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Assessment of Heavy Metals and Major Oxides in Accumulated Dust from Eastern Baghdad, Iraq

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ABSTRACT

This research assessed the concentrations of heavy metals and major oxides in street dust from three urban areas in East Baghdad, Iraq. Dust samples were collected from main, service, and residential streets of Zayouna, Baghdad, Al-Jadeda, and Al-Mashtal. A total of 54 samples were analyzed to quantify Pb, As, Fe, and Mo, as well as sulfur trioxide (SO_3) and phosphorus pentoxide (P_2O_5). Organic matter and pH were also determined. The results revealed spatial variations in pollutant distribution across the sites. Lead concentrations ranged from 12.6 to 93.5 ppm, with the highest values recorded in Zayouna. Arsenic levels varied between 1.5 and 6.9 ppm, while iron ranged from 12,810 to 31,970 ppm. Molybdenum concentrations (6.7–19.92 ppm) were highest in Zayouna's main streets. There was elevated SO_3 (13,350–40,450 ppm) and P_2O_5 (735–1364 ppm), particularly in Al-Mashtal. Organic matter levels were generally low (0.98–2.30%), while dust pH values were strongly alkaline (9.5–10.5). Correlation analysis revealed significant negative associations between Pb and As ($r = -0.521$) and between SO_3 and Mo ($r = -0.516$). The findings highlight the contribution of vehicular emissions, waste burning, and industrial activities to urban dust contamination, with potential risks to environmental and human health. The calculated pollution indices (CF, EF, and Igeo) indicated moderate to high enrichment of Pb and Mo due to anthropogenic sources such as traffic, fuel combustion, and waste burning, whereas Fe remained within the natural background level.

1. INTRODUCTION

Heavy metals are defined as any metal element that is toxic at high concentrations and has a density greater than 5 mg/L. They are naturally occurring substances found in the Earth's crust [1]. These metals contain a wide range of chemical elements that are about five times denser than water [2]. Despite being necessary for life, at least 26 naturally occurring chemical elements can be hazardous at high concentrations for living things, which makes their presence in the environment concerning [3]. This type of pollutant has drawn the attention of academics and society because of its high toxicity and extreme difficulty in removing it naturally by decomposition [4]. In recent years, human exposure to these elements has increased due to their frequent use in many industries, and this raises concerns for public health and pollution-related ecosystems, including agricultural, industrial, and technological industries [5]. Pharmaceutical, industrial, and agricultural waste and atmospheric sediments are the most prominent sources of heavy metals [6].

Environmental studies are particularly interested in heavy metals like lead, zinc, arsenic, and molybdenum because of their detrimental and pervasive effects on the ecosystem, their high stability over extended periods of time, and their numerous negative health effects on people. These metals also pollute populated areas, which can result in a variety of symptoms, such as cancer, kidney and liver disease, neurological system damage, and allergies [7]. The concentrations of heavy metals in surface soil and atmospheric dust rise as a result of natural geological processes like weathering and erosion of crustal rocks, which are the main sources of these metals. These metals can then travel to different locations by wind, water runoff on the earth's surface, or groundwater transfer, so that different concentrations of heavy metals can be seen in the atmosphere and the ground [8].

Dust is the most frequent substance with which humans come into contact, and it is a major source of trace elements in urban environments. Significant amounts of heavy hazardous substances may be present in street dust [9]. One substance that collects on paved roads and is perfect for sampling outdoor urban pollution is street dust [10]. Due to variations in weathering and a relatively short lifespan in the environment, which are both directly related to climate, street dust is a rather complex material, and its compositions are rarely corrected [11]. Numerous studies have been carried out worldwide to determine the concentrations of certain heavy metals in street dust, including those in Turkey [12], Nigeria [13], China [14], Iran [15], Saudi Arabia [16], Algeria [17], and Iraq (Dhi Qar Governorate [18] and Babylon Governorate [19]) and Basrah [20, 21].

Given the significance of these metals and their direct effects on human health, the current study was conducted to measure the concentrations of heavy metals in selected areas of East Baghdad. Also, the study determined the levels of certain oxides, organic matter, and pH in the same locations to evaluate the extent of pollution associated with these metals. This study is innovative in simultaneously assessing heavy metals, oxides, organic matter, and pH in urban dust across East Baghdad, offering a holistic environmental evaluation. Its necessity arises from the urgent need to identify pollution sources, map contamination patterns, and highlight potential risks to ecosystems and human health, thereby informing sustainable urban management and pollution control strategies.

