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Assessment of Heavy Metal Contamination on Road Dust: A Case Study of Khulna City

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Abstract

The concentration of heavy metals in road dust poses significant risks to human health and the environment. This study investigates the characteristics of road dust, focusing on the contamination level of heavy metals like lead (Pb), iron (Fe), and arsenic (As). Road dust samples were collected from various locations in Khulna city. They went through acid digestion to determine the Pb, Fe, and As levels using ICP-OES, and bioavailable iron was assessed by mixing the dust samples with water. This study found no detectable levels of As in the road dust. Pb concentrations varied across different sites in the following order: Shiromoni Industrial Area > Fulbarigate > New Market > Sonadanga Residential Area. Iron concentrations followed slightly different orders: Shiromoni Industrial Area > New Market > Fulbarigate > Sonadanga Residential Area. The highest bioavailable iron was found at 2.73% in the Shiromoni Industrial Area, indicating a higher potential for iron uptake, followed by the New Market Area, Fulbarigate, and the lowest was 0.53% in the Sonadanga Residential Area, indicating a lower potential. The highest Pb, Fe, and bioavailable Fe concentrations were 62.0 μg g^{-1}, 12450 μg g^{-1}, and 132 μg g^{-1} in Shiromoni Industrial Area. Compared with other literary studies, this study concluded that the contamination levels of heavy metals in Khulna's road dust were comparatively high compared to other cities globally and within Bangladesh. The contamination factor (CF), enrichment factor (EF), and geo-accumulation index (Igeo) indicated that the extent of Pb contamination ranged from moderately to heavily contaminated. In contrast, the road dust was uncontaminated by Fe. The results of this research will enhance our comprehension of heavy metal levels in road dust, supporting policymakers in making well-informed choices to reduce health risks and safeguard the environment.

Keywords
Road dust; heavy metal; ICP-OES; health impacts; contamination factor; geo-accumulation index

1. Introduction

Bangladesh's rapid economic development increase has led to a higher risk of pollution from dust particles on roads [1, 2]. Dust, made up of tiny solid particles, can pick up heavy metals and various pollutants from human activities and natural sources [3, 4]. Road dust accumulates on city roads and is a repository for multiple pollutants, especially toxic heavy metals. These metals originate from natural geological processes and various human activities, including vehicle traffic, industrial emissions, and household and commercial operations [5, 6]. Heavy metals in road dust can infiltrate the soil, eventually entering the tissues of plants and animals and making their way into the human food chain, affecting health and well-being [7-9]. Dust particles containing organic and inorganic pollutants can migrate from roads to residential areas, leading to air pollution [10]. It has been observed that road and soil dust contribute to about 60% of air pollution in the winter, which decreases to 33% during the rainy season, with motor vehicles contributing approximately 30% of the air pollution [11-13]. Therefore, it is important to thoroughly study the composition, amount, distribution, and sources of road dust to understand urban environmental conditions accurately.

Road dust is primarily derived from the deposition of atmospheric aerosols and displaced soil, which contribute to the accumulation of heavy metals in topsoil. Atmospheric deposition processes, such as sedimentation and impaction, are the main factors in transferring heavy metals onto road surfaces. Additionally, road dust is generated from various human and environmental activities, including vehicle emissions, heating systems, construction, and the corrosion of metal structures [12, 14]. The significant sources of road dust are construction and mineral dust, which are particles originating from building activities and natural geological sources; carbonaceous emissions, which include soot and particulates produced during combustion processes; and brake and tire wear from vehicle components releasing delicate particulate matter. Various studies have shown regional differences in the composition and sources of road dust. In European cities, the key contributors include road surface abrasion, vehicle exhaust, and brake and tire wear. In contrast, in Chinese cities, the dominant sources include soil particles, coal combustion residues, and cement dust [15]. Bangladesh road dust is a complex mixture of industrial and natural particles, encompassing exhaust (combustion-related) and non-exhaust (mechanical abrasion-related) sources. Natural components are often derived from mineral sources such as volcanic ash and wind-blown soil. Significant contributors include the abrasion of vehicle parts, tire wear, and the erosion of road surfaces [16, 17]. Some anthropogenic sources also contribute to heavy metals in Khulna City, including industrial emissions, vehicular traffic, urban construction activities, and improper waste disposal, which can cause various impacts on human health, environmental degradation, and food safety concerns.

