Assessment of Heavy Metal Contamination in Roadside Soil along Dhaka-Mymensingh Highway, Bangladesh

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ABSTRACT: This study aims at evaluating the contamination level of heavy metals in roadside soils along Dhaka Mymensingh highway. Composite surficial soil samples were collected from 8 sites along the highway. The samples have been analyzed for the six potentially toxic heavy metals (HM) namely Cr, Cd, Ni, Pb, Zn and Cu through X-ray Fluorescence (XRF). Zn exhibits the highest average concentration, followed by Cu, Pb, Cr, Ni, and Cd. The degree of contamination levels of these heavy metals were assessed using two widely used geochemical indices such as contamination factors (CF) and Pollution Load Index (PLI). The CF values vary in the order Cr (56.58)> Cd (25.25)> Ni (20.78)> Pb (6.18)> Zn (5.51) >Cu (4.36) reflecting Cr as the prominent contaminant. On the other hand the value of PLI of the sampling points varies in the order S6> S7> S3> S4> S2> S5> S8> S1 revealing the sampling site S6 as the heavily contaminated portion of the study area. Pearson correlation reveals that the anthropogenic sources are the chief contributors of the HM pollution. Chemical industries, steel workshop, open dumping sites and roadside markets have been emerged as the major contributing sources. The findings from the study will contribute to sustainable environmental management in the study area.

Keywords: Heavy Metals; Geochemical Indices; Contamination Factor (CF); Pollution Load Index (PLI); Dhaka-Mymensingh Highway

INTRODUCTION

Soil is a fundamental component of the terrestrial ecosystem which plays a crucial role in supporting plant growth, regulating water, recycling nutrients and serving as a habitat for a wide range of organisms. Soil quality has a direct impact on human well-being, agricultural productivity and environmental health. However, the contamination of soil through various emerging pollutants like Heavy metals (HM) has become one of the burning major concerns of the modern days (Khan et al., 2008). The very characteristics such as potential toxicity, bio-accumulation capability and long persistent in nature makes HM a stunning threat to the present ecosystem. The situation is getting worse day by day due to the rapid rise of urbanization,

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industrial development and increased vehicular activity (Kubra et al., 2022). These heavy metals are mainly sourced from various anthropogenic encounters to the environment such as emission from automobiles, industrial effluents, Oil leaks, breakage of tires, open dumping and unplanned urban solid waste management (Chakraborty et al., 2021). Impact of vehicular activity on soil contamination is widely recognized. High traffic density roads are particularly vulnerable to pollution because of continuous deposition of particulate matter enriched with heavy metals. Once present in the soil, heavy metals can persist over time, leading to potential health hazards for humans and ecological imbalances (Sankhla et al., 2019). The sources of heavy metal contamination vary from country to country but mining, landfill, tanning, chemical, pharmaceutical, agricultural and textile industries are among the main culprits, as they discharge untreated wastes directly onto adjacent land, resulting in metal contamination in the soil (Bhuiyan et al., 2011; Zhang et al., 2011).

Roadside soil plays a crucial role in ecosystems,

providing various habitats and environments. However, heavy metals found in roadside soil have become significant environmental pollutants of growing concern (Wang et al., 2005). These metal pollutants can be deposited on adjacent soil and may be transported and transformed into other parts of the environment, such as vegetation (Sharmin et al., 2010; Abechi et al., 2010). Heavy metals can enter the body through soil and dust, dermal contact, breathing, and the food chain, and exposure to these metals has been associated with a wide range of health issues, particularly neurological disorders, impaired organ function, and developmental abnormalities, especially in children (Samuel and Christiana, 2012; Jomova and Valko, 2011). Bangladesh, being a densely populated country, is particularly vulnerable to heavy metal contamination due to rapid industrialization and inadequate waste management systems (Nasreen et al., 2017; Bhuiyan et al., 2010). The roadside soil and adjacent areas in Bangladesh are continuously being contaminated by heavy metals, and the Dhaka-Mymensingh Highway, one of the busiest roads in the country, is prone to significant heavy metal contamination due to heavy traffic and industrial activities along the highway (Rahman et al., 2019). The accumulation of heavy metals in the biotic components of these areas and their entry into the food chain create pollutant hotspots, leading to potential health issues.