2. MATERIALS AND METHODS

2.1 Study areas

The study areas are situated on the Al-Rusafa side in the eastern parts of Baghdad (Al-Mashtal, Baghdad Al-Jadeda, and Zayouna). Each area was separated into three streets: a main street, a service street, and a residential street. The latitude and longitude of each area were then calculated as presented in Figure 1 and Table 1.

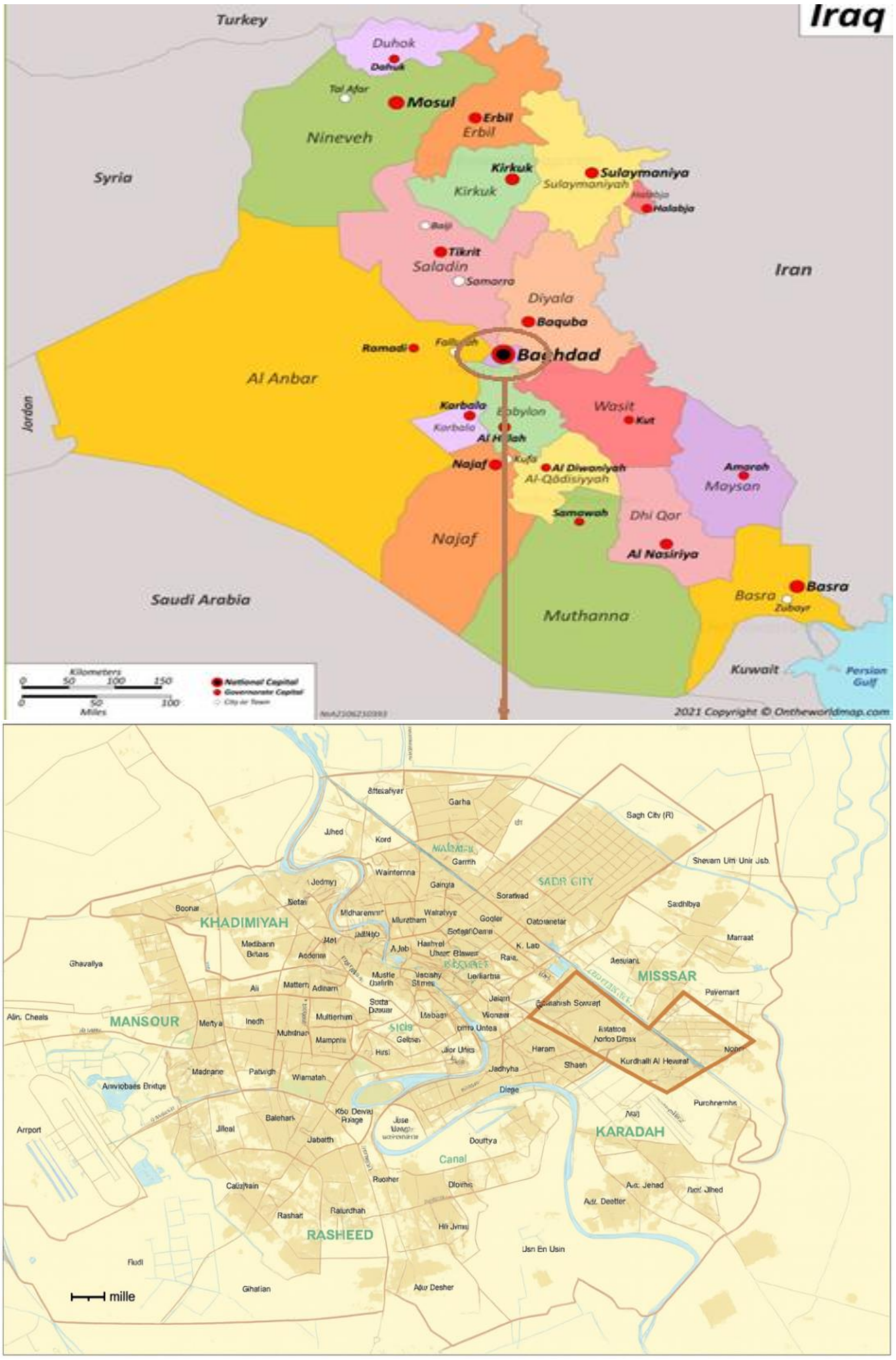

Figure 1. Map of Iraq, including study areas in Baghdad Governorate (Googlemap.com, 2024)