Heavy metals in dust particles can enter the human body through inhalation, ingestion, and skin absorption. This can affect children's and older people's health, especially in areas with high metal contamination. High lead levels in the environment can raise blood lead levels, lower IQ, and alter behavior. Children are particularly vulnerable to ingesting lead through finger-sucking and mouthing non-food objects, which can harm their neurobehavioral and cognitive development [18-20]. Lead exposure can also affect the reproductive system and cause microcytic anemia, leading to health issues like hypertension and chronic kidney failure [21, 22]. Additionally, heavy metals can accumulate in the environment and pose significant risks to ecosystems and heavy metal contamination can interfere with essential plant functions like photosynthesis, transpiration, and respiration [23]. Therefore, we should work harder to reduce road dust pollution.

This study collected road dust from different areas of Khulna city to assess its contamination. The collection and analysis of the samples focused on analyzing the lead, iron, and arsenic content in road dust in various locations of Khulna city, measuring the bioavailable iron content in the road dust, comparing the lead, iron, and arsenic concentration in road dust with other studies and evaluation of the contamination factor (CF), enrichment factor (EF), geo-accumulation index (Igeo) of heavy metals in road dust.

There is extensive research on heavy metal concentrations in street dust for industrialized and developed countries, but not much for emerging nations like Bangladesh. Our study is unique in its goal to identify potentially harmful metallic elements present in road dust. These metals could pose health risks if proper remedial actions are not taken. The findings from this research will improve our understanding of the contamination by metallic compounds in road dust.

2. Materials and Methods

2.1 Study Area

This study took place in Khulna, the third-largest city in southwestern Bangladesh. Samples were collected from the Shiromani Industrial Area, Fulbarigate, New Market, and the Sonadanga Residential Area, Khulna's most densely populated areas. Figure 1 shows these locations and Table 1 provides their latitude and longitude.

