., Zong, K., Zeng, Z. and Hu, Z. (2024). A two-step chromatographic purification method for Ni for its isotopic analysis by MC-ICP-MS. *Journal of Analytical Atomic Spectrometry,* 39, 1938–1947. https://doi.org/10.1039/d4ja00120f

Lipy, E.P., Hakim, M., Mohanta, L.C., Islam, D., Lyzu, C., Roy, D.C., Jahan, I., Akhter, S., Raknuzzaman, M. and Sayed, M.A. (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

Mohammadi, A.A., Zarei, A., Majidi, S., Ghaderpoury, A., Hashempour, Y., Saghi, M.H., Alinejad, A., Yousefi, M., Hosseingholizadeh, N. and 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

Muller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. *GeoJournal*, 2(3), 108–118. Retrieved from http://ci.nii.ac.jp/naid/10030367619

Rakib, MR.J., Jolly, Y.N., Begum, B.A., Choudhury, T.R., Fatema, K.J., Islam, M.S., Ali, M.M. and Idris, A.M. (2022). Assessment of trace element toxicity in surface water of a fish breeding river in Bangladesh: a novel approach for ecological and health risk evaluation. *Toxin Reviews,* 41, 420–436. https://doi.org/10.1080/15569543.2021.1891936

Rappazzo, A.C., Papale, M., Rizzo, C., Conte, A., Giannarelli, S., Onor, M., Abete, C., Cefali, P., De Domenico, E., Michaud, L. and Lo Giudice, A. (2019). Heavy metal tolerance and polychlorinated biphenyl oxidation in bacterial communities inhabiting the Pasvik River and the Varanger Fjord area (Arctic Norway). *Marine Pollution Bulletin* 141, 535–549. https://doi.org/10.1016/j.marpolbul.2019.01.070

Raza, J., Hassan, M.Q., Ahmed, K.M., Zahid, A. and Khandaker, N. (2022). Assessing the Impact of Urbanization on the Declining Groundwater Level of Gazipur District, Bangladesh 2019. GSA Connects 2022 meeting in Denver, Colorado. https://doi.org/10.1130/abs/2022am-379416

Salama, A.K. (2019.) Health risk assessment of heavy metals content in cocoa and chocolate products sold in Saudi Arabia. *Toxin Reviews,* 38, 318–327. https://doi.org/10.1080/15569543.2018.1471090

Samaila, B., Aisha, I.J., Shehu, A.A. and Bako, A. (2021). Evaluation of Chronic Daily Intake , Pollution Index and Incremental Life Cancer Risk to Adults Due to Exposures to Heavy Metals in Surface and Ground water. *International Journal of Scientific Research in Physics and Applied Sciences,* 9(6), 72–80. Retrieved from https://www.isroset.org/journal/IJSRPAS/full_paper_view.php?paper_id=2629

Sani, A., Idris, K.M., Abdullahi, B.A. and Darma, A.I. (2022). Bioaccumulation and health risks of some heavy metals in Oreochromis niloticus, sediment and water of Challawa river, Kano, Northwestern Nigeria. *Environmental Advances,* 7, 100172. https://doi.org/10.1016/j.envadv.2022.100172

Santhosh, K., Kamala, K., Ramasamy, P., Musthafa, M.S., Almujri, S.S., Asdaq, S.M.B. and Sivaperumal, P. (2024). Unveiling the silent threat: Heavy metal toxicity devastating impact on aquatic organisms and DNA damage. *Marine Pollution Bulletin,* 200, 116139. https://doi.org/10.1016/J.MARPOLBUL.2024.116139

Shipp, A.M., Gentry, P.R., Lawrence, G., Van Landingham, C., Covington, T., Clewell, H.J., Gribben, K. and Crump, K. (2000). Determination of a site-specific reference dose for methylmercury for fish-eating populations. *Toxicology and Industrial Health,* 16, 335–438. https://doi.org/10.1177/074823370001600901