Table 1. Latitude and longitude of the three areas studied

Station No.	Quarter Main	Location	Altitude	Latitude
1	Baghdad Al-Jadeda	South East	33° 30' 52" N	44° 48' 71" E
2	Al-Mashtal	South East	33° 31' 78" N	44° 49' 70" E
3	Zayouna	South East	33° 32' 16" N	44° 45' 68" E

2.2 Sample collection

Dust was collected using polyethylene buckets (15 cm diameter × 30 cm height) suspended three meters above ground for thirty days in dry, stable weather. After exposure, buckets were retrieved, and accumulated dust was weighed to determine deposition rates following standard dust fall collection protocols [22]. Six replicates per street were made for the collection. The dust samples were stored in strong boxes and transported to the Department of Earth Sciences, College of Science, University of Baghdad. The analyses of the collected dust samples were carried out in the German-Iraqi laboratory, where the concentration of lead (Pb), arsenic (As), iron (Fe), and molybdenum (Mo), as well as sulfur trioxide (SO_4) and phosphorus pentoxide (P_2O_5), were determined. The percentage of organic matter in the samples and the pH were also estimated.

2.3 Methodology

2.3.1 Determination of falling dust concentration

The buckets for sample collection were collected one month after they were suspended and brought to the laboratory [22]. Eq. (1) was used to determine the total amount of dust that fell (TDF).

$$TDF = \frac{(W_2 - W_1)}{A} \quad (1)$$

where W_1 is the bucket weight before collecting dust while empty, W_2 is the bucket weight after collection, and A is the area of the base of the circular bucket that was extracted according to Eq. (2).

$$A = R^2 \times \pi \quad (2)$$

where π is 3.14, and R is the bucket base radius.

2.3.2 Determination of heavy metal concentrations

In the current research, 54 carefully chosen samples were collected and analyzed for heavy elements from the areas under study. Five grams of samples were taken from each of the areas analyzed. To achieve high analysis accuracy, the device employed received samples in the form of powder, which was compressed and turned into a tablet using a special piston and five tons of pressure. The goal was to identify the oxides associated with the heavy elements of dust particles and analyze their components by dropping the rays on the samples. To perform these analyses, the X-ray fluorescence (XRF) Spectro-2010 (Germany) instrument was utilized.

2.3.3 Estimation of organic matter

The method described by Carver [23] was used to determine the organic matter present in the samples. After one gram of the sample was taken, it was reacted with 30% hydrogen peroxide for a full day while being constantly stirred. The sample was then cleaned with distilled water, dried in a drying oven, and finally weighed precisely. The amount of organic matter is represented by the weight difference, and the percentage of organic matter was then determined by applying the percentage law.

2.3.4 Determination of the sample pH

The pH of each dust sample was measured using a digital pH meter (Hanna HI 2211). A 1:5 dust-to-distilled-water suspension was prepared by mixing 5 g of dust with 25 mL of distilled water and stirring for 30 minutes. The mixture was allowed to settle for 15 minutes before immersing the electrode to record pH values at room temperature (25 ± 1°C).

2.3.5 Pollution assessment indices

To assess the degree of heavy metal contamination, pollution indices were calculated, including the geoaccumulation index (Igeo), enrichment factor (EF), and pollution factor (CF).

The geoaccumulation index (Igeo) was computed as:

$$Igeo = log_2 (C_n \ / \ \left(1.5 \times B_n\right) \quad (3)$$

where C_n is the measured concentration of metal n in the sample and B_n is the background concentration (average shale value or crustal abundance).

The enrichment factor (EF) helps to distinguish anthropogenic sources:

$$EF = \left(C_n \ / \ C_{ref}\right) \div \left(B_n \ / \ B_{ref}\right) \quad (4)$$

where C_{ref} and B_{ref} reference element concentrations (commonly Fe or Al).

The pollution factor (CF) evaluates contamination levels:

$$CF = C_n \ / \ B_n \quad (5)$$

Interpretation of these indices followed the classifications of Muller [24] and Hakanson [25], where values indicate contamination degrees from unpolluted to extremely polluted conditions.

