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Heavy Metal Pollution and Ecological Risk Assessment of the Soil and Grass from Major Riverside Areas in Megacity Dhaka, Bangladesh

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ABSTRACT

Heavy metal (HM) contamination in soil and plants endangers living organisms due to its toxic, persistent, and bioaccumulative nature. In this study, soil and grass samples were collected from the Buriganga, Turag, and Bongshi riverside areas of megacity Dhaka, Bangladesh. In this investigation, pollution levels, ecological risk, and HM transfer from soil to grass were assessed using the geo-accumulation index, contamination factor, ecological risk index, and correlation analysis. HM concentrations in both soil and grass were found in descending order of Lead (Pb) > Chromium (Cr) > Nickel (Ni) > Copper (Cu) > Cadmium (Cd). The highest concentrations of Pb were 73.45 ± 15.76 mg/kg and 64.23 ± 8.68 mg/kg in soil and grass, respectively. The maximum geo-accumulation index was < 1, indicating the unpolluted soil quality. The mean contamination factors of HMs were 0.85 in Cr (low contamination), 0.96 in Cu (low contamination), 3.61 in Ni (considerable contamination), 0.039 in Cd (low contamination), and 2.29 in Pb (moderate contamination). The degree of contamination was above 6, indicating moderate contamination. One site near the Bongshi River and six sites in the dairy farm area showed a pollution load index value (PLI) < 1, indicating no pollution. The other 17 areas showed PLI > 1, indicating polluted sites. Ecological risk index analysis indicates that all the sites are ecologically safe, but HM mobility from soil to grass indicates a high accumulation of HM in grass. Effective environmental management is essential to control HM pollution at its source and protect riverside ecosystems.

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INTRODUCTION

Heavy metal (HM) pollution has been increasing extensively in developing countries due to accelerated urbanization and industrialization (Pandit et al., 2025; Sahen et al., 2025). HM contamination in soil and water is a serious problem for the ecosystem due to its toxic nature and has become a great concern due to its pervasive toxic effects on human health and the environment (Ali et al., 2013; Saifullah et al., 2025; Adimalla 2020; Hossain and Okino 2024). HMs can persist and accumulate in the environment, especially in soils. HMs, particularly Pb, Zn, Cu, Mn, and Fe, are potentially toxic and environmentally concerning issues (Uwah and

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John, 2014; Shaibur 2023). Higher concentrations of HMs in soil can alter the soil properties, lower the nutrient content, destroy the soil structure, degeneration of soil biology, resulting decrease in crop yield (Zhao et al., 2019; Guan et al., 2018).

HM contamination in soils is caused by both natural and anthropogenic processes, while anthropogenic activity contributes more to surface soil contamination (Adimalla and Wang 2018; Shao et al., 2018). Anthropogenic sources of HMs are wastewater discharge, mining, industrial manufacture, traffic congestion, coal combustion, agricultural activities, landfill leachate, and atmospheric deposition (Viard et al 2004; Zhang 2006; Liang et al., 2017). HMs can be released into the environment through domestic and commercial activities, pesticides, and fungicides, as well as manure from poultry farms in agricultural areas (Wild, 1993; Jahan et al., 2024). Increasing urban populations generate large volumes of solid waste, making disposal sites more vulnerable to soil HM contamination (Alam et al., 2020; Shaibur et al., 2022). Urban river sediments are also contaminated by HMs from moderate to significant levels by extensive industrialization and urbanization, which is alarming for the near future (Al Mamun et al., 2021; Siddique et al., 2025). HMs in the riverine sediments are attributed to both natural and anthropogenic sources, particularly from different industries (Kubra et al., 2022). River estuarine sediments are moderately polluted by Pb and Zn from anthropogenic sources of diesel fuel from engine boats, whereas As, Ni, Cu, and Cr are from natural origin, which indicates moderate pollution at present but could be a potential risk in the future (Hossain et al., 2020; Rahman et al., 2023). In aquatic ecosystems, sediment serves as a source and sink of toxic trace metals (Huang et al., 2020; Hossain et al., 2022). Groundwater is also contaminated with trace metals such as Mn and As, and exceeds the recommended value of the World Health Organization (WHO). This metal contamination has a potential health risk to human health as they use this groundwater for drinking purposes in developing countries, including Bangladesh (Shaibur et al., 2024; Anzum et al., 2023). HMs are persistent in soil, sediment, food chains, and the environment, causing different diseases, and chronic exposure to HMs could be a long-lasting threat to human health (Wieczorek-Dąbrowska et al., 2013; Budi et al., 2024). Bioaccumulation of these HMs in plants mainly depends on the uptake mechanism, physical-chemical properties of soil, physiological properties of plants, and some other environmental factors (Hu et al., 2020). Plants can uptake HMs from soil, and these HMs can accumulate in herbivores' bodies with final accumulation or biomagnification in the human body by consuming these herbivores (Peijnenburg et al., 2007; Khan et al., 2015; Rajendiran et al., 2015).

HMs enter the human body mainly through three pathways: ingestion, dermal contact, and inhalation (Hui et al., 2017; Jiang et al., 2020). Some of them, such as As, Cd, Pb, and Hg, are identified as cumulative poisons (Kocharea and Tamirb 2015). Nowadays, the toxic effects of HMs on human health have become a great concern all over the world (Hasan et al., 2025; Yang et al., 2002; Nordberg, 2003). When HMs are not metabolized by the body, they accumulate in the tissue and express their cumulative toxic effects. Long-term excessive intake of Cu and Pb can damage the central nervous system (Ren et al., 2019; Yang et al., 2019), while acute exposure to As causes severe skin lesions with respiratory and cardiovascular diseases in some extreme cases (Ali et al., 2019). Chromium (Cr) is carcinogenic, linked to cardiovascular and liver diseases, and acute ingestion may cause severe gastrointestinal disorders and even death (Bahadır et al., 2014). In general, some fetal diseases like cardiovascular, kidney, nervous, and bone diseases, impairment of reproductive functions, spontaneous abortion, stillbirth, blue line on gum, mottling of teeth, low birth weight and abnormal pregnancy, gastrointestinal morbidity, and language delay can be caused by HM accumulation in human body (Ogabiela et al., 2011; Yebpella et al., 2011).