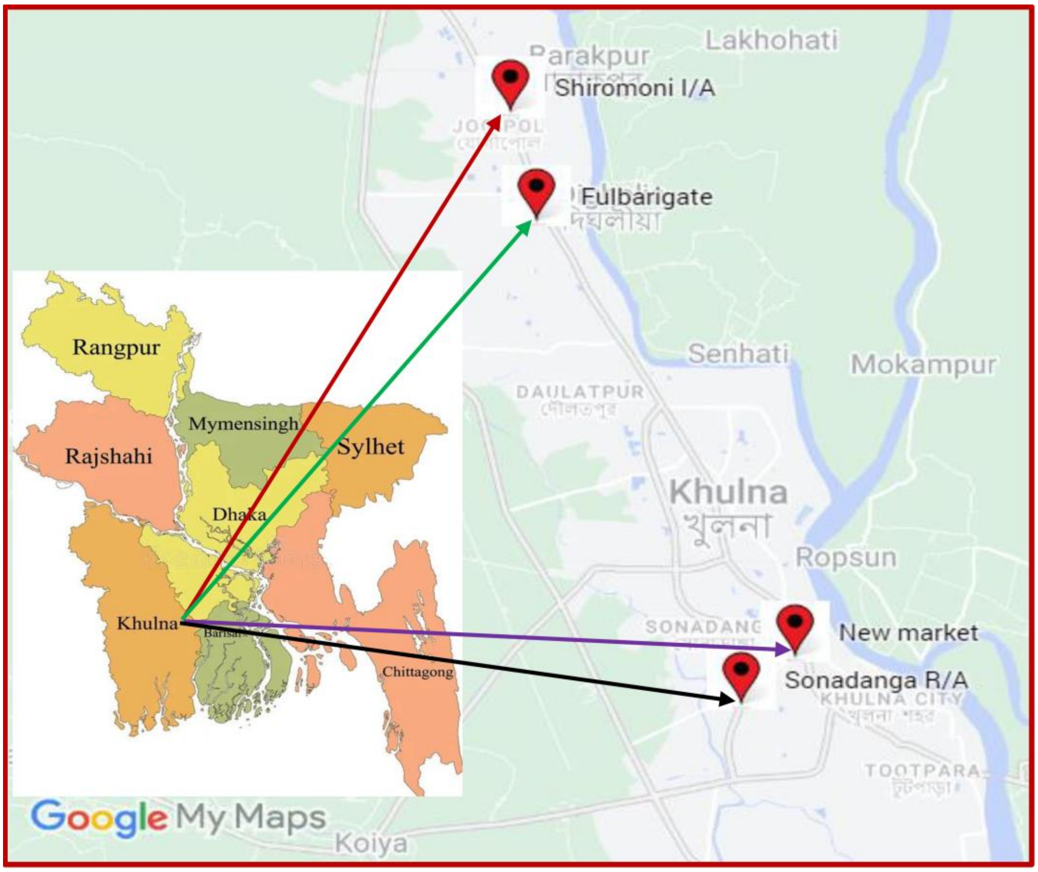

Figure 1 Sample Collection Locations.

Table 1 Sample collection locations latitude and longitude.

Sampling location	ID Mark	Latitude	Longitude	Types of Area
Shiromani Industrial Area	SIA	22°49′12″ N	89°33′01″ E	Industrial
Fulbarigate	FA	22°53′53″ N	89°30′35″ E	Public
New Market	NMA	22°48′35″ N	89°33′51″ E	Public
Sonadanga Residential Area	SRA	22°49′0.12″ N	89°32′60″ E	Residential

2.2 Collection of Road Dust and Tests

Twelve dust samples were collected from different locations in Khulna using a plastic dustpan and brushes, and the dust was then placed into a plastic bottle. The samples were collected during the dry season when air pollution is at its highest in the city. Approximately 250 grams of each sample was sieved through sieve no. #200 (75 µm) and samples were oven dried at 110°C for 24 hours.

Then 0.4 g sample was digested with 20 ml (8N) Nitric acid (HNO_3) in an infrared cooker for 1.5 hours and filtered through 150 mm diameter Whatman filter paper with a particle retention capacity of 11 µm to make 50 ml of prepared sample by adding distilled water for the analysis of lead (Pb) and was directly analyzed in the lab using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES), Model: Prodigy 7. For Fe and As analysis one gram dust sample was digested with a ratio of 3:1 with the mixture of hydrochloric acid (HCl) and nitric acid (HNO_3) in an infrared cooker for 45 minutes and filtered through Whatman filter paper to make 100 ml prepared sample by adding distilled water. For iron, 0.5 ml of previously prepared digested sample was taken into the 50 ml measuring cylinder, and 9.5 ml water was added for dilution. It was brought into the glass cell for analyzing iron using the FerroVer Iron Reagent Method (Hach DR 3900). For Arsenic, 50 ml of preparing sample was taken into the sampling bottle for analyzing arsenic using the HACH EZ Arsenic Reagents Set method. For bioavailable iron, 1.0 g of the dust sample was taken into a 250 ml beaker to make a 100 ml sample by adding distilled water and filtered through Whatman filter paper after stirring with a magnetic stirrer for 24 hours for analyzing the bioavailable iron using the FerroVer Iron Reagent Method (Hach DR 3900) [24]. The experimental procedure for determining heavy mental concentration was elucidated in Figure 2.