2.4 Statistical analysis

Data were statistically analyzed using the one-way analysis of variance (ANOVA) and the Pearson Chi-square (χ^2) analysis with the IBM Statistical Package for the Social Sciences (SPSS, version 24). The standard error values, correlation coefficient, rates, and ranges were also computed. Statistical significance was determined at probability levels of $p \leq 0.05$ and $p \leq 0.001$. Graphs were generated using Microsoft Excel 2016 (Microsoft Corporation, Berkshire, UK).

3. RESULTS AND DISCUSSION

The results showed clear spatial variations among the sites, with Zayouna recording the highest Pb and Mo levels, Baghdad Al-Jadeda showing the highest Fe, and Al-Mashtal exhibiting elevated SO_3 and P_2O_5. Organic matter was highest in Zayouna (Station 3), while all stations had alkaline pH values. Most parameters differed significantly ($p \leq 0.05$), except for pH, which showed no significant variation (Table 2).

Table 2. Concentrations of selected heavy metals, major oxides, organic matter, and pH in dust samples collected from different sites in Baghdad

Station No.	Pb	As	Fe	Mo	SO_3	P_2O_5	Mo	pH
	mean ± standard deviation							
1	24.73±10.96	5.27±0.15	21456.67±9715.44	14.03±4.00	25686.67±7365.41	871.00±117.93	1.733±0.51	10.00±0.50
2	45.97±20.01	5.73±1.32	1626.75±939.20	11.87±5.05	30950.00±8247.66	1162.33±192.31	1.28±0.35	9.50±0.50
3	50.17±38.69	3.40±1.71	19513.33±5084.84	15.87±3.10	20456.67±6474.46	993.00±107.70	2.133±0.34	9.67±0.29
P-value	0.001*	0.001*	0.05*	0.001*	0.001*	0.001*	0.05*	0.09**

*Significant differences at $p \leq 0.05$
** Non-significant differences at $p > 0.05$

3.1 Heavy metal contents of dust from the study areas

The results in Figure 2(a) indicated that the lead content of the accumulated dust ranged from 12.6 to 93.5 parts per million, with the main street in Zayouna having the highest lead percentage and the residential street in Baghdad Al-Jadeda having the lowest. The total rate of 40.29 parts per million was found in the dust accumulation. In general, the New Baghdad area was less recorded for this element compared to the Zayouna and Al-Mashtal areas, with a significant difference below the $p \leq 0.001$ probability level. As illustrated in Figure 2(b), the results show that the percentage of arsenic varied from 1.5 to 6.9 parts per million, with a total rate of 4.8 parts per million. The main street in Zayouna had the highest percentage, while the residential street in Baghdad Al-Jadeda had the lowest. There was a significant difference below the $p \leq 0.001$ probability level between the Zayouna area and the Baghdad Al-Jadeda and Al-Mashtal areas, with the former recording less of this metal overall. Iron concentrations ranged from 12810 to 31970 parts per million, with a total rate of 20860 parts per million. The highest percentage was found in the Baghdad Al-Jadeda area's main street, while the lowest percentage was found in the same area but in a residential street (Figure 2(c)). The statistical analysis's results indicate that, at the $p \leq 0.05$ level of probability, the Al-Mashtal area had the lowest percentage of this element when compared to the other two areas. According to Figure 2(d), the concentration of molybdenum ranged between 6.7 and 19.92 parts per million, with the highest percentage found in the Zayouna area's main street and the lowest in the Al-Mashtal area's residential street. The results of the statistical analysis revealed that the Al-Mashtal area had the lowest percentage of this element when compared to the other two areas, and at the level of probability $p \leq 0.001$.