Excessive accumulation of HMs in roadside soils may result in HM contamination of vegetation, wildlife, domestic animals, and human settlements, which can have negative impacts on the tissue of both animals and humans. Human beings, at the top of the trophic level, are the most vulnerable due to the enrichment or biomagnification of HMs in their food taking place at each trophic level of the food chain (Baby et al., 2010; Croteau et al., 2005; Rouhani et al., 2025). Thereafter, it is essential to find out the distribution pattern of toxic HMs in soil and vegetation to identify the pollution and its probable risk factors. In Bangladesh, the tendency to disregard environmental protection laws and their effective enforcement has led to the release of untreated or poorly treated industrial and municipal effluents into surrounding areas. This has resulted in soil, water, and sediment pollution, thereby escalating ecological risk (Islam et al., 2022; Rahman et al., 2014). Some river sediments near urban areas of Bangladesh, Dhaleshwari River, Karnafuli River, Meghna River, and Rupsha River have been investigated by several researchers to identify HM pollution (Al Mamun et al., 2021; Hossain et al., 2019; Bhuyan et al., 2017; Kubra et al., 2022). Despite numerous studies on agricultural soil HM pollution in Bangladesh (Ahmed et al., 2018; Islam et al., 2024; Ahmad and Goni 2010), research on riverside soil HM pollution in central Dhaka city is limited. Moreover, there is a notable deficiency in comprehensive evaluations of HM concentrations in soil and grass within such megacities. A thorough assessment of pollution and ecological risks associated with HM in these regions has not been conducted to provide a complete understanding of the situation. Additionally, to our best knowledge, there is limited systematic investigation into HM pollution in soils and grasses adjacent to riversides and dairy farms.

To address this gap, this study was conducted to assess the levels of HM contamination in soil and grass collected from three major rivers and dairy farms in Dhaka, Bangladesh, and aimed to compare the contamination levels with established pollution indices. This study has specific objectives to evaluate the extent of HM contamination in riverside soil and grasses and assess the potential ecological and human health risks associated with HMs.

MATERIALS & METHODS

Study area and sample collection

A total of 24 soil samples from 5 to 15 cm depth (Kravchenko et al., 2025) were collected from four different sites of Keraniganj, Ashulia, Savar, and the Dairy farm area (Savar). The first three sites are in riverside areas of the Buriganga, Turag, and Bongshi rivers, respectively, and the last one is situated near Dhaka city, specifically in the Savar dairy farm area (Fig. 1). The mapping of sampling sites was performed using QGIS. A total of 24 grass samples were also collected from the same locations as the soil samples. Soil samples were oven-dried at 80 ºC for 72 h and ground into a fine powder using a pestle and mortar. Then, 1 g of fine powder soil sample was taken in a beaker to which 10 mL of 1 M nitric acid (HNO_3) was added and heated for 15 to 20 min on a hot plate. After that, 5 mL of perchloric acid ($HClO_4$) was also added and again heated for 15 min. After cooling, the samples were diluted with 100 mL of deionized water and filtered to store in a compatible volume of the sample bottle (Kumar et al., 2025).

Soil and grass sample preparation and HM analysis

Grass samples were first washed as fresh grass using tap water. All washed samples were carefully dried in an oven at 80 ºC for 72 h. This was followed by grinding and homogenization of the dried samples into fine powder using an electric grinder. The powdered samples were stored in a closed container in the absence of humidity. Grass samples were prepared by the wet oxidation method using the di-acid mixture. In this method, exactly 1 g of finely ground grass sample was taken into a 250 mL conical flask, and a di-acid mixture (conc. HNO_3:$HClO_4$ = 2:1) was added to it (10 mL HNO_3) (Kanwal et al., 2024). Then, the flask was placed on an electric hot plate for heating at 180-200ºC until the solid particles disappeared and white fumes evolved from the flask. After that, 5 mL $HClO_4$ was also added and again heated for 15 min. Then, it was

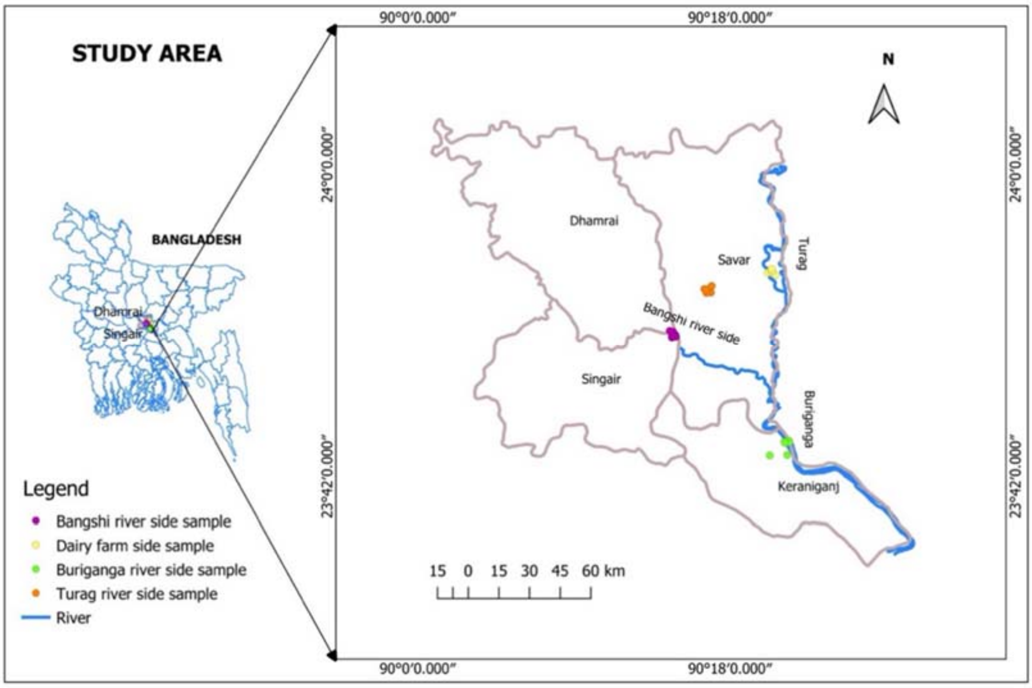

Fig. 1. Map of riverside soil and grass sampling locations in Dhaka City, Bangladesh.

cooled at room temperature, washed with distilled water, and filtered into 100 mL volumetric flasks through a 0.22 µm membrane acetate filter paper. Then the HMs were analyzed by atomic absorption spectroscopy (SHIMADZU AA-7000) at Wazed Miah Science Research Centre, Jahangirnagar University, Savar, Dhaka.

