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Assessment of Indoor and Outdoor Heavy Metal Contamination from Dust Storms: A Case Study in Residential Areas of Anbar Governorate, Iraq

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ABSTRACT

This research examines the concentrations of heavy metals in dust collected from indoor and outdoor environmental settings in selected residential areas of Anbar Governorate, Iraq. The metals investigated are iron (Fe), manganese (Mn), Zinc (Zn), Lead (Pb) and Copper (Cu). The metal concentrations in dust samples were determined and the level of environmental risk was measured using the Geo-accumulation Index (Igeo), Enrichment Factor (EF) and Contamination Factor (CF). The outcomes of the study reveal that Fe and Mn pollution levels are higher than the acceptable standards while the environmental impacts are relatively low owing to natural element occurrences. Zn and Pb, however, exhibited moderate to high contamination, particularly in indoor environments, with Pb concentrations far exceeding WHO and USEPA permissible limits, indicating a significant health risk. Cu contamination was minimal across all sites. The study underscores the importance of mitigation efforts, particularly for Pb and Zn, to reduce exposure risks in residential areas. It suggests that one should practice systematic surveillance and specific actions to control the levels of heavy metals, especially indoors.

1. INTRODUCTION

Over the past few decades, the environment of countries, especially Iraq in the Middle East, has been threatened and this is evidenced by the increase in sand and dust storms which are hazardous to human health as well as to the ecosystem. These dust storms are associated with heavy metals, which are released by different anthropogenic processes like petroleum refining, power generation, automobile fumes, and construction activities in cities. Because of traffic-related emissions, pollutants such as lead (Pb), zinc (Zn), manganese (Mn), iron (Fe) and copper (Cu) can stick to dust particles and be redeposited far away from the source thus posing human health risks through inhalation, ingestion and skin contact. This exposure is associated with a number of chronic health diseases like respiratory diseases, cardiovascular diseases and diseases of the neurological system [1, 2].

The consequences of exposure to toxic heavy metals transported by dust storms have been discussed extensively with respect to their impact on health [3]. It has earlier been established that exposure to metal-laden dust is a cause of higher incidence of asthma, bronchitis, lung cancer and other respiratory ailments. For instance, Mediterranean countries have been experiencing a higher incidence of asthma since the 1970s, especially where dust storms have become more frequent and more intense [4].

Because Iraq is near several desert zones such as the Sahara Desert, the Arabian Peninsula's drylands, Syria, and Jordan, it experiences a relatively high number of dust storms. The Iraqi Ministry of Environment has said that there is likely to be an increase in the number of dust storms in the country within the next ten years due to ongoing environmental degradation and desertification. These storms occur mainly in the central and southern parts of Iraq but spread their impacts to the countries around Iraq, for instance, Kuwait, Saudi Arabia and even parts of Iran [5, 6].

It is, therefore, important to promote research on the distribution and density of heavy metals in dust storms to come up with the best strategies to reduce them. Earlier research shows that the level of contamination is affected by factors such as the size of the dust particles, time of exposure and type of metals [7-10]. Recent studies involve analysis of various cities around the globe for the presence of urban dust and showed that there are considerable concentrations of Cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) which are mainly due to industrial sites [11-15].

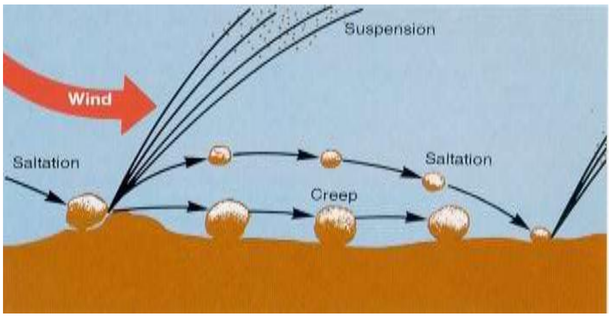

Figure 1. Wind-driven soil particle transport: Saltation, creep, and suspension [16]

Crawling, jumping and suspension are how dust is transported, which depend on wind speed and the size of the associated particles (see Figure 1) [16]. At higher wind speeds, the dust particles are lifted up and transported to great distances before they fall and deposit on the surfaces in residential areas. It is, therefore, very important to determine the sources and intensity of these heavy metals in order to manage the health issues arising from dust storm incidents.

This study, therefore, seeks to analyze the elevated levels and the origin of the heavy metal concentration in the dust storms within some of the residential areas in Anbar Governorate, Iraq [17]. Also, the goal of this study is to fill critical information gaps related to the environment and health effects of dust storms and the indoor air quality of residents in circulating dust storms, where indoor air quality is often neglected. Despite much research into heavy metal contamination in the outdoor environment, dust storm interactions with indoor contamination have been little studied. This study, focusing on Anbar Governorate, not only records contamination levels but also proposes strategies for disaster mitigation and policy making. These gaps need bridging and there is an urgent demand for monitoring and mitigation measures.