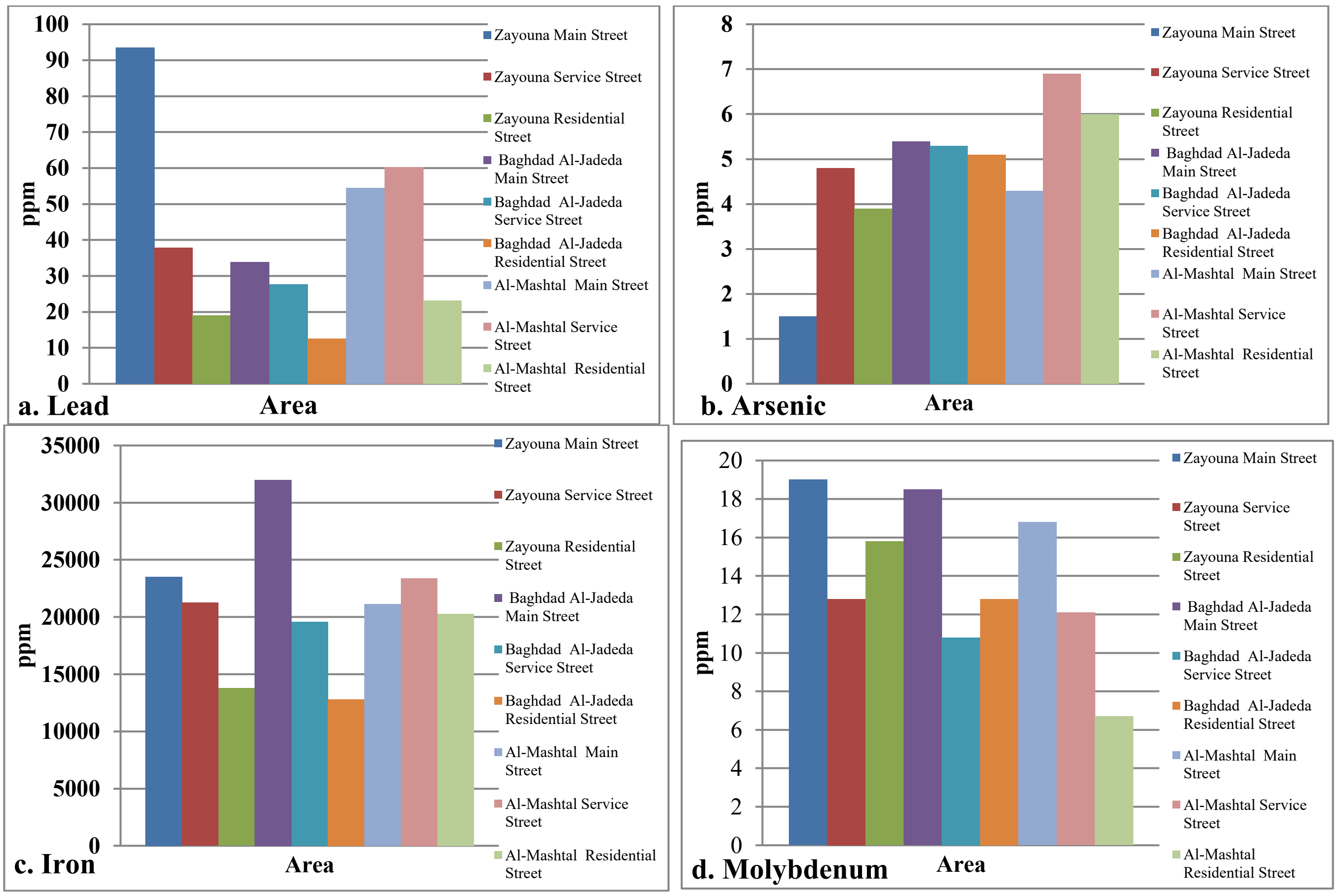

Figure 2. The concentration of different metals in the dust across the three study areas: (a) lead, (b) arsenic, (c) iron, (d) molybdenum

3.2 Oxide contents of dust deposits from the study locations

According to Figure 3(a), the concentration of sulfur trioxide (SO_3) was between 13350 and 40450 parts per million, with a total rate of 25697.78 parts per million. The highest percentage of this compound was found in the Al-Mashtal area's service street, while the lowest percentage was found in the Zayouna area's residential street. The statistical analysis revealed that the Zayouna area had the lowest percentage of this compound when compared to the other two areas, and at the level of probability $p \leq 0.001$. The percentage of phosphorus pentoxide varied from 735 to 1364 parts per million, with a total rate of 1008.78 parts per million. The highest percentages were found in the service street in the Al-Mashtal area of Baghdad, while the lowest percentage was found in the residential street in the Al-Jadeda area (Figure 3(b)). This element was generally less common in the Baghdad Al-Jadeda area than in the Zayouna and Al-Mashtal areas, with a significant difference below the $p \leq 0.001$ probability level.