Determination of geo-accumulation index in soil

A common criterion to evaluate HM pollution in the soil is the geo-accumulation index (I_{geo}). It was originally defined by Muller (1969) to determine metal contamination in sediments by comparing current concentrations with pre-industrial levels. The I_{geo} was calculated using equation (1) (Muller, 1969),

$$I_{geo} = \log_2 (C_n / (1.5B_n)) \quad (1)$$

where C_n is the concentration of element n and the B_n was the world surface rock average given by Martin and Meybeck (1979), the factor 1.5 indicates the background matrix correlation value responsible for lithospheric differences (Ke et al., 2017). The I_{geo} values are interpreted as follows: < 0 indicates unpolluted sediments; 0–1, unpolluted to moderately polluted; 1–2, moderately polluted; 2–3, moderately to strongly polluted; 3–4, strongly polluted; 4–5, strongly to extremely polluted; and > 6, extremely polluted (Kabir et al., 2020).

Determination of contamination factor

The contamination factor (C_f) and the degree of contamination (C_d) are used to determine the HM concentration status of soils. The C_f is calculated using equation (2),

$$C_f = \frac{\text{Measured concentration}}{\text{Background concentration}} \quad (2)$$

where the Background concentration of each metal was the world surface rock average given by Martin and Meybeck (1979). $C_f < 1$ indicates low contamination; $1 \le C_f < 3$ indicates moderate contamination; $3 \le C_f < 6$ indicates considerable contamination, and $C_f \ge 6$ indicates very high pollution (Hakanson 1980). The C_d was defined as the sum of contamination factors for all tested metals.

Determination of pollution load index (PLI)

The Pollution Load Index (PLI) is employed to investigate the combined pollution impact across various sites caused by different metals present in soil and grass. It provides an assessment of the overall toxicity status of each sampling site. Each sampling site was evaluated for the extent of metal pollution by employing the method based on the PLI developed by Thomilson et al. (1992) as equation (3),

$$PLI = n\sqrt{(Cf1 \times Cf2 \times Cf3 \times \ldots\ldots \times Cfn)} \quad (3)$$

where n is the number of metals studied, and Cf is the contamination factor. The PLI provides simple but comparative means for assessing a site quality, where a value of PLI < 1 denotes perfection, PLI = 1 is present at only the baseline level of pollutants are present, and PLI > 1 indicates deterioration of site quality (Khasman et al., 2004).

Analysis of potential ecological risk index

The potential ecological risk index (PERI) was originally introduced by Hakanson (1980) to assess the degree of HM pollution in soil, according to the toxicity of the metals and the response of the environment. RI could evaluate the ecological risk caused by toxic metals comprehensively. The evaluation methods of RI are listed below in equations 4-1 and 4-2,

$$E_r^i = T_r^i \times C_f \quad (4\text{-}1)$$
$$\text{and } RI = \sum_{i=1}^{n} Ei \quad (4\text{-}2)$$

where C_f is the contamination factor, E_r^i is the monomial potential ecological risk factor, T_r^i is the metal toxic response factor (Hakanson, 1989). The value for each element is in the order of Zn = 1, Cr = 2, Cu = Ni = Pb = 5, As = 10, and Cd = 30 (Hossain et al., 2019). According to Hakanson (1980), the ecological risk index (E_r^i) and the overall risk index (RI) are used to assess the potential environmental impact of toxic metals. An E_r^i value less than 40 indicates low risk, while values between 40 and 80 suggest moderate risk. Values ranging from 80 to 160 represent considerable risk, 160 to 320 indicate high risk, and values exceeding 320 correspond to very high risk. Similarly, the RI categorizes overall ecological risk: values below 110 are considered low, 110–200 indicate moderate risk, 200–400 represent considerable risk, and values above 400 signify very high ecological risk. These indices provide a comprehensive framework for evaluating the severity of metal contamination in the environment.

Determination of transfer factor

Techniques such as reagent single extraction and DPTA extraction are used to determine the mobility and/or bioavailability of HMs (Miles and Parker, 1979). The bioavailability of HMs in soil is assumed to be available to all plants. As a result, HMs can transfer to plants when they are in a mobile form. To estimate the HMs transferred to plants (grass in this case), the transfer coefficient is a function of both soil and plant properties, is used due to its representative bioavailability of HMs to plants as equation (5),

$$TF = \frac{Cplant}{Csoil} \quad (5)$$

where TF is the transfer factor, C_{plant} is the HM concentration in plant tissue (mg/kg), and C_{soil} is the HM concentration in soil (mg/kg).

Statistical analysis

The collected data were organized and presented in a suitable format and then underwent statistical analysis using Microsoft Office Excel 2010. Additionally, correlation matrix and Principal Component Analysis (PCA) were conducted using R programming software to unveil the connections between the examined HMs in the soil and grass samples, aiming to identify potential sources of contamination, and to reveal the interrelationship among the HMs.

RESULTS & DISCUSSION

HM concentration in soil

Across the 24 samples from four different sites, a wide variation in HM concentrations in the soil was observed with Cr, Cu, Ni, Cd, and Pb, varied in 28.57-72.65 mg/kg, 6.85-43.47 mg/kg, 21.27-56.18 mg/kg, 0-0.47 mg/kg, 53.32-129.75 mg/kg, on average (± SD), being 54.81 ± 13.38, 24.88 ± 13.67, 39.70 ± 12.59, 0.28 ± 0.19 and 73.45 ± 15.76, respectively. Average concentrations of five HMs followed a descending order as Pb > Cr > Ni > Cu > Cd, which indicates that Pb, Cr, and Ni are the most abundant HMs in the soil of the study area. The concentration of Cr, Cu, Cd, Ni, and Pb was found to be high in the Turag River area, the Bongshi River area, and the Buriganga River area, respectively, indicating that riverside areas are more polluted with HMs than the dairy farm area.

Geo-accumulation index (I_{geo}) in soil

From Fig. 2, the maximum I_{geo} values for HMs were found in the order of Pb (1.45) > Ni (O.87) > Cu (0.15) > Cd (-1.52) > Cr (-0.43). The Buriganga riverside area is moderately polluted by Pb. Maximum I_{geo} values in Ni and Cu within 0-1, indicating unpolluted to moderately polluted in the Bongshi riverside region, whereas I_{geo} values of Cr and Cd are < 0, indicating unpolluted. Maximum I_{geo} values in Cr, Cu, and Cd are < 0, indicating that the studied areas are unpolluted by these HMs, whereas Ni and Pb have a positive value but < 1, indicating not polluted to moderately polluted areas by them, or may have potential risk.