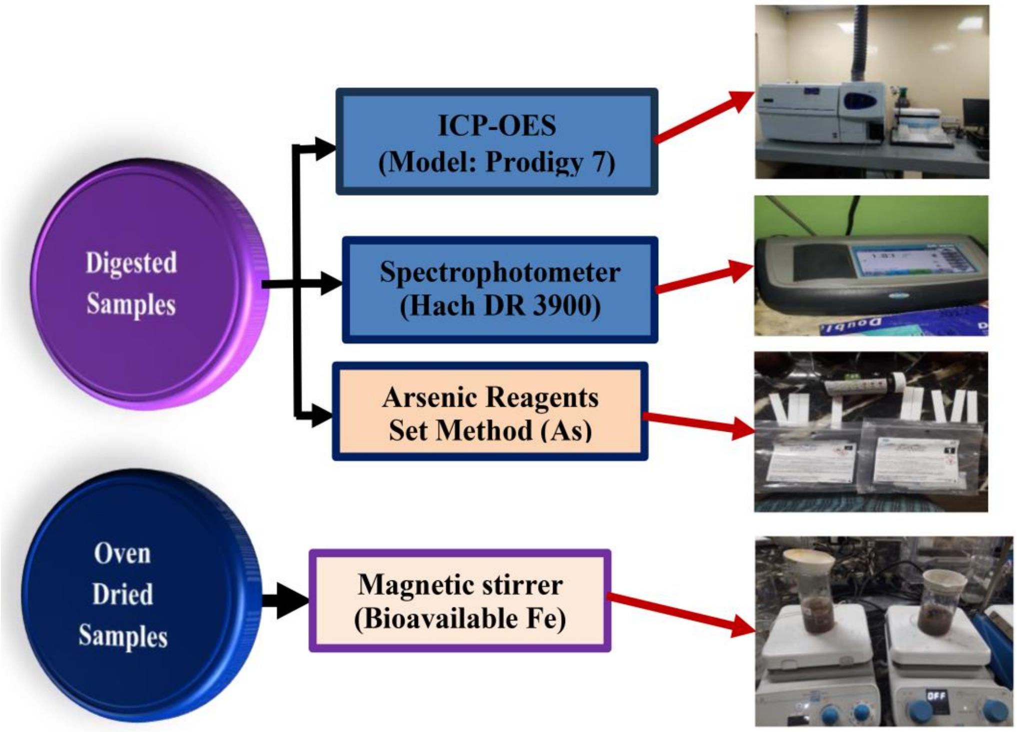

Figure 2 Typical experimental process for determining the levels of lead, iron, arsenic, and bioavailable iron in road dust.

2.3 Evaluation of Contamination Factor (CF), Enrichment Factor (EF), and Geo-Accumulation Index (Igeo)

The contamination factor (CF) is determined by taking the concentration of a particular heavy metal in a road dust sample and dividing it by its background level. This calculation can be performed using equation (1):

$$\mathrm{CF} = \frac{\mathrm{C_m}}{\mathrm{C_b}} \quad (1)$$

Where, Cm represents the concentration of heavy metal in the road dust sample, while C_b represents the background value of the heavy metal. Due to the lack of known background values for roadside dust in Khulna City, this study utilized the C_b values from the upper continental crust (UCC).

The enrichment factor (EF) assesses the contributions of human activities and natural sources to the presence of heavy metals in road dust. This method involves comparing the concentration of a heavy metal to that of a reference metal, like iron (Fe) by using equation (2):

$$\mathrm{EF} = \frac{\left(\frac{\mathrm{CM}}{\mathrm{CFe}}\right)\mathrm{dust}}{\left(\frac{\mathrm{CM}}{\mathrm{CFe}}\right)\mathrm{background}} \tag{2}$$

Where (CM/CFe)dust represents the ratio of the concentration of the heavy metal (CM) to iron (CFe) in road dust samples, while (CM/CFe)background denotes the ratio of the concentration of the same metal to iron in the background value, the background values for iron and lead are 30890 μg g^{-1} and 17 μg g^{-1} respectively [25].