Tabassum, N. and Singh, P.K. (2025). Heavy metal content in agricultural soils around an industrial city and their remediation using legume and leafy plants. *Journal of Applied Biology and Biotechnology,* 13, 136–145. https://doi.org/10.7324/JABB.2025.210297

Tseng, Y., Dominguez, D., Sivagurunathan, U., Zamorano, M.J., Philip, A.J.P. and Izquierdo, M. (2025). Effects of the dietary supplementation of manganese on growth, skeletal development, oxidative stress and bone metabolism related genes in gilthead seabream (*Sparus aurata*) larvae. *Aquaculture,* 594, 741439. https://doi.org/10.1016/J.AQUACULTURE.2024.741439

Ukah, B.U., Egbueri, J.C., Unigwe, C.O. and Ubido, O.E. (2019). Extent of heavy metals pollution and health risk assessment of groundwater in a densely populated industrial area, Lagos, Nigeria. *International Journal of Energy and Water Resources,* 3, 291–303. https://doi.org/10.1007/s42108-019-00039-3

USEPA. (2020). National primary drinking water regulations. https://www.epa.gov/groundwater-anddrinking-water/national-primary-drinking water regulations# Inorganic.

USEPA, Risk-based Concentration Table. (2000). Philadelphia PA. Retrieved from https://www.sciepub.com/reference/13120

USEPA. (2004). Risk assessment guidance for superfund (RAGS). Volume I. Human health evaluation manual (HHEM). Part E. Supplemental guidance for dermal risk assessment. Us Epa 1. https://doi.org/EPA/540/1-89/002

USEPA. (1999). Screening level ecological risk assessment protocol for hazardous waste combination facilities, vol 3 (1999)., Appendix E: Toxicity reference values. EPA 530-D99-001C.

WHO. (2004). Guidelines for drinking-water quality: recommendations, World Health Organization. Retrieved from https://iris.who.int/bitstream/10665/42852/1/9241546387.pdf

Wikipedia, The Free Encyclopedia, Gazipur district (2024). Retrieved from http://en.wikipedia.org/wiki/Gazipur

Wilschefski, S.C. and Baxter, M.R. (2019). Inductively Coupled Plasma Mass Spectrometry: Introduction to Analytical Aspects. *Clinical Biochemist Reviews,* 40, 115–133. https://doi.org/10.33176/AACB-19-00024

Zakir, H.M., Sumi, S.A., Sharmin, S., Mohiuddin, K.M. and Kaysar, S. (2015). Heavy metal contamination in surface soils of some industrial areas of Gazipur, Bangladesh. *Journal of Chemical Biological and Physical Sciences,* 5, 2191–2206. Retrieved from www.researchgate.net/publication/281272563_Heavy_metal_contamination_in_surface_soils_of_some_industrial_ar

Zaynab, M., Al-Yahyai, R., Ameen, A., Sharif, Y., Ali, L., Fatima, M., Khan, K.A. and Li, S. (2022). Health and environmental effects of heavy metals. *Journal of King Saud University - Science,* 34, 101653. https://doi.org/10.1016/j.jksus.2021.101653

Zhao, G., Ma, Y., Liu, Y., Cheng, J. and Wang, X. (2022). Source analysis and ecological risk assessment of heavy metals in farmland soils around heavy metal industry in Anxin County. *Scientific Reports,* 12, Article Number 10562. https://doi.org/10.1038/s41598-022-13977-6

Zhao, K., Wang, Q., Qian, S. and Li, F. (2023). Spatial and temporal distribution characteristics of antibiotics and heavy metals in the Yitong River basin and ecological risk assessment. *Scientific Reports,* 13, Article Number 4202. https://doi.org/10.1038/s41598-023-31471-5

Zhao, M., Li, Y. and Wang, Z. (2022). Mercury and Mercury-Containing Preparations: History of Use, Clinical Applications, Pharmacology, Toxicology, and Pharmacokinetics in Traditional Chinese Medicine. *Frontiers in Pharmacology,* 13, 807807. https://doi.org/10.3389/fphar.2022.807807