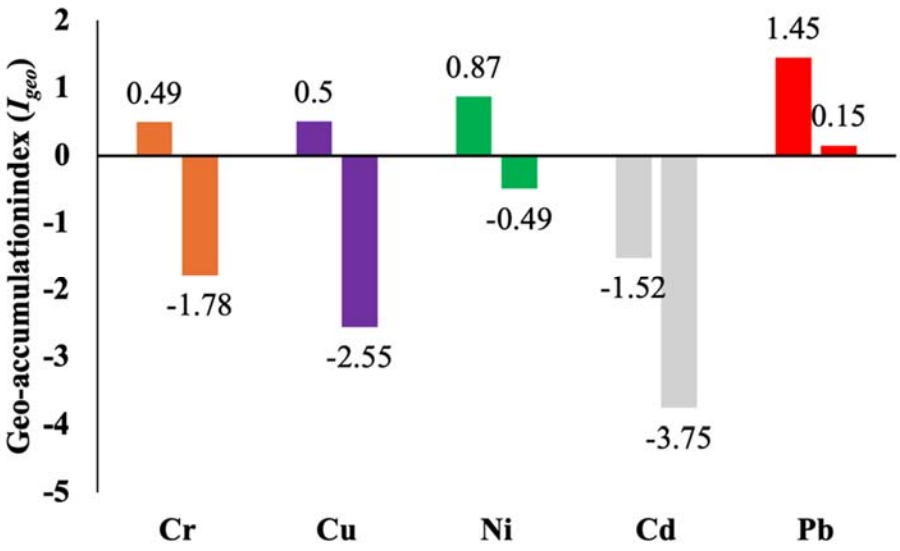

Fig. 2. Minimum and maximum values of geo-accumulation index (I_{geo}) of the study area.

Previous studies also found similar results for the Pd, Cd, and Cr (almost in all sampling sites, I_{geo} value was <1) from Dhaleswari River sediments, indicating almost unpolluted sediments (Al Mamun et al., 2021).

Contamination factor and level of contamination

Values of C_f decrease in the order of Ni (5.10) > Pb (4.05) > Cu (1.67) > Cr (1.12) > Cd (0.52) (Fig. 3), indicating low contamination with Cd in the soils and considerable contamination by Ni in the Bongshi riverside area. The C_f value for Cr (0.44-1.12 and Cu (0.26-1.67) indicates low to moderate contamination, whereas Ni (1.13-5.10) and Pb (1.67-4.05) have moderate to considerable contamination risk.

The highest degree of contamination (C_d) was 9.95 in the Bongshi riverside area (Fig. 4). C_d factor for site ScS_1 is 9.95, which indicates ($6 \leq C_d < 12$) a moderate degree of contamination (Hakanson, 1989). The lowest C_d was found at 5.08 at the sampling site S_DS_5 (Dairy farm area), indicating a low degree of contamination ($C_d < 6$). The average C_f of all the metals in Cr was 0.85 (Low contamination), Cu was 0.96 (low contamination), Ni was 3.61 (considerable contamination), Cd was 0.039 (low contamination), and Pb was 2.29 (moderate contamination)

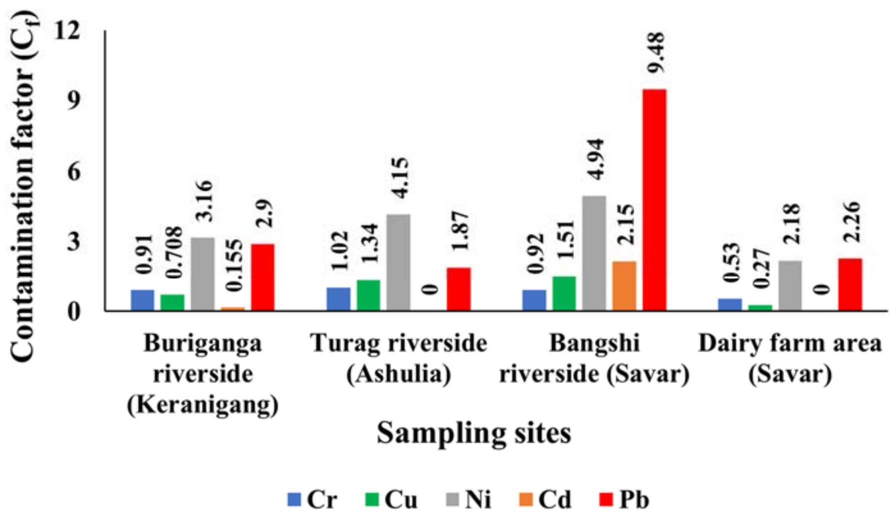

Fig. 3. Average contamination factor of different soil heavy metals.

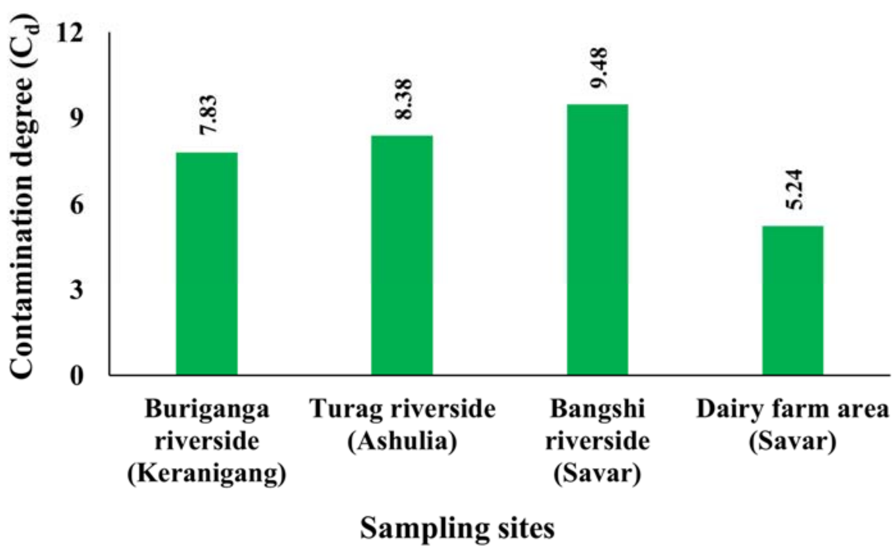

Fig. 4. Contamination degree of studied heavy metals.

(Hakanson, 1989).

Pollution Load Index (PLI)

The Pollution Load Index (PLI) for the examined HMs varied between 0.90 and 1.78, with an average value of 1.36 (Fig. 5), indicating polluted areas of sampling sites. The highest PLI value was observed in the soil collected from the Bangshi Riverside area. Among the 24 sampling sites, 17 sites (5 in the Buriganga riverside, 6 in the Turag riverside, and 6 in the Bongshi riverside) have a PLI value > 1 (Figure 5), indicating the deterioration of soil quality with HMs. The remaining 7 samples had a PLI value < 1, indicating the perfection of the site quality. One sampling point in the Buriganga riverside area and all six sampling sites in the dairy farm area had a PLI value < 1, indicating not polluted areas. A similar result was found for the sediment sample of the Rupsha River experimented by Kubra et. al. (2022).