The geo-accumulation index (Igeo) evaluates the present heavy metal content in collected samples against background values (such as UCC or local soil) to determine the extent of contamination. This index was initially proposed by Muller [26] and is calculated using equation (3):

$$\mathrm{I_{geo}} = \log_2\left(\frac{\mathrm{C_m}}{1.5 \times \mathrm{C_b}}\right) \tag{3}$$

C_m denotes the measured concentration of the heavy metal in roadside dust, and C_b refers to the background concentration of the heavy metal.

3. Results and Discussion

3.1 Lead Analysis

Lead in road dust is a significant public health and environmental concern. It can cause neurological effects, cardiovascular problems, and developmental issues in humans. It can also cause soil contamination, water pollution, bioaccumulation, and air pollution, as well as reduce urban cleanliness. The primary lead sources in road dust are vehicle emissions, industrial activities, construction and demolition, atmospheric deposition, wear and tear of lead-containing materials, and contaminated soil. In this study, the concentration of lead in road dust in Khulna city is shown in Table 2. The highest levels are in the Shiromoni industrial area, followed by the New Market, Fulbarigate, and Sonadanga residential areas. Lead concentrations range from 28.0 μg g^{-1} to 67.0 μg g^{-1} with an average of 43 μg g^{-1}. The lead concentration is high in the Shiromoni industrial area because of the area type and different industrial activities. On the contrary, it is low in the Sonadanga residential area because of lower traffic volume, distance from industrial sources, better urban planning and maintenance, and better regulatory and community measures.

Table 2 Lead concentration in road dust.

ID Mark	Lead concentration (μg g^{-1})			
	S–1 location	S–2 location	S–3 location	Avg ± SD
SIA	62.0	56.5	67.0	61.8 ± 5.25
FA	44.6	38.1	51.5	44.7 ± 6.70
NMA	34.9	36.4	34.1	35.1 ± 1.17
SRA	30.4	28.0	33.4	30.6 ± 2.71

Table 3 compares the lead concentration found in this study with that from other studies. The lead levels we found are within the ranges reported by other studies. The highest lead concentration in our study was about 62.0 μg $g^{-1,}$ which is within the range of other areas studied but still exceeds the standard limit of 60 mg kg^{-1} (ECR-2023), indicating significant pollution [27]. The highest lead concentration in another study area was 1250 μg g^{-1}.

Table 3 Comparison of lead concentration with other studies.

Reference(s)	Study location	Lead concentration (μg g^{-1})	
		Min–Max	Avg ± SD
This study	Khulna, Bangladesh	28-62	43.1 ± 3.96
Faiz et al. [28]	Islamabad, Pakistan	60-150	104 ± 29
Han et al. [29]	Kuala Lumpur	7.1-422.8	-
Victoria et al. [30]	Bolgatanga, Ghana	3.55-10.79	-
Harb et al. [31]	Saudi Arabia	3.3-113.5	26 ± 22.4
Men et al. [32]	Beijing	22.4-261.4	-
Maeaba et al. [33]	Suva City, Fiji	33.6-234.5	71 ± 47.5

3.2 Iron Analysis

Table 4 presents the concentration of iron in road dust from various places in Khulna city. The highest concentration of iron is found in the Shiromoni industrial area at 9950 μg g^{-1} while the lowest is in Fulbarigate at 4840 μg g^{-1}. Sources of iron in roadside dust include metal construction works, iron bending, welding, iron filings from these activities, vehicle exhaust emissions, oil spills from gasoline, diesel, engine oil, lubricating oils, tire wear, and brake lining wear. The high iron concentration in Shiromoni's roadside dust is due to extensive industrial activities, metal construction, and iron-related work, which are prevalent along major roads and in mechanical workshops. Other areas also have metal construction and iron-related activities but to a lesser extent than Shiromoni. The contributions to the iron concentration also come from vehicle emissions and oil spills, which are more frequent in Shiromoni than in other areas studied. All roads in the study area have low iron concentrations indicating uncontaminated road dust. But people should be careful about inhalation of high iron concentration road dust poses a risk of causing coughing in both children and adults.