The specific objectives are: (i) identifying the distribution of the heavy metal concentrations in the dust samples collected from inside and outside homes; and (ii) assess the contamination levels by using pollution indices such as the Enrichment factor (EF), Contamination factor (CF), and Geo-accumulation index (Igeo). These indices have been extensively used in environmental studies to estimate pollution severity and to determine anthropogenic influence. Due to their ability to identify whether natural or anthropogenic factors contribute to heavy metal levels, this application helps in dust storm studies. The outcomes are important in establishing an understanding of the impact of dust storms on the environment in Iraq and the possibilities of minimizing the threat of heavy metal exposure to human beings.

2. MATERIALS AND METHODS

2.1 Location of the study site

This research was accomplished in the western part of Iraq in Anbar Governorate, which is always exposed to sand and dust storms. The research focused on four cities: Khalidiyah, Ramadi, and Hit. As depicted in Figure 2, this sampling was carried out in three areas in Fallujah, two in Khalidiyah, three in Ramadi and two in Hit. Based on this distance we chose the cities as these are closest to industrial and urban cities which are believed to be the main emitters of heavy metal contaminates in the surrounding environment.

Figure 2. Geographic distribution of sampling points in the study area

The region is hot and dry generally during summers when temperatures can beat 50 degrees Celsius in July and August. Regarding the temperatures in the winter season, it is usually between 1°C to 11°C including the months between November, December and February. Sand and dust storms are most prevalent during the spring months of March and April, when strong winds carry dust particles over vast distances. These storms significantly reduce visibility as dust plumes rise to thousands of meters in the atmosphere.

The predominant winds in the region blow from the north and northwest, carrying dust across Iraq and extending into neighboring countries such as Kuwait, Qatar, the United Arab Emirates, and Bahrain. Another wind pattern, known as the Sharqi, originates from the southern Arabian Gulf and is characterized by dry conditions [18, 19]. Both wind systems contribute to the transportation of dust and heavy metals, depositing them in residential and urban areas across Iraq.

2.2 Sampling collection and analysis

Dust samples were collected from ten residential locations across Anbar Governorate, as illustrated in Figure 2 and detailed in Table 1. Each site involved duplicate sampling, with dust collected from both inside and outside the same house. The study was conducted between March and June 2024, during which four significant dust storms were observed and monitored. Sampling was carried out in both spring and summer seasons to capture the seasonal variations in dust accumulation.

Table 1. Locations of samples of residential areas

Sambol Region	Sambol No.	Symbol Site	Latitude (N)	Longitude (E)
AL-Fallujah	1	FPO1 FPI1	33.34848	43.76149
	2	FPO2 FPI2	33.35397	43.78912
	3	FPO3 FPI3	33.35689	43.81112
AL-Khalidiyah	1	KHPO1 KHPI1	33.41745	43.44774
	2	KHPO2 KHPI2	33.40764	43.45079
AL-Ramadi	1	RPO1 RPI1	33.44950	43.28171
	2	RPO2 RPI2	33.43368	43.31938
	3	RPO3 RPI3	33.43644	43.27871
Hit	1	HPO1 HPI1	33.63922	42.80963
	2	HPO2 HPI2	33.63924	42.81253

Samples were collected using brushes and sweeping techniques, with two distinct conditions for collection:

Outside sampling: Dust was collected from rooftops to assess the concentration of chemical elements deposited from dust storms.

Inside sampling: Samples of indoor dust were taken from surfaces free of potential indoor contaminants such as kitchens or areas where cigarette smoke or perfumes were emitted.

At all sites, a standardized data collection form was used to record details including site name, storm time, average temperature, humidity, wind speed, wind direction and visibility during the storm to provide consistency. The small plastic containers (beakers) that contained the dust samples were then sent to the laboratory for analysis.

There were seasonal variations in the concentration of heavy metals with higher concentrations observed during spring (corresponding to high dust storm activities) and with lower concentrations occurring in summer when the frequency of storms was lower and the wind patterns changed. Four major dust storms in Iraq occurred between March and July 2024, during which sampling was conducted. Aluminum sheets dust collection barriers were mounted on the rooftops and indoors, avoiding interference with the surrounding environment and indoor use. The barriers accumulated dust naturally and deposited significantly after storms. The barriers were reinstalled between samplings, after which the dust collected each time was carefully brushed into beakers for analysis.

An appropriate timeframe for this was chosen based on the fact that dust storms reached their height in the spring and early summer, caused by temperature changes and wind erosion. The dynamic conditions, therefore, necessitate continuous monitoring of heavy metal pollution. In total, 20 samples were collected—10 from outside and 10 from inside residential areas. In cities such as Fallujah and Ramadi, three sites were sampled, while in other districts like Khalidiyah and Hit, two sites were selected. Each sample was given a label depending on its position, outside samples were coded as 0 while inside samples were coded as I. Twenty samples for 10 residential locations were selected to ensure geographic representation and to capture variability within the study area. Logistical feasibility and statistical adequacy were considered in determining the sample size for heavy metal concentrations. Although the number of samples might not cover all of Anbar Governorate, they do cover important residential zones that were affected by dust storms, thereby allowing us to assess the trends of contamination of air at these zones.