Ecological Risk Index

The average ecological risk index E^i_r of HMs in 24 soil sampling sites is ranked in the following order: Cd < Cr < Cu < Pb < Ni (Table 1). The highest RI value is 56.66 in the soil of the Buriganga Riverside area, and the lowest RI value is 23.57 in the soil dairy farm area. The average monomial ecological risk for all selected metals was found to be below 40, indicating that all metals posed a low risk to the surrounding ecosystem. The risk index was also found to be below 110 at all sampling sites, indicating that the surrounding environment was exposed to a low risk.

HM concentration in grass

HM concentrations of Cr, Cu, Ni, Cd, and Pb in grass varied widely across 24 samples collected from four different sites. The maximum concentration of HMs in grass was in the descending order of Pb (83.42 mg/kg) > Cr (58.54 mg/kg) > Ni (27.32 mg/kg) > Cu (15.03mg/kg) > Cd (0.23 mg/kg) which reveals that grass samples are more polluted by Pb than others HMs. The mean concentrations with ± Std in Cr, Cu, Ni, Cd, and Pb were 39.57 ± 10.72, 10.14

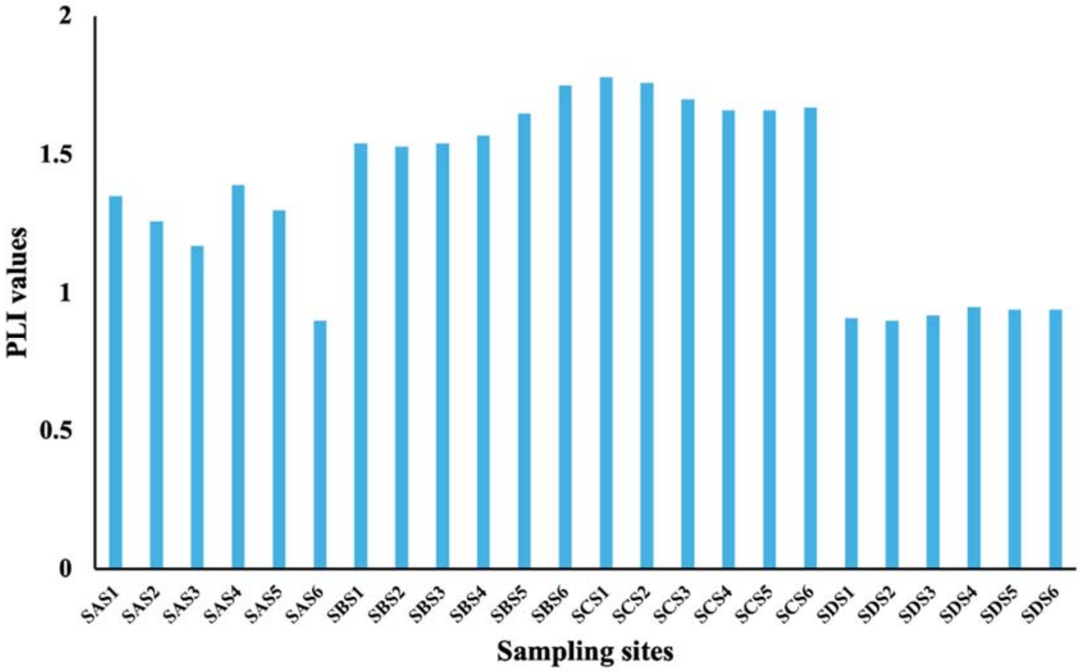

Fig. 5. Pollution Load Index (PLI) of the study area. (1-6 from the Buriganga River area; 7-12 from the Turag River area; 13-18 from the Bongshi River; 19-24 from the Dairy farm area).

Table 1. Potential ecological risk index values of the three riversides and the Dairy farm area's soil in Dhaka city of Bangladesh.

Sample ID	Sampling area	Ecological Index Risk for Single metal E_r^i					Risk Index
		Cr	Cu	Ni	Cd	Pb	(RI)
S_AS_1	Buriganga riverside (Keraniganj)	2.2	3.45	11.4	0	13.2	30.2
S_AS_2		2.04	3	10	0	12.85	27.89
S_AS_3		1.86	4.3	18.75	9	12.65	37.56
S_AS_4		1.76	5.5	21.4	15.6	12.4	56.66
S_AS_5		1.52	2.35	17.1	0	15.55	36.52
S_AS_6		1.58	2.65	16.05	3.3	20.25	43.83
S_BS_1	Turag riverside (Ashulia)	1.88	6.6	19.4	0	9.15	37.03
S_BS_2		1.88	6.5	19.55	0	8.9	36.83
S_BS_3		2.12	6.25	20.2	0	8.35	36.92
S_BS_4		2.24	5.9	21.2	0	8.5	39.19
S_BS_5		2.04	7.2	21.45	0	9.85	40.52
S_BS_6		2.08	7.7	22.75	0	11.35	43.88
S_CS_1	Bongshi riverside (Savar)	1.92	8.2	25.2	0	11.55	46.87
S_CS_2		1.9	8.35	24.7	0	10.95	45.9
S_CS_3		1.94	7.7	24.3	0	9.95	43.89
S_CS_4		1.82	6.95	24.15	0	10.5	43.42
S_CS_5		1.78	6.75	25.5	0	10.4	44.43
S_CS_6		1.64	7.25	24.4	0	11.25	44.54
S_DS_1	Dairy farm (Savar)	0.88	1.3	12.25	0	11.15	25.58
S_DS_2		0.9	1.35	11.55	0	11.05	24.85
S_DS_3		1	1.35	11.15	0	11.45	24.95
S_DS_4		1.26	1.3	10.2	0	11.55	24.31
S_DS_5		1.22	1.4	9.65	0	11.3	23.57
S_DS_6		1.08	1.45	10.75	0	11.25	24.53
Mean		1.69	4.78	18.04	1.1625	11.47	36.82

± 3.06, 20.35 ± 4.19, 0.175 ± 0.077, and 64.23 ± 8.68, respectively.

The highest concentration of Cr, Cu, and Ni was found in the sample, which was collected from the Bongshi Riverside area in Savar. The lowest concentration was found in the Dairy farm area. The highest concentration of Cd and Pb was found in the sample collected from the Buriganga Riverside area, whereas the lowest concentration was below the detection level (BDL) in most of the samples.