The HM contamination in various environmental compartments such as marine sediments, river sediments, agricultural soils, groundwater and surface water has been extensively investigated in the context of Bangladesh (Ali et al., 2016; Chakraborty et al., 2021; Choudhury et al., 2021; Rakib et al., 2022; Kumar et al., 2022; Kubra et al., 2022). But only a few researches have been performed focusing on the HM contamination in roadside soil (Ahmad et al., 2016; Islam et al, 2024). The studies have been conducted along various road network connected Dhaka to the rest of the country. Numerous international studies have investigated the spatial distribution, concentration levels, and ecological risks of heavy metals in roadside soils. For instance, Duong and Lee (2011) reported elevated concentrations of Zn, Pb, and Cu along major urban highways in Korea, with contamination levels decreasing exponentially with increasing distance from the road edge. In Iran, Soltani et al. (2021) found that roadside soils near industrial and urban highways exhibited higher metal accumulations compared to

rural ones, emphasizing the role of land-use patterns. Similarly, research conducted in China (Peng et al., 2024) and India (Singh et al., 2018) revealed significant enrichment of heavy metals along busy transport corridors, posing potential health and ecological risks. In the context of South Asia, heavy metal pollution from traffic emissions is particularly critical due to high population densities and inadequate pollution control measures. A study by Rajaram et al., 2014 in Delhi, India, documented substantial contamination of roadside soils with Pb, Zn, and Ni, particularly in areas with high vehicular density. Likewise, studies in Pakistan (Naseem et al., 2025) showed heavy metal concentrations exceeding safe thresholds in roadside soils, highlighting the cumulative impact of traffic emissions over time.

In Bangladesh, studies focusing on heavy metal contamination in urban environments have primarily concentrated on industrial zones, landfill sites, and riverbanks (Ahmed et al., 2016; Rahman et al., 2012). However, investigations specifically targeting roadside soils, particularly along major national highways, remain limited. Notable exceptions include a study by Haque et al. (2022), which assessed Pb and Zn levels along the Dhaka-Aricha highway, and found concentrations exceeding permissible limits near bus terminals and traffic intersections. Similarly, Howlader et al. (2025) examined heavy metal contamination in roadside dust within Dhaka city, revealing alarming levels of Cr and Ni in high-traffic areas. Despite these efforts, the Dhaka-Mymensingh highway—a critical transport corridor connecting two major urban centers in Bangladesh—has not been sufficiently studied in terms of heavy metal contamination in adjacent soils. Given the increasing traffic volume, urban sprawl, and unregulated vehicular emissions along this highway, there is an urgent need for a systematic assessment of heavy metal accumulation and distribution patterns. This research aims to fill this critical gap by evaluating the concentration of selected heavy metals in roadside soils along the Dhaka-Mymensingh highway, determining their spatial variability, and source.

While the Dhaka-Mymensingh highway has not been previously studied for heavy metal contamination in roadside soils, the novelty of this research extends beyond its geographic focus. Methodologically, the study integrates spatial

sampling from varying Landuse Landcover pattern adjacent to the road, allowing for a nuanced understanding of pollutant dispersion patterns. The application of contamination indices such as the Geo-accumulation Index (I_geo), Enrichment Factor (EF), and Pollution Load Index (PLI), alongside multivariate statistical technique such as Pearson correlation, adds a robust analytical framework to identify pollution sources. Scientifically, the study contributes to the broader understanding of how traffic-related heavy metal pollutants behave in transitional zones between rapidly urbanizing and semi-rural regions—an area often overlooked in previous studies focused predominantly on either highly urban or industrial corridors. This integrative approach offers valuable insights for environmental management and policymaking in developing countries experiencing rapid highway expansion and motorization.

METHODOLOGY

Study Area

The Dhaka-Mymensingh Highway, one of the largest highways in Bangladesh, plays a crucial role in the country's development and industrialization. It is located adjacent to the capital city, Dhaka, and is witnessing rapid expansion in industrial and agricultural sectors in its surrounding areas. Bangladesh, being highly susceptible to environmental pollution, has seen the establishment of various industries along the Dhaka-Mymensingh Highway, including packaging, dyeing, brick kilns, textile, pesticide and fertilizer, and food processing industries. These industries generate a significant amount of waste containing trace metals. The Dhaka-Mymensingh Highway spans a length of 115 kilometers, starting from the Dhaka airport area and ending at Sadar Upazila in the Mymensingh district. The study area covers a length 42km from Mawna to Bhaluka and situated between latitudes and longitudes24°14'19.55" N to 24°21'19.69" N and 90°24'12.61" E to 90°22'30.87" E. This area was selected due to its critical role as a transportation link between the two divisions of Dhaka and Mymensingh, where high traffic density and industrial activities are prominent. Additionally, this area experiences perennial inundation during the monsoon flood season (June to August) and is affected by roadside runoff.

MATERIALS AND METHODS

The current study is a compilation of field investigation, laboratory analysis, and computational analysis. The field investigation encompasses the collection of samples. The laboratory analysis consists of the primary analysis of samples and determination of HM concentrations through instrumental analysis. The computational analysis covers the computation of various indices for assessing the contamination status of the soil and the Geospatial analysis involves the mapping of contamination indices through out the study area.