Table 4 Iron concentration in road dust.

ID Mark	Iron concentration (μg g^{-1})			
	S–1 location	S–2 location	S–3 location	Avg ± SD
SIA	12450	9150	8250	9950 ± 2211.3
FA	5120	4900	4500	4840 ± 314.3
NMA	6700	5550	5150	5800 ± 804.7
SRA	5300	4850	3200	4450 ± 1105.7

Table 5 compares the iron concentration found in this study with other studies [28-36]. The iron levels found in this study were within the ranges reported by other studies. This study indicates that the amount of iron from sources like metal construction, iron bending, welding, vehicle exhaust emissions, and oil spills in Khulna city is less than in other studied areas. The highest iron concentration in the study areas was 12450 μg g^{-1}, much less than the maximum value in different studies.

Table 5 Comparison of iron concentration with other studies.

Reference(s)	Study location	Iron concentration (μg g^{-1})	
		Min–Max	Avg ± SD
This study	Khulna, Bangladesh	3200-12450	6260 ± 1109
Faiz et al. [28]	Islamabad, Pakistan	21510-36020	27720 ± 4760
Han et al. [29]	Kuala Lumpur	3757-19545	-
Victoria et al. [30]	Bolgatanga, Ghana	188.80-198.98	-
Harb et al. [31]	Saudi Arabia	12516-31382	220921 ± 6968.6
Men et al. [32]	Beijing	21221-55420	29744.62
Maeaba et al. [33]	Suva City, Fiji	26092-104,807	41010.4 ± 19299.3
Rajaram et al. [34]	Delhi, India	22704-35082	27047
Skorbiłowicz et al. [35]	Bialystok, Poland	400-10130	-
Adewumi [36]	Akure City, Nigeria	463.01-992.61	115.21

3.3 Bioavailable Iron Analysis

Table 6 presents the levels of bioavailable iron and the percentage of bioavailability found in road dust across different areas of Khulna city. In the Shiromoni industrial area, the concentration of bioavailable iron ranges from 72 to 132 μg g^{-1} with an average of 108.7 μg g^{-1} which is higher and lower in Sonadanga residential area, where the concentration averages 23.3 μg g^{-1}. The maximum bioavailability percentage of iron was 2.74% in SIA and the minimum was 0.53% in SRA. This study suggests that the potential for iron absorption through human skin is more significant in the Shiromoni industrial area, particularly with prolonged exposure in wet conditions. Over time, continuous low-level exposure could lead to harmful toxic effects.

Table 6 Bioavailable iron concentration (μg g^{-1}) and average bioavailability percentage.

ID Mark	Bioavailable iron concentration (μg g^{-1})				Avg % bioavailability ± SD
	S–1 location	S–2 location	S–3 location	Avg ± SD	
SIA	132	122	72	108.7 ± 32.1	2.74 ± 0.4
FA	45	28	31	34.7 ± 9.1	0.62 ± 0.1
NMA	106	86	51	81.0 ± 27.8	1.83 ± 0.05
SRA	25	18	27	23.3 ± 4.7	0.53 ± 0.1

3.4 Arsenic Analysis

Table 7 shows the levels of arsenic in road dust from various locations in Khulna. This study indicates that arsenic is not present in the road dust samples. Arsenic can come from human activities and natural sources, such as mining, waste incineration, metal industries, fuel use, cement production, agricultural burning, geothermal steam, and lead smelting. Natural sources include volcanic activity, plant exudates, and wind-blown dust. The absence of arsenic in Khulna's road dust is mainly because these natural sources are absent. Human activities that release arsenic, like metal smelting and fuel consumption, are occurring but not at high levels. Additionally, no cement factories, agricultural burning, geothermal steam development, or secondary lead smelting facilities are nearby. It is important to note that the arsenic measurement kit has a minimum detection limit of 5 ppb, so any value below this is recorded as not detected (nd). The comparison of the average concentration of different heavy metals in road dust is shown in Figure 3.