HM transfer from soils to grass

The transfer factor (TF) values varied 0.48-0.91, 0.24-0.97, 0.24-0.96, 0-0.85, and 0.53-0.97 in Cr, Cu, Ni, Cd, and Pb, respectively (Table 2). The mobility of metals from soil to plants is a function of the physical and chemical properties of the soil and the vegetable species and is altered by innumerable environmental and human factors (Zurera et al., 1987). High concentrations of these metals in polluted areas of vegetables might be due to high contents of metals in the soil as caused by irrigation with metal-contaminated water released from industries. Overall TF values of Pb and Ni are found to be significant, and this supports the findings that the accumulation of Pb and Zn was comparatively less than that of Cd in plants (Olaniya et al., 1998).

Correlation between HMs in soil and grass

A correlation matrix can identify the possible common sources of HMs in the studied area. A total of 11 positive significant correlations out of 45 pairs of correlations are found at both 0.01 and 0.001 significant levels, which is 24.5% (Fig. 6). In soil, there are significant ($p<0.001$) positive relationships between Cr and Cu ($r = 0.92$), Cr and Ni (0.87), and Cu and Ni ($r = 0.99$), whereas in the grass sample, there is no such correlation.

Table 2. Transfer factor of HMs from soil to grass.

Sample ID	Sampling area	Transfer factor				
		Cr	Cu	Ni	Cd	Pb
S_AG_1	Buriganga riverside (Keraniganj)	0.64	0.47	0.95	0	0.78
S_AG_2		0.65	0.40	0.87	0	0.77
S_AG_3		0.53	0.67	0.66	0.85	0.96
S_AG_4		0.69	0.50	0.41	0.25	0.91
S_AG_5		0.88	0.78	0.71	0	0.84
S_AG_6		0.90	0.97	0.76	0	0.53
S_BG_1	Turag riverside (Ashulia)	0.61	0.33	0.56	0	0.94
S_BG_2		0.65	0.33	0.56	0	0.91
S_BG_3		0.48	0.31	0.56	0	0.93
S_BG_4		0.57	0.42	0.56	0	0.94
S_BG_5		0.50	0.36	0.39	0	0.92
S_BG_6		0.50	0.26	0.40	0	0.76
S_CG_1	Bangshi riverside (Savar)	0.93	0.31	0.29	0	0.90
S_CG_2		0.90	0.34	0.32	0	0.96
S_CG_3		0.89	0.32	0.31	0	0.97
S_CG_4		0.91	0.26	0.27	0	0.75
S_CG_5		0.89	0.26	0.30	0	0.97
S_CG_6		0.91	0.24	0.28	0	0.96
S_DG_1	Dairy farm (Savar)	0.89	0.96	0.64	0	0.97
S_DG_2		0.80	0.92	0.67	0	0.97
S_DG_3		0.79	0.76	0.63	0	0.95
S_DG_4		0.60	0.87	0.88	0	0.93
S_DG_5		0.78	0.96	0.88	0	0.94
S_DG_6		0.83	0.93	0.96	0	0.91

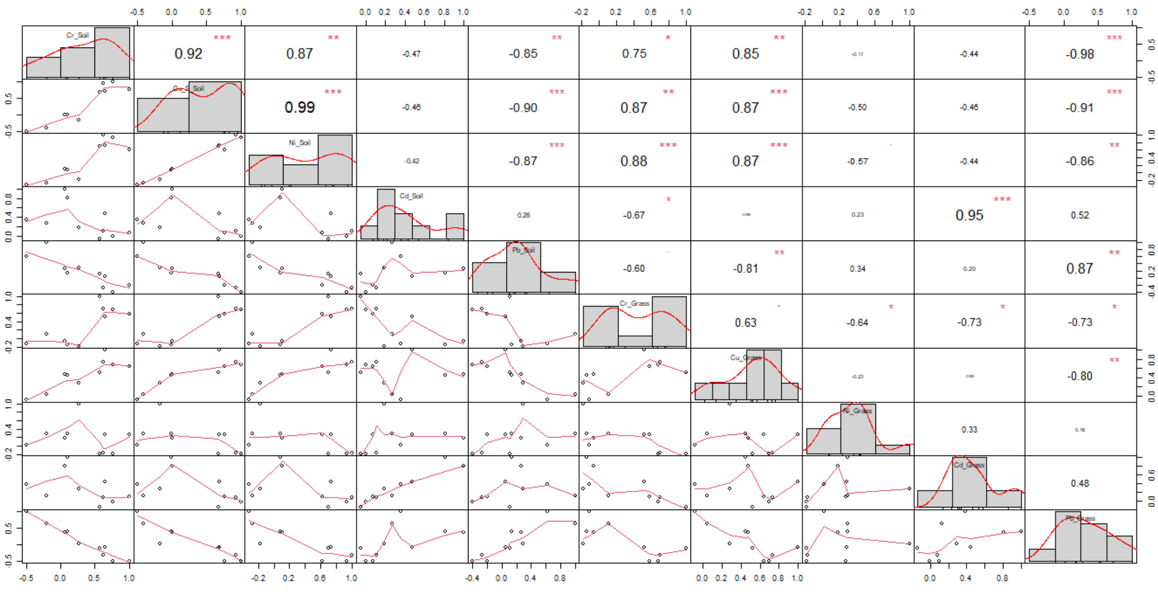

Fig. 6. Correlation matrix of heavy metals in soil and grass. , , and indicate correlation is significant at the 0.05, 0.01, and 0.001 level, respectively.

There is also a strong positive correlation between soil and plant HMs. Positive correlation among soil and grass HMs, including Cr and Cr (r = 0.75), Cu and Cr (r = 0.87), Ni and Cr (r= 0.88), Cr and Cu (r = 0.85), Cu and Cu (r= 0.87), Ni and Cu (r= 0.87), Cd and Cd (r = 0.95), Pb and Pb (r= 0.87). These results imply that the possible source of HM in grass is the soil. Positive correlations among different minerals in the environment mainly indicate the common anthropogenic sources of their origin (Malvandi 2017).

Principal component analysis (PCA)

In this study, PCA was performed based on the HM concentration to explore the possible distribution patterns of the studied HMs (Fig. 7A). In the soil, PC1 accounted for 54.1% of the total variance, and its representative congeners include Cu, Ni, and Cr, showing a negative correlation. In this case, Cu shows the strongest contribution, which means this variable strongly influences the principal component (PC1), while Pb has the lowest contribution. Cd has a slightly negative correlation, and only Pb has a positive correlation with PC1. Here, Pb presents the highest positive PC1 scores, suggesting that the soil samples of the study area are predominantly contaminated with Pb. In this study, HM concentrations in soil followed a descending order of Pb>Cr>Ni>Cu>Cd, indicating that the samples are predominantly contaminated with Pb. This finding is also consistent with the results of the PCA. The other component, PC2, accounted for only 24.6% of the total variance in soil and showed a positive correlation with Ni, Cr, Cd, and Pb, while Cu is slightly positively correlated.