Sample Collection and Preservation

The fieldwork and sampling has been conducted from the 1st January to the 15th January , 2024 from Mawna to Bhaluka along the Dhaka-Mymensingh highway. Eight sampling points were selected and sequentially numbered from 1 to 8 based on the landuse landcover pattern and anthroppgenic interventions adjacent to the highway (Fig. 1). Among them, sampling points 1 and 8 were designated as control points, as they are located at a considerable distance from sources of anthropogenic contamination (USEPA, 2001).Three composite surface soil samples were collected from each sampling locations with a depth of 0 to 5cm using spatula. The sampling was conducted maintaining the standard protocol of the U.S Environmental Protection Agency (USEPA), 2001.Samples were placed in airtight polythene bag and labeled.

Laboratory Analysis

Sample Preparation

Laboratory analysis involves the separation of unwanted substances such as tree roots, plastics, debris etc from the collected sample through, oven drying and pulverization as a mean of sample preparation for the HM concentration analysis using instrumental analysis. The methodology for the initial purification and sample preparation for HM analysis through instrumental analysis has been adopted from Kubra et al., 2022.
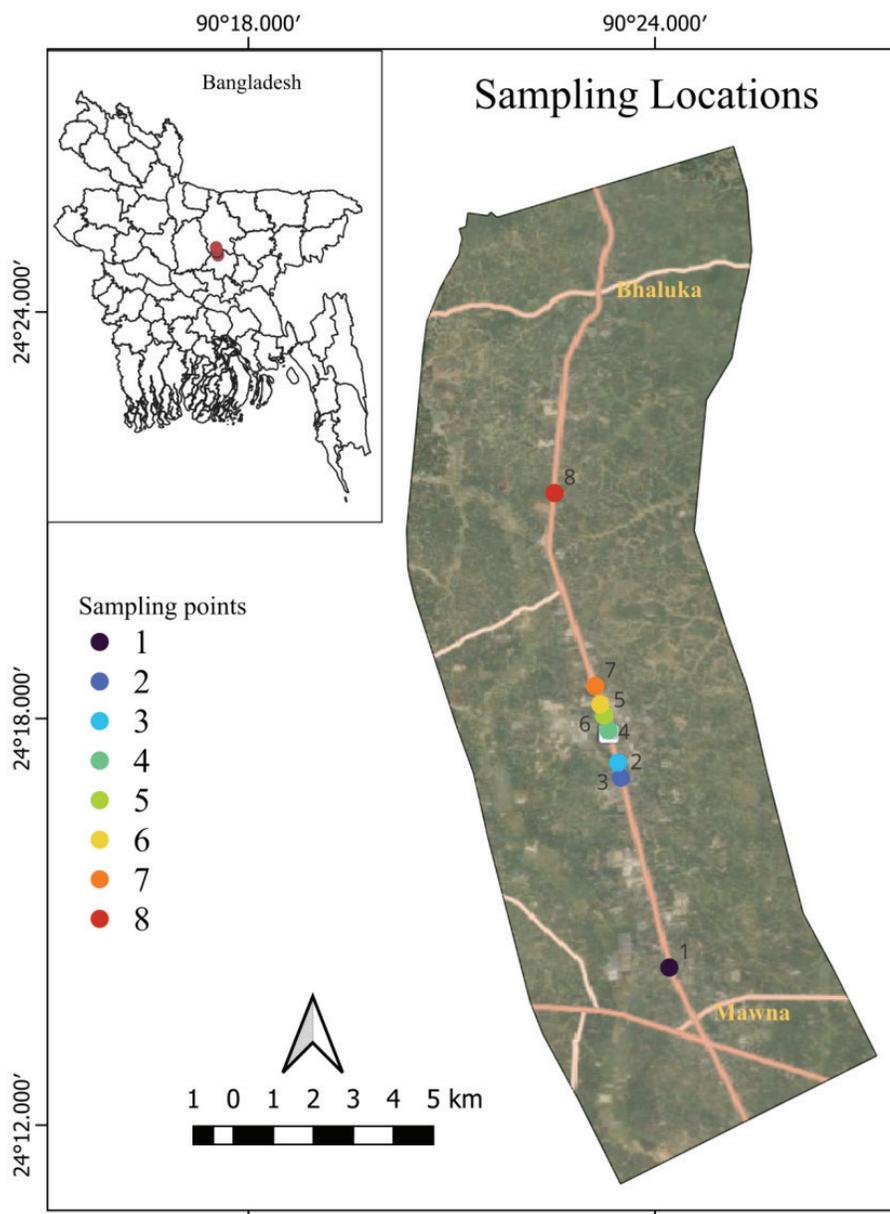
Figure 1: Study Area Highlighting Sampling Points

Analytical Technique and Accuracy Check

The samples processed as per the previous steps have been analyzed through X-ray Fluorescence (XRF) at the Laboratory of Bangladesh Atomic Energy Centre, Dhaka following the standard protocol. The samples were analyzed for the metals such as Cr, Cd, Ni, Pb, Zn and Cu. The accuracy of the results have been determined through the analysis of certified reference materials (CRMs) that contain HM within a known range. The measured concentrations were compared to the certified values to calculate percentage recovery, serving as an indicator of analytical accuracy.

Assessment of Contamination Status

The status of HM contamination of soil has been widely assessed in terms of various geochemical indices computed through some scientifically established equations where the HM concentration is

used as computation variable. In the current study the contamination status has been assessed employing two most common indices which are as follows:

Contamination Factor (CF)

CF was suggested by Hakanson (1980), and defined as follows:

$$CF = C_n/C_B \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where, C_n stands for the measured concentration of an individual HM from the sample and

C_B stands for the baseline value of and individual metal in the study area. In the current study the value of the lowest occurrence of a specific metal has been used as the base value for this very metal.

Table 1: Grading of Contamination Based on CF Values

CF value	Contamination level	Reference
0	None	Muller, 1969; Hakanson (1980
1	None to medium polluted	
2	Moderately polluted	
3	Moderate to strongly polluted	
4-6	Strongly polluted	
>6	Very strongly Polluted	

Pollution Load Index (PLI)

The pollution load index accounts for the overall contamination status of a specific site. The value of PLI is very much context specific that depends mainly on the number of HM recovered from a specific sample. The PLI has been computed as per the following equation developed by Tomlison et al. in 1980.

$$PLI = (CF_1 * CF_2 * CF_3 * \ldots\ldots\ldots\ldots * CF_n)^{1/n} \ldots\ldots (3)$$

Where CF stands for the contamination factor of individual metals

The value of PLI has been ranked as per the following limit to assess the degree of contamination:

PLI 0 = Perfect quality; PLI >1 Polluted; PLI<1 Non-Polluted (Tomlison et al. in 1980).

The selection of X-ray fluorescence (XRF) for elemental analysis, combined with Contamination Factor (CF) and Pollution Load Index (PLI) for contamination assessment, reflects a methodologically robust and widely endorsed approach in environmental studies. XRF offers rapid, non-destructive multi-elemental analysis with high reproducibility, making it particularly appropriate for large datasets generated from spatially distributed soil samples. The CF and PLI metrics, meanwhile, provide standardized frameworks to assess contamination severity and integrate multi-metal pollution profiles. These methods are especially pertinent in the context of Bangladesh, where practical, cost-effective, and scientifically validated techniques are essential for reliable environmental risk evaluation across extended transport corridors.

RESULTS AND DISCUSSIONS

### Results

Concentration of HM in Roadside Soil

Heavy metals such as Pb, Zn, Cu, Cr, and Ni have been identified in eight different locations within the study area. The concentration of these metals along with their fundamental statistical attributes have been sown in the table below (Table 2):

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Table 2: The Concentration of Heavy Metals in Roadside Soils of Dhaka Mymensingh Highway

Concentration of Heavy Metals (mg/kg)						
Sample	**Pb**	**Zn**	**Cu**	**Cr**	**Cd**	**Ni**
S1	14	65	21	1.13	0.08	1.35
S2	71	494	114	126	3	54
S3	152	530	50	129	4	58
S4	188	334	149	82	2	57
S5	55	483	143	164	1	29
S6	178	576	122	92	5	55
S7	92	572	146	83	5	41
S8	17	77	23	1.87	0.12	2.23
Avg	95.87	391.37	96	84.87	2.52	37.20
Min	14	65	21	1.13	0.08	1.35
Max	188	576	149	164	5	58

Zn exhibits the highest average concentration, followed by Cu, Pb, Cr, Ni, and Cd. Specifically, the concentration of Zn ranges from 65 to 576 mg/kg with an average value of 391.57 mg/kg. The lowest, highest and average concentration of Cu are 21, 149 and 96 mg/kg respectively. The concentration of Pb ranges from 14 to 188 mg/kg with an average value of 95.87 mg/kg. For Cr the concentration ranges from 1.13 to 164 mg/kg with an average value of 84.87 mg/kg. The concentration of Ni ranges from 1.35 to 58 mg/kg with an average value of 37.20 mg/kg. The Cd shows the concentration varies within the range from 0.08 to 5 mg/kg with an average value of 2.52 mg/kg. The mutual relationship and the spatial distribution of the concentration of these metals can be represented by the figure below (Fig. 2). Figure 2 illustrates the distributions of these heavy metals, showcasing a wide range of values among the sampling sites.
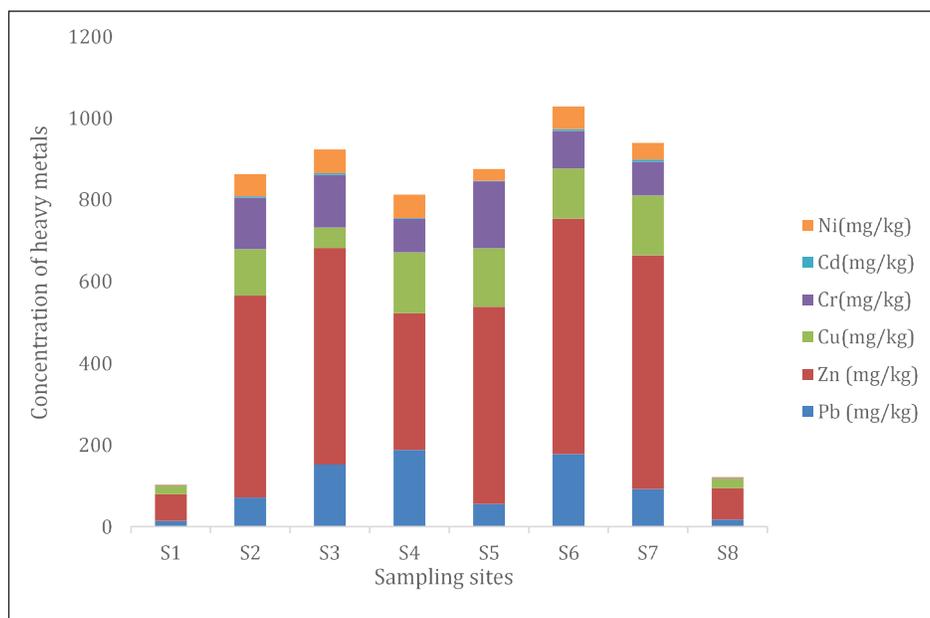
Figure 2: Comparison of the Relative Abundance of Selected Heavy Metals (e.g., Ni Cd, Cr, Cu Zn and Pb) across the 8 Sampling Locations along the Dhaka-Mymensingh Highway. The Figure Illustrates Spatial Variations in Metal Concentrations, Highlighting Site-specific Contamination Patterns

The concentration of Zn is the highest in the sampling site 6 and the lowest in the site S1. The Cu shows the highest concentration in the sampling site S4 and the lowest in the site S1. The concentration of Pb is the highest in the site S4 and the lowest in the site S1. The Cr shows its highest concentration in the site S5 and the lowest in the site S1. The Ni shows the highest concentration in the site S3 and the lowest in the site S1. The sites S6 and S7 show the highest concentration of Cd and the site S1 shows the lowest concentration. It is evident that the concentrations of heavy metals at S1 and S8 sites are significantly lower than the other sites. In contrast, the remaining samples show high levels of HM concentration, attributed to the Landuse Landcover status and the modes of human interventions adjacent to these sites.

Contamination Status of Roadside Soil

The HM contamination status of roadside soil has been assessed through some geochemical indices such as Contamination Factor (CF) and Pollution Load Index (PLI) among which the CF accounts for individual metal based contamination whereas the PLI gives the overall contamination status of a specific sampling site (Kubra et al., 2022; Chakraborty et al., 2021).

Contamination Factor (CF)

The average value of CF of the HM varies in the order Cr (56.58)> Cd (25.25)> Ni (20.78)> Pb (6.18)> Zn (5.51) >Cu (4.36). The spatial variation of contamination status based on CF has been shown in the figure 3.
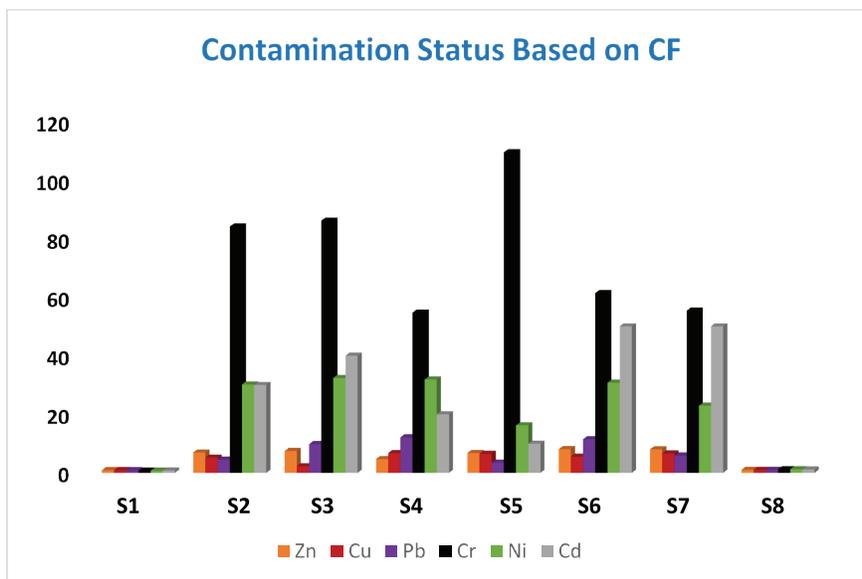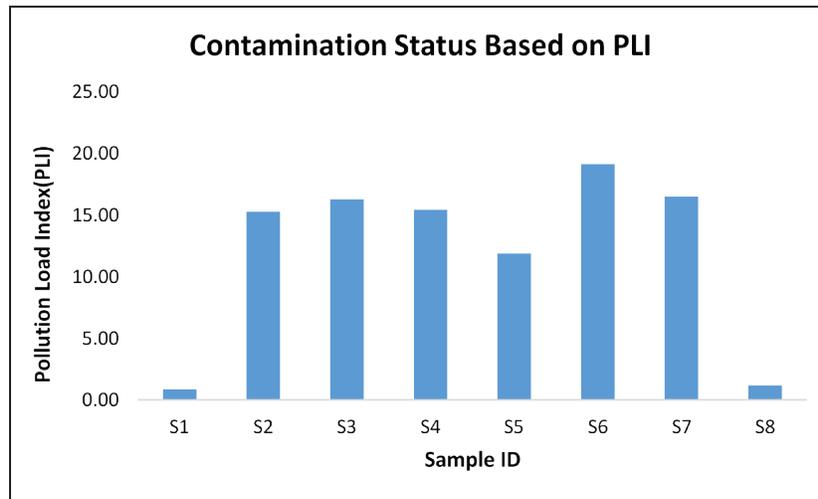

Figure 3: Spatial Trend of Contamination Status in the Study Area Based on CF

The above figure depicts that the sampling sites S1 and S8 shows minimal level of contamination because these two were designated as control sites due to their spatial separation from potential sources of anthropogenic influence. Sites S2 to S7 show contamination in varying degrees for various metals. The roadside soil in the study area is heavily contaminated with Cr and least contaminated with Cu. From a spatial comparison it has been documented that the contamination level of Cr is the highest in the site S5. The highest contamination level of the metals Cd, Ni, Pb, Zn and Cu have been encountered in the sites S6, S3, S4, S6 and S4 respectively.

The average value of CF of the metals Cu and Zn falls within the range of 4 to 6 and signifies strongly polluted status on the other hand the average CF values of the rest of the metals are above 6 and so symbolizes very strong pollution (Table 1)

Pollution Load Index (PLI)

The value of PLI of the sampling points varies in the order S6> S7> S3> S4> S2> S5> S8> S1. The spatial variation of contamination status based on PLI has been shown in the figure 4.

Figure 4: Spatial Trend of Contamination Status in the Study Area Based on PLI

The above figure depicts that the sampling sites S1 and S8 shows minimal level of contamination. Sites S2 to S7 show contamination in varying degrees. The roadside soil from the sampling site S6 shows the highest level of overall contamination. Followed by the sites S7, S3, S4 and S2.

DISCUSSIONS

Roadside soil of each of the studied sampling sites shows the HM contamination above base level. Among which the sampling sites S1 and S8 shows the lowest level of contamination on the other hand the sites from S2 to S7 shows higher degree of contamination. The highest level of contamination have been encountered in the sites S6 and S7 based on the CF and PLI values which can be attributed to their proximity to the anthropogenic interventions such as industrial area (both chemical and textile industry), open dumping sites, markets, steel workshops etc (Fig. 5).

The concentrations of Zn, Cu, Pb and Cr are considerably higher than the others where Zn shows the extensively higher concentrations. The higher concentration of these metals in roadside soil can be attributed to various anthropogenic activities linked to urbanizations and transportation Tire of the vehicular traffic that contains ZnO eventually release Zn rich particles into the roadside soils through abrasion (Kabir et al., 2021; Anwar et al., 2025). Additionally, brake linings, engine oil additives, and exhaust emissions also contribute to Zn accumulation in the roadside environment where urban runoff perform as a triggering factor. The sources

of HM mentioned above can be explained through the Pearson correlation heatmap of metal concentrations as per the figure 6 below:

The Pearson correlation analysis of heavy metal concentrations reveals significant positive relationships among several metals, indicating potential common sources or similar geochemical behaviors. A significantly strong positive correlation have been found among various dominant metal pairs such as Ni and Pb (r=0.87), Zn and Cd (r=0.86) and Zn and Cr (r= 0.83) that accounts for the common possible anthropogenic sources such as industrial effluents and urban runoff ((Bai et al., 2009; Yassoglou et al., 1987). Similarly the correlation status between Ni and Pb may pointing towards battery recycling and steel workshops on the other hand electroplating or galvanization processes can be attributed to major pollution sources as per the correlation between Zn-Cd and Zn-Cr pairs (Bai et al., 2009; Ahmed et al., 2016). The moderate correlations among the rest of the metal pairs suggest mixed sources and also the interference of transport mechanisms (Kabir et al., 2021; Anwar et al., 2025).

Moderate correlations, such as between Copper (Cu) and Zinc (r = 0.70), further support the likelihood of mixed sources, including corrosion of metal infrastructure and vehicular emissions (Kabir et al., 2021; Anwar et al., 2025). The above analysis reveals the complexity in the journey of HM from source to sink. The HM concentrations has also been compared with that of the previous investigations to reveal the comparative contamination status (Table 3).
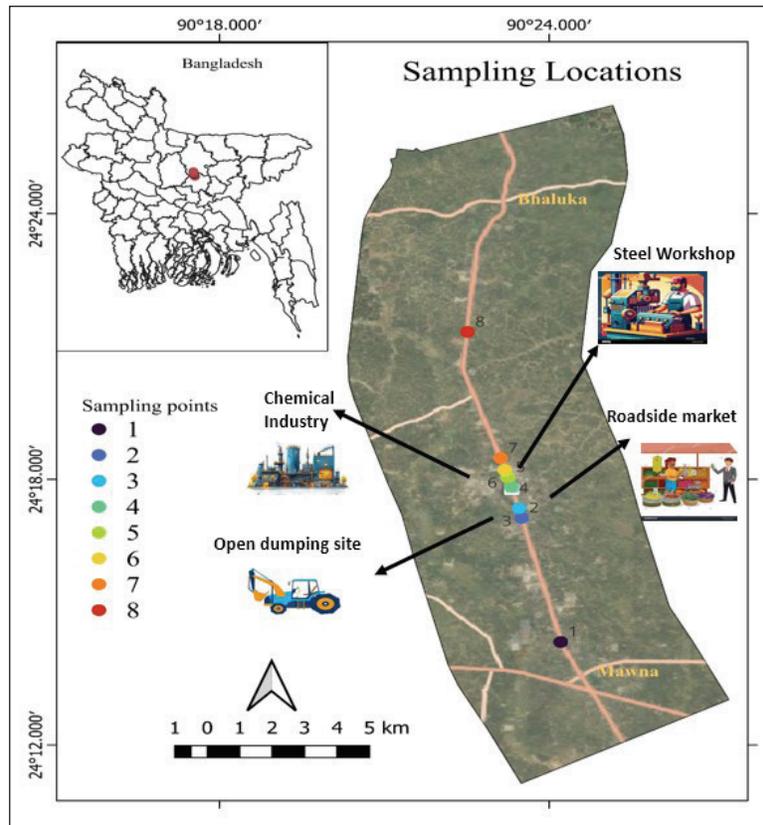
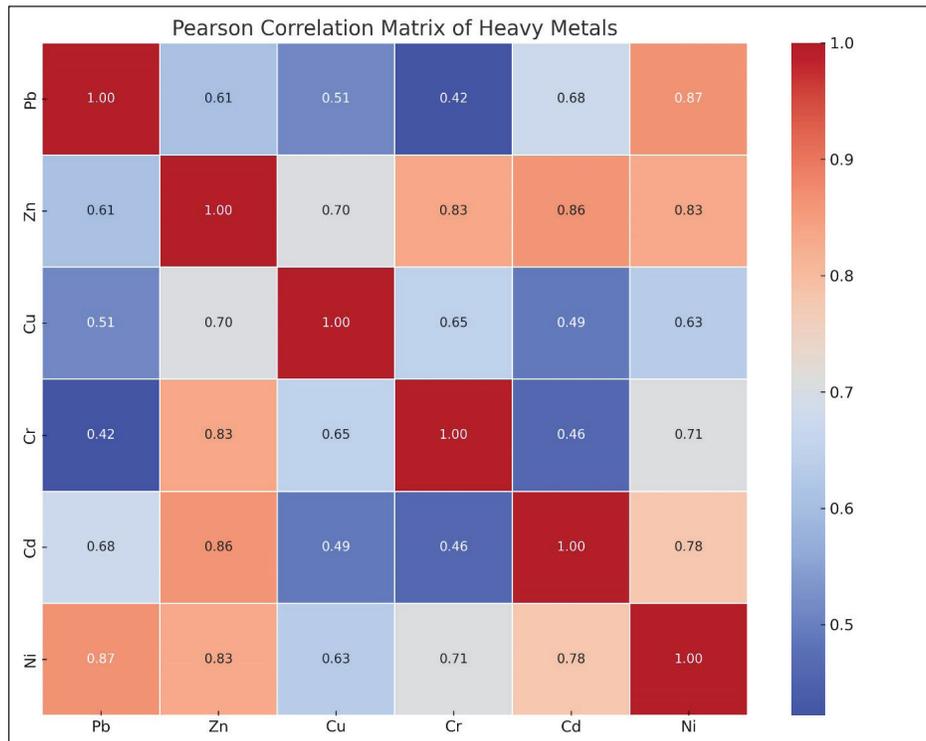**Figure 5:** Sources of HM in the Roadside Soil

Figure 6: Pearson Correlation Heatmap of Heavy Metals

Table 3: Comparative Scenario of Roadside HM Contamination

Source	Sample Type	Average Concentration of HM (mg/kg)					
		Pb	**Zn**	**Cu**	**Cr**	**Cd**	**Ni**
Current Study	Roadside soil	95.87	391.37	96	84.87	2.52	37.20
Kabir et al., 2021	Roadside dust	69.5	367	76.3	67.3	-	40.5
Moslehuddin et al., 1998	Roadside soil	25.86	97.62	34.69	89.72	34.59	41.17
Rahman et al., 2021	Roadside soil of academic institution	19.5	77.05	22.64	-	-	-
Rakib et al., 2014	Roadside soil	67.60	144.20	98.90	61.24	-	-
Upper Continental Crust (UCC) [Taylor,& McLennan, 1995; Gao et 1l., 2004)	World standard average	20	71	25	68	0.98	47

The concentrations of heavy metals observed in the current study are notably elevated compared to both global baseline values and findings from previous investigations. For instance, the measured levels of Pb (95.87 mg/kg), Zn (391.37 mg/kg), and Cu (96 mg/kg) considerably exceed the average concentrations reported for the Upper Continental Crust (UCC) as well as those recorded by Kabir et al. (2021) and Moslehuddin et al. (1998). Although Cr (84.87 mg/kg) is comparable to or slightly higher than values reported in earlier studies, the concentration of Cd (2.52 mg/kg) surpasses the UCC reference value (0.98 mg/kg) by more than twofold. These elevated concentrations suggest a pronounced anthropogenic influence on the roadside soils in the study area. This study provides valuable insights into the spatial distribution and potential sources of heavy metal contamination in urban roadside soils. A major strength of the research lies in its use of a combination of field sampling and geochemical analysis supported by comparative baseline data. However, certain limitations should be acknowledged. The sample size, although representative, was limited to specific locations, which may not capture the full spatial variability across broader regions. Additionally, potential seasonal variations were not considered, which could influence the contamination levels. Future studies incorporating temporal datasets and broader spatial coverage would enhance the robustness of the findings.

CONCLUSIONS

The HM contamination in roadside soil has become one of the major environmental problems in the urban ecosystem now-a-days. From this context the main focus of the current study was to investigate the degree of contamination of HM in roadside soil along one of the busiest highways of Bangladesh. The study is a compilation of field investigation, laboratory analysis and statistical analysis. A total of 8 composite samples were collected from 8 sampling sites along the Dhaka-Mymensingh Highway during the fieldwork. The HM analysis was conducted in search for the six potentially toxic metals. The concentration of the metals varies in the order Zn followed by Cu, Pb, Cr, Ni and Cd. The contamination factor, and pollution load index have been used in assessing the contamination levels, which shows higher degree of contamination. The roadside soil has been documented as highly contaminated by Cr followed by Cd, Ni, Pb, Zn and Cu in terms of CF. The PLI shows that the overall contamination is the highest in the sampling site S6 followed by the sites S7, S3, S4 and S2. Statistical analysis indicates the industrial activities, Poor urban management and vehicular eminent are the prime producer of the HM in the roadside soil. Measures such as improved waste management, stricter industrial regulations, and sustainable practices can help mitigate the heavy metal contamination and preserve the ecological balance. This study acknowledges certain limitations, including the limited access to sampling sites and the absence of seasonal data, which may affect the generalizability of the findings. Future research should focus on broader spatial and temporal coverage and incorporate biological indicators to better assess ecological risks. Policymakers are encouraged to implement regular monitoring programs, strengthen emission control measures, and consider the use of vegetative buffers along highways to mitigate heavy metal contamination.

ACKNOWLEDGMENT

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