Table 7 Arsenic concentration in road dust (μg g^{-1}).

ID Mark	Arsenic concentration (μg g^{-1})		
	S–1 location	S–2 location	S–3 location
SIA	nd	nd	nd
FA	nd	nd	nd
NMA	nd	nd	nd
SRA	nd	nd	nd

nd: not detected.

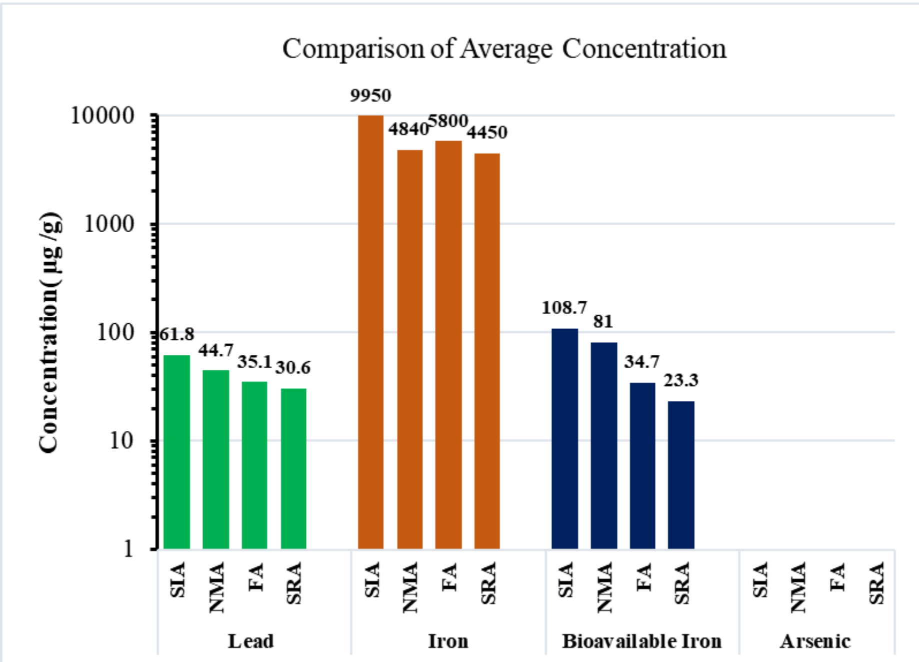

Figure 3 Comparison of the average concentration of different metals at different locations.

Table 8 compares the levels of arsenic in road dust from this study with those found in other studies. Three studies conducted in Bangladesh reported no arsenic in the road dust, which matches the findings of this study. However, a survey in Jimeta-Yola, Adamawa State, Nigeria, found arsenic levels between 70.36 and 199.94 μg g^{-1}, and a survey in Bolgatanga, Ghana, reported levels between 0.07 and 0.31 μg g^{-1}. These studies concluded that the arsenic in road dust may come from various natural and human-made sources.

Table 8 Comparison of arsenic concentration with other studies.

Reference(s)	Study location	Arsenic concentration (μg g^{-1}) (Min-Max)
This study	Khulna, Bangladesh	nd
Mohiuddin & Hossain [37]	Bangladesh	nd
Pal et al. [38]	Bangladesh	nd
D. Shinggu [39]	Jimeta, Nigeria	70.36-199.94
Victoria et al. [30]	Bolgatanga, Ghana	0.07-0.31

Nd: not detected.