Sampling in unoccupied rooms and with minimal activity during collection was conducted to minimize the influence of indoor variables. To minimise variability, the selection was made of the rooms that were uniform in building material and furniture. To ensure consistent conditions across sites, residents were instructed to avoid the use of heating, ventilation, or air conditioning systems during sampling periods. The environment was also assessed for potential indoor pollution sources (such as the number of occupants, the use of pesticides and other potential pollutants) to avoid these sources as well. For each site, a form was completed with the site name, temperature, and humidity. Within each site, sampling locations were carefully chosen to avoid these influences.

In the laboratory, the samples were prepared for chemical analysis using atomic absorption spectroscopy (AAS) to determine the concentration of the heavy metals which includes iron (Fe), manganese (Mn), zinc (Zn), lead (Pb) and copper (Cu).

2.3 Chemical analysis and examination of samples

After collecting 20 dust samples from indoor and outdoor sources in Anbar Governorate each dust sample was prepared for chemical analysis to predict the concentration of the heavy metals. Each dust sample was initially weighed for 20 grams in order to conduct the analysis.

Preparing the samples involved digesting 1 gram of dust with a mixture of concentrated mineral acids. Solution containing 10 ml concentrated sulfuric acid (H_2SO_4), 3 ml concentrated hydrochloric acid (HCl) and 3 ml concentrated nitric acid (HNO_3). The samples of dust were gradually heated while their digestions took place in an acid mixture. First, the temperature was set at 120°Cfor 20 minutes and followed by 320°Cfor 60 minutes. When the solution had a white colour the process of digestion was complete and a process of sedimentation and formation of organic compounds with heavy metals was released to the solution.

To eliminate the remaining cells, the solution was filtered by the standard filter paper and then filled up to 50 mL using distilled water. This solution was then used for the analysis of heavy metals, such as iron (Fe), manganese (Mn), zinc (Zn), lead (Pb) and copper (Cu).

The quantities of these metals were thereafter determined using an Atomic Absorption Spectrophotometer (AAS) made in Australia. The AAS gave a quantitative measure of the concentration of heavy metal in each sample, making it convenient to determine the level of contamination in the different residential areas.

2.4 Assessment of metal contamination

To assess the extent of heavy metal contamination in the residential areas studied, three key parameters were employed: the Enrichment Factor (EF), Contamination Factor (CF), and Geographical Accumulation Index (Igeo). These indices offer a systematic assessment of natural and human-facilitated aspects of metal levels and aid in identifying the potential threat of dust storms in delivering hazardous heavy metals to residential districts.

2.4.1 Enrichment Factor (EF)

The Enrichment Factor (EF) is one of the most convenient methods to evaluate the impact of toxic elements, specifically heavy metals, on the environment [20]. It aids in determining whether the concentration of a specific metal in the dust is a result of natural occurrences or human intervention. The EF is calculated as the ratio of concentration of a specific metal to the concentration of the reference metal, which is iron (Fe), considering that this metal occurs naturally and is common in the Earth's crust [21, 22]. This method helps to separate the natural as well as anthropogenic influences on the metal concentrations.

The EF for each metal in the dust samples was calculated using the following formula, as proposed by Martin and Meybeck [23]:

$$EF = \frac{\left(\frac{Me}{Fe}\right)_{sample}}{\left(\frac{Me}{Fe}\right)_{backround}} \tag{1}$$

where, $\left(\frac{Me}{Fe}\right)_{sample}$ is the ratio of the concentration of the metal of interest to the concentration of iron in the sample, and $\left(\frac{Me}{Fe}\right)_{backround}$ is the ratio of the metal to iron in the natural background, which was sourced from global surface rock averages in this study due to the absence of localized background values.

Iron (Fe) was selected as the normalization element because natural sources dominate its input (1.5% of the Earth's crust) and it is less influenced by anthropogenic activities [24]. The

EF provides a quantitative measure of the extent of metal enrichment, which is categorized into different levels, as shown in Table 2. These categories range from deficiency to minimal enrichment, indicating natural contributions, to extremely high enrichment, suggesting significant anthropogenic impact.

Table 2. Enrichment factor categories [25]

Enrichment Factor (EF)	Enrichment Factor (EF) Categories
EF < 2	Deficiency to minimal enrichment
2 ≤ EF < 5	Moderate enrichment
5 ≤ EF < 20	Significant enrichment
20 ≤ EF < 40	Very high enrichment
EF ≥ 40	Extremely high enrichment

These categories allow for the classification of metals based on their likely sources, where higher EF values typically indicate a significant influence from human activities, while lower values suggest a predominantly natural origin.

2.4.2 Contamination Factor (CF)

CF is a quantitative measure applied to determine the extent of contamination of individual metals in dust samples. It is used to compare the density of a particular metal in the chosen sample with the density of that same metal of the background level that was not contaminated with industrial activity and offers information on how polluted the level currently is.

The CF is calculated using the following formula:

$$CF = \frac{(C_m)_{sample}}{(C_m)_{backround}} \tag{2}$$

where, $(C_m)_{sample}$ is the concentration of the metal (Me) in the dust sample, and $(C_m)_{backround}$ is the background concentration of the metal. Since there is no locally available baseline data for the area of study, the $(C