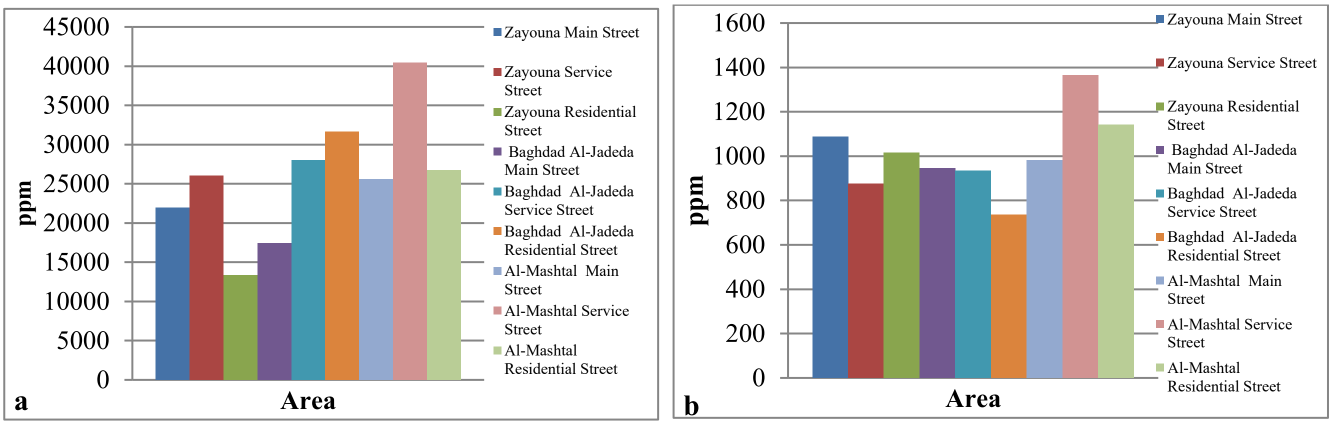

Figure 3. Oxide concentrations in the dust across the three study areas: (a) sulfur trioxide, (b) phosphorus pentoxide

3.3 Organic matter composition of dust across the study areas

Figure 4 shows that the percentages of organic materials in the street dust samples for the study areas are nearly identical, ranging from 0.98 to 2.30 at a rate of 1.72. The highest percentage was found in the residential street of Baghdad Al-Jadeda and the Zayouna areas of the service street, while the lowest percentage was found in the Al-Mashtal area. Overall, the Al-Mashtal region had a much lower percentage of this metal, below the $p \leq 0.05$ probability level.

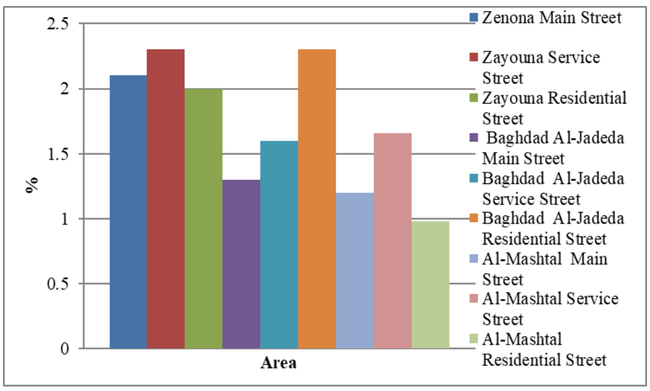

Figure 4. Concentration of organic matter in the dust in the streets across the three study areas

3.4 pH of accumulated dust across the study areas

The results of Figure 5 make it evident that the average pH of the accumulated dust in the areas under study was 9.72, with values ranging from 9.5 to 10.5. The main street in the Baghdad Al-Jadeda area had the highest pH value, while the Al-Mashtal service street had the lowest. Overall, the pH values in the Baghdad Al-Jadeda area were higher than those in the other areas, which ranged closely from strongly alkaline to extremely alkaline. The differences for this factor were not significant in the three areas below the probability level $p > 0.05$.

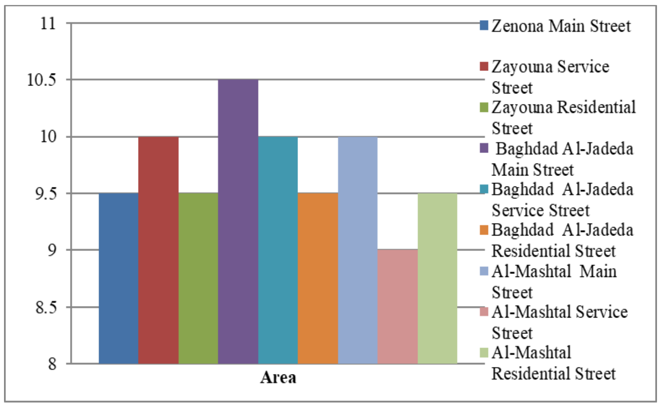

Figure 5. pH values of the accumulated dust across the streets of the three study areas

3.5 Correlation trends among elements

Lead and arsenic have an average negative correlation ($r = -0.521$). The elements sulfur trioxide and molybdenum have an average negative correlation ($r = -0.516$), sulfur trioxide and pH have an average negative correlation ($r = -0.518$), and the elements sulfur trioxide and phosphorus pentoxide have an average positive correlation ($r = 0.561$), indicating an inverse relationship (Table 3).

Table 3. Pearson's correlation coefficient for heavy elements, oxides, and some factors in the three study sites

Metals	Pb	As	Fe	Mo	SO_3	P_2O_5	OM	pH
Pb	1							
As	-0.521	1						
Fe	0.457	0.084	1					
Mo	0.499	-0.652	0.357	1				
SO_3	0.125	0.561	-0.078	-0.516	1			
P_2O_5	0.492	0.228	0.315	-0.155	0.331	1		
OM	0.052	-0.404	-0.445	0.230	0.010	-0.393	1	
pH	-0.187	-0.084	0.479	0.343	-0.518	-0.573	-0.239	1

This study identified six major heavy metals (lead, arsenic, iron, molybdenum, sulphur trioxide, and phosphorus pentoxide) that affect humans, animals, plants, and the environment. While natural sources such as wind and dust storms contribute to their occurrence, anthropogenic activities such as fuel combustion, vehicle emissions, construction waste, and building materials play an important role in urban dust pollution and have an impact on human health and ecosystems [26].

In Baghdad Al-Jadeda, the accumulation of metals such as lead and iron can be attributed to the proximity of waste incinerators, industrial sheds, and the incineration of waste containing lead-based materials commonly used in welding, painting, glass, and plastic manufacturing [27, 28]. The dense urban environment with tall buildings and shopping centres further restricts air circulation and allows the accumulation of pollutants, which increases local pollution. In Zayouna, the high concentration of metals such as molybdenum and lead is likely due to heavy traffic, minor industrial activities, and the local accumulation of organic waste from residential areas. In Al-Mashtal, there is evidence of anthropogenic phosphorus input, which can be linked to urban horticulture, fertiliser application, and landscaping on the central islands. These site-specific sources of pollution explain the spatial differences observed in the study areas and emphasise the importance of relating pollution levels to local activities and not just general sources [29-31].

Arsenic is mainly derived from sulphide ores in the earth's crust, but its mobilisation and accumulation in urban dust is enhanced by agricultural activities, emissions from fossil fuel combustion, and ash dispersion [32, 33]. Chronic exposure through ingestion or dermal contact can lead to serious health effects, including skin and lung cancer and kidney inflammation [34]. The results are consistent with previous studies by Sultan et al. [30] and Atiya and Abed [31], which demonstrate the persistence of arsenic in the urban environment.

Iron is an essential metal for human health, which enters haemoglobin and other physiological systems. However, its accumulation in dust is largely influenced by industrial emissions, vehicle activities, and resuspension of soil and sand particles. This study shows a localised increase in iron in Baghdad Al-Jadeda and Zayouna, in contrast to previous reports that showed no significant increase in these areas [30].

Molybdenum pollution is primarily associated with human activities, including chemical weathering of rocks, fertiliser application, and waste disposal [35]. The accumulation of molybdenum in urban dust, particularly in Zayouna, indicates the influence of both agricultural and residential inputs. The consistency of these findings with those of Al-Ameen [29] and Atiya and Abed [31] emphasises that Baghdad dust represents a mixture of natural and anthropogenic sources associated with environmental and health risks such as renal dysfunction, stunted growth, and gastrointestinal problems [36].

Sulphur trioxide and phosphorus pentoxide are products of combustion and agricultural activities, respectively. In Al-Mashtal, sulphur oxides from generators and local waste incineration probably contribute to atmospheric SO_3, while phosphorus compounds from fertilisers and manure play a major role in urban green spaces [37-42]. These compounds can be precursors of acid rain, cause respiratory problems, and damage property and plants.