3.5 Evaluation of Contamination Factor (CF), Enrichment Factor (EF), and Geo-Accumulation Index (Igeo)

The extent of heavy metal pollution in the roadside dust of Khulna City was evaluated using a specific classification system for contamination. According to the CF system: a CF of less than 1 indicates low contamination, a CF between 1 and 3 indicates moderate contamination, a CF between 3 and 6 indicates considerable contamination, and a CF greater than 6 indicates very high contamination [40]. The findings revealed that iron had a considerable level of contamination, while lead exhibited moderate contamination levels.

The enrichment factors (EF) of heavy metals were calculated using iron (Fe) as a reference and the upper crust content of the Earth as a baseline. An EF value of 1 or less indicates that the heavy metals in the soil likely originate from natural sources, such as crustal materials or weathering processes; hence, they can be considered unpolluted. However, an EF value greater than 1 suggests that human activities are likely responsible for soil pollution [41]. In this study, the EF values for lead (Pb) were more significant than the unity indicating that human activities might contribute to lead pollution. Similarly, the EF values for iron (Fe) were 1, implying that the dust is not significantly polluted by iron, likely due to anthropogenic sources.

The Geo-accumulation Index, defined by Müller, measures metal contamination in soil. According to this index, Igeo less than 0 means the soil is uncontaminated, and Igeo greater than 5 means the soil is extremely contaminated [26]. This study showed that the Igeo value for iron and lead is less than 5, indicating that road dust is not contaminated by lead in the study areas. The contamination level of iron and lead based on different factors is shown in Table 9.

Table 9 Site status of Khulna City based on CF, EF, and Igeo.

ID Mark	CF		EF		Igeo	
	Iron	Lead	Iron	Lead	Iron	Lead
SIA	0.32	3.65	1.0	11.32	-2.20	1.28
FA	0.16	2.63	1.0	16.75	-3.26	0.80
NMA	0.19	2.10	1.0	10.94	-3.0	0.45
SRA	0.14	1.79	1.0	12.41	-3.38	0.25
Average	0.2	2.5	1.0	12.9	-3.0	0.70
Site Status	Low Contamination	Moderate Contamination	Not Polluted	Strongly Polluted	Uncontaminated	Moderately Contaminated

4. Conclusions

This study deals with the contamination of heavy metals in road dust. The highest concentrations of lead and iron were found in the Shiromoni industrial area, measuring 62.0 µg g^{-1} and 12450 µg g^{-1}, respectively. The lowest concentrations were in the Sonadanga residential area, with lead at 30.4 µg g^{-1} and iron at 3200 µg g^{-1}. On average, Khulna city had lead levels of 43.1 µg g^{-1} and iron levels of 6850 µg g^{-1}. The higher levels of lead and iron in the road dust along the Khulna-Jashore highway may be due to increased traffic, metal construction work, industrial discharge from battery or metal factories, and welding dust carried by the wind. The amount of bioavailable iron in road dust ranged from 23.3 to 108.7 µg g^{-1}, with an average of 1.43% bioavailable. The likelihood of absorbing iron through the skin is higher in the Shiromoni residential area, especially with long-term exposure to water or wet conditions, and lower in the Sonadanga residential area. Arsenic is not a problem in road dust of Khulna City as it was not detected in any of the samples from the study areas. The road dust of Khulna City is classified as uncontaminated by iron and moderately to strongly contaminated by lead based on CF, EF, and Igeo. The findings of this study will be an important reference for future research on road dust contamination in southwestern Bangladesh. This study will also assist policymakers in making informed decisions to protect public health and the environment.

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Author Contributions

Mamun Mahmud: Conceptualization, Methodology, Literature review, Investigation, Data curation, Formal analysis, Software Analysis, Writing-original draft, review & editing, and Project management. Md. Mujahid Hasan: Conceptualization, funding, acquisition, Formal analysis, Visualization, Writing – review & editing.

Competing Interests

The authors state that they have no financial interests or personal relationships that could have affected the work described in this paper.

Additional Materials

The following additional materials are uploaded at the page of this paper.

1. Supplementary.

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