In the grass sample, PC1 and PC2 accounted for 35.1 and 29.9% of the total variance, respectively (Fig. 7B). Pb, Ni, Cd, Cu, and Cr are negatively correlated with PC1. Although Cr is negatively correlated, it is very close to a positive PC1 score, which means its pollution contribution is higher than other HMs. PC2 exhibited a positive correlation to Cu and Cr, while a negative correlation to Ni, Cd, and Pb. Cu and Pb have the highest and lowest contributions, respectively. This principal component analysis reveals that Pb and Cr are the major contributors to the pollution level for soil and grass samples, respectively.

In the soil sample, PC1 accounts for 54.1% variance, while PC2 accounts for 24.6% variance, and accounts for a total of 78.7% variance (Fig. 8A). In this case, two eclipses from the sampling areas of Bongshi and Turag riverside overlap, which indicates that most of the sources or origins of HM pollution in these two areas are the same. Similarly, considering PC1 and PC3, the HM content of soil from Bangshi and Turag riverside areas has some similarities, and so they overlap in the biplot (Fig. 9). Only 12.8% variance was explained by PC3, which means minimal contribution to the total variance in the PCA (Fig. 9).

When the biplots overlap, the HM data within the shared biplot is correlated, suggesting that their pollution sources are similar. The two eclipses from the Dairy farm area and Buriganga overlap, indicating similarity in their HM sources (Fig. 8A). In the case of the biplot for grass samples (Fig. 8B), almost all eclipses of the four sampling areas are mixed and overlap, meaning the source of HMs in the grass is the same and non-anthropogenic.

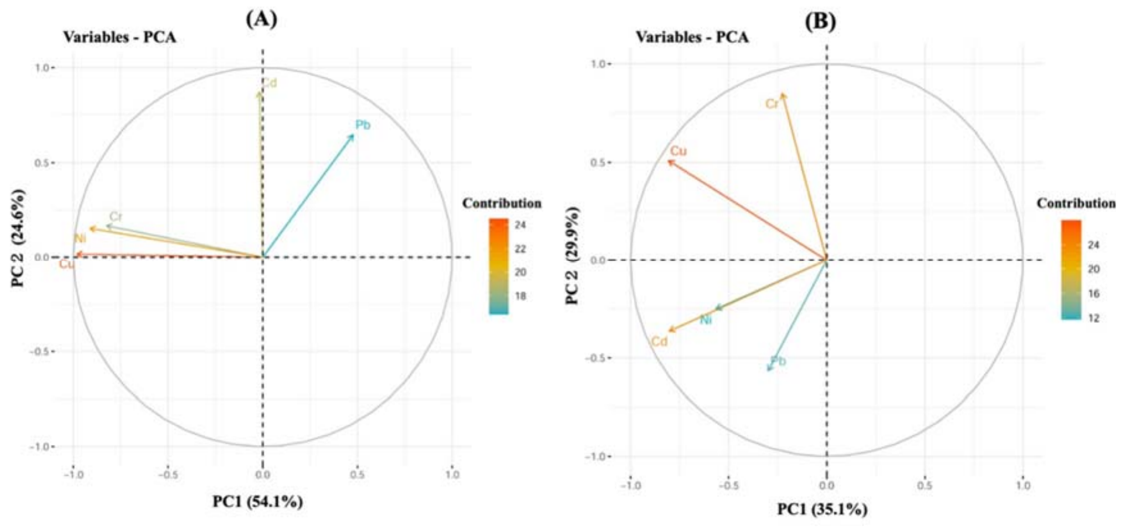

Fig. 7. Loading plot of the Principal Component Analysis (PCA) of the heavy metals in soil (A) and grass (B) samples. Correlation of HMs is shown in these figures.

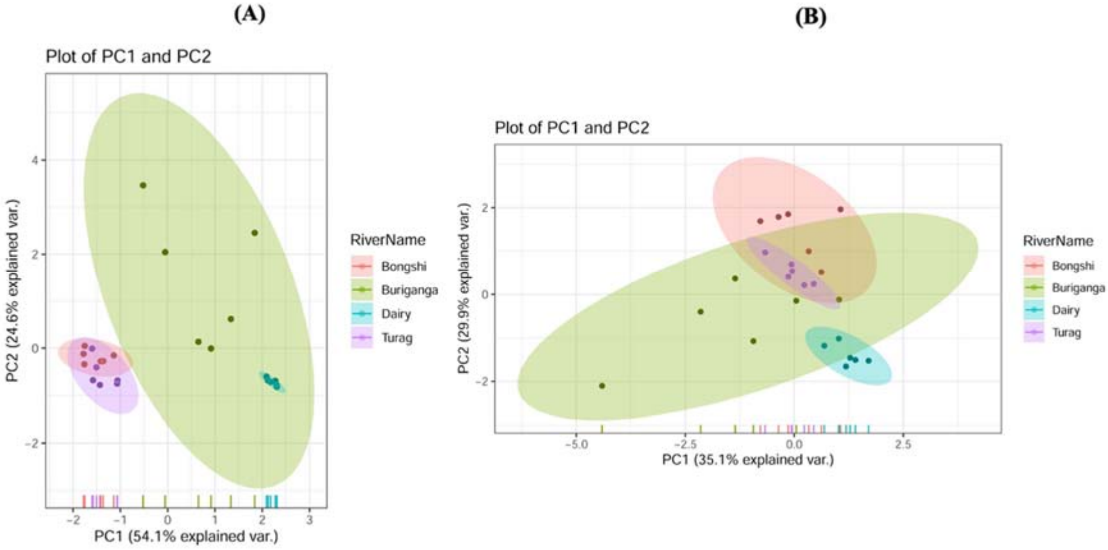

Fig. 8. Biplot of PCA of HMs obtained from the grass sample of three riversides and one land area in Dhaka city of Bangladesh. Sampling areas are shown in the biplot of PCA analysis separately

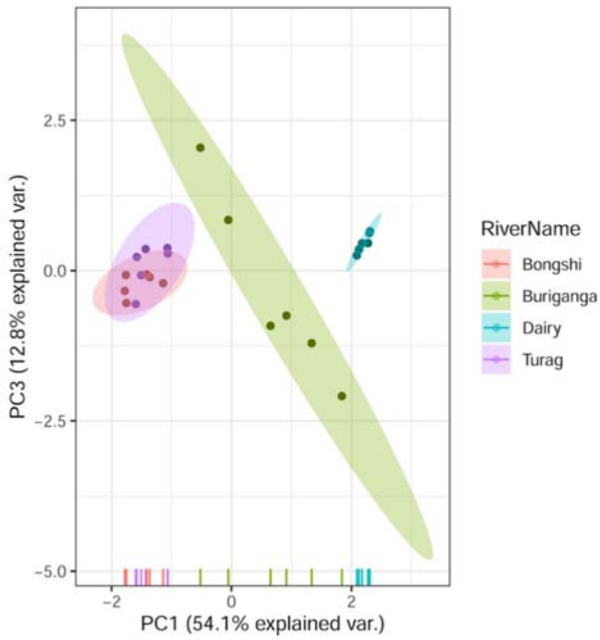

Fig. 9. Biplot of PC1 and PC3 of HMs obtained from the soil of three riversides and one land area in Dhaka city of Bangladesh.