Organic matter, especially in Zayouna, plays a key role in the adsorption of metals and their stabilisation in soils and sediments due to the contribution of urban vegetation and decomposed plant residues [43-45]. The pH was highly alkaline at all sites studied, which favours the deposition of metals in the form of oxides, hydroxides, phosphates, and carbonates, thus limiting their mobility, while they can accumulate in road dust [46-50].

Overall, the study shows that the distribution of heavy metals and oxides in the dust of Baghdad is very site-specific and reflects the combined influence of natural processes and local human activities. The results emphasise the need for targeted monitoring and management strategies that take into account both the sources and the spatial variability of urban contamination.

The concentrations of Pb, As, and Fe in the street dust samples exceeded the World Health Organization [3] and USEPA [51] permissible limits for soil and dust contamination (Pb: 50 ppm, As: 5 ppm, Fe: 20,000 ppm). These exceedances indicate moderate to strong contamination, especially in the Zayouna and Al-Mashtal districts, where urban traffic and industrial emissions are dominant. According to the ECC [52] Directive 86/278/EEC, the observed lead and arsenic levels also surpass the safe limits for urban soils, suggesting a potential health risk from prolonged exposure.

Table 4. Pollution assessment indices (CF, Igeo, EF) of selected metals in accumulated dust from East Baghdad

Metal	Background (ppm)*	Range (ppm)	CF	Igeo	EF	Pollution Level
Pb	20	12.6–93.5	0.6–4.7	0.7–1.6	3–12	Moderate–Considerable
As	1.5	1.5–6.9	1.0–4.6	0.0–1.6	2–5	Low–Moderate
Fe	47,000	12,810–31,970	0.27–0.68	<0	≈ 1	Natural
Mo	2	6.7–19.9	3.4–10.0	1.1–2.7	6–15	Moderate–High

*Background concentrations from Turekian and Wedepohl [53].

3.6 Pollution indices assessment

To better quantify the degree of contamination and identify potential anthropogenic sources, three standard pollution indices, contamination factor (CF), geoaccumulation index (Igeo), and enrichment factor (EF), were calculated for the analyzed metals. Calculations were based on global average shale background values proposed by Turekian and Wedepohl [53]. The results are summarized in Table 4.

The CF values of Pb (0.6-4.7) and Mo (3.4-10.0) indicated moderate to considerable contamination, particularly in Zayouna and Al-Mashtal. Arsenic showed low to moderate contamination (CF = 1.0-4.6), while Fe exhibited CF values below 1, suggesting a natural crustal origin.

The Igeo values revealed that Pb and Mo were within the moderately contaminated class (Igeo ≈ 1-2), while Fe and As mostly fell into the uncontaminated to slightly contaminated range (Igeo < 1).

Enrichment factors further distinguished the sources: Pb (EF = 3-12) and Mo (EF = 6-15) showed significant enrichment, confirming anthropogenic influence from vehicular emissions, industrial waste, and fuel combustion. In contrast, Fe (EF ≈ 1) remained within the natural background range.

Overall, the pollution indices demonstrate that heavy metals in the studied dust are derived mainly from human activities, particularly in high-traffic and industrialized areas, whereas Fe largely reflects lithogenic inputs.

4. CONCLUSION

This study demonstrated that accumulated dust in East Baghdad is contaminated with heavy metals and oxides at concerning levels. Lead (12.6-93.5 ppm) and iron (12,810-31,970 ppm) were the most severely elevated elements, while arsenic and molybdenum also exceeded safe limits. Oxides such as sulfur trioxide (13,350-40,450 ppm) and phosphorus pentoxide (735-1,364 ppm) were notably high, reflecting contributions from vehicular emissions, fuel combustion, industrial activities, and waste burning. Organic matter content was generally low, whereas pH values (9.5-10.5) indicated strong alkalinity, influencing pollutant stability. The study was limited by short sampling duration, restricted geographic coverage, and reliance on a single analytical technique. Future research should expand monitoring, apply multi-analytical approaches, and assess ecological and health risks to guide pollution mitigation strategies in urban environments. The present study recommends implementing stricter emission controls, regulating waste burning, increasing green spaces, monitoring dust regularly, and raising community awareness to reduce pollution exposure.

Pollution indices (CF, EF, and Igeo) confirmed moderate to high enrichment of Pb and Mo, suggesting dominant anthropogenic inputs from traffic, fuel combustion, and waste burning, while Fe showed natural background levels.

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