In the soil and grass samples, the most dominant pollutant is Pb, and the least dominant pollutant is Cd. Although the average concentration of Pb, Cr, Ni, Cu, and Cd is below the maximum acceptable concentration (MAC) for soil in Bangladesh (Alamgir et al., 2015), some of the sampling sites exceed the MAC value, particularly for Pb, which indicates that the future contamination level can increase. MAC value in soil for Pb, Cr, and Cu is 100 mg/kg. Ni has a lower MAC of 50 mg/kg, reflecting its higher toxicity at lower concentrations (Shammi et al., 2021). Cd has a strict limit with an MAC of just 3 mg/kg due to its significant health risk even at trace levels (Alamgir et al., 2015; Shammi et al., 2021). Unplanned industrialization and improper waste management in these areas are affecting the surrounding surface and agricultural lands. Dhaka Export Processing Zone (DEPZ) is located upstream of the Bongshi River. Effluents from these industries are the probable sources of soil HM pollution. Improper and untreated effluents from these industries have caused deterioration of soil and water quality. Riverside soils in Bangladesh are mostly silty-clay to sandy-silt, containing clay minerals such as kaolinite, illite, and montmorillonite. Chemically, these soils are rich in silica and alumina, with variable amounts of iron, calcium, magnesium, and potassium, which influence soil fertility and their capacity to adsorb metals or nutrients (Mollah 1993). HM pollution was also found in Shitalakhya, Karnafuli, Rupsha, Meghna, and other urban rivers, which indicates that different industries located in riverside areas might be the origin of the HM pollution in soil and water (Kabir et al., 2020; Hossain et al., 2019; Al Mamun et al., 2021; Kubra et al., 2022). Water from the Bongshi River was found to be contaminated by Cd in concentrations ranging from approximately 5.58 to 6.50 mg/L in the upstream points, with the source of Cd pollution traced back to the DEPZ (Hossain et al., 2012). This is how the soil and grass in the Bongshi, Turag, and Buriganga riverside areas are being polluted by HMs. Both industrial and municipal waste effluent are polluting the Buriganga River (Hossain et al., 2019). As Dhaka is a megacity with 10.2 million population this city has experienced rapid and unplanned urbanization in the last few decades. This unplanned expansion of urbanization and industrialization has accelerated anthropogenic pressures, resulting in soil metal pollution. In Dhaka city, Pb contamination in soils is especially pronounced, largely due to traffic-related activities (Rahman et al., 2021). In this study, the average concentration of Cd, Cr, and Pb in the soil has exceeded the levels reported by Shammi et al. (2021), and the order of these three metals follows the same descending order of Pb > Cr > Cd. The highest Cr concentration in the grass sample was found in the Bongshi riverside area, and the lowest Cr concentration was found in the Dairy farm area. Again, in this study, the Bongshi riverside area is considered to be more polluted than the Dairy farm area, as the wastes from DEPZ and other industries have a connection with the Bongshi river, whereas the Dairy farm area is comparatively less industrialized with fewer probable pollution sources. Concentrations of Cr and Pb in the locally grown vegetables in the Dhaka city area were found 20 mg/kg, and 0.5 mg/kg, respectively. These HMs were translocated from the soil to the vegetables, which exceeded the WHO permissible limits. The possible Pb and Cr pollution sources, both in soil and water, are tanneries and battery industries near the Buriganga River (Islam et al., 2020). During winter, HM concentrations in the sediments of the Turag River were found in the descending order of Cr > Ni > Cu > Pb, and the metal concentrations decreased downstream of this river, and the source of these HMs is the extensive discharge of urban waste (Hossain et al., 2021). Bioaccumulation of HMs from the soil is the common source of HMs in the grass samples of these areas. Although the transfer factor (TF) of HMs from soil to grass is not higher, it depends on the concentration of HMs in the soil and the mobility of phloem tissue. Symplastic transport of HMs via phloem allows redistribution and assimilation within plants (Page et al., 2006). HMs are first taken from the soil and loaded into the plant's root xylem, followed by their uptake and retention within root cells. They move basipetally to the roots through the phloem, spread cell-to-cell within meristems and areas lacking active phloem, and are carried in the transpiration stream via the xylem to mesophyll cells. From there, they are transferred from the xylem to the phloem by transfer cells in small vascular bundles, and eventually remobilized from senescing leaves for transport to sink tissues through the phloem. (Page and Feller 2015). Thus, HMs are transferred from the soil to plants and subsequently distributed throughout the plant tissues. Ni and Zn are more phloem-mobile than Cd and can be redistributed more extensively in the plant tissues, which demonstrates that metal uptake and distribution are also specific to each metal (Riesen and Feller, 2005).

CONCLUSION

Industrial effluent, automobile, and municipal sewage for irrigation may increase the concentration of the HMs Ni, Cu, Cd, Cr, and Pb in surface soil. The present study reveals that the concentration of the HMs in both the soil and grass samples was in the order of Pb> Cr > Ni >Cu>Cd. Among the studied HMs, the contamination factor for Ni, Pb, and Cu was several times higher compared to Cr and Cd, which indicated that Ni, Pb, and Cu were the major pollutants in that environment. This increases the possibility of accumulating these HMs in the soils and eventually transferring to plants. This can also lead to the accumulation of the HMs in the tissues of organisms that feed on the plants, which can be transferred to other consumers in the food chain. Out of 24 locations, a total of 17 sites had PLI value >1.0, indicating the deterioration of the soil quality. So, it is necessary to identify the origin and potential sources of HMs to minimize pollution levels in the Dhaka city area.

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The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

DATA AVAILABILITY STATEMENT

Data will be made available on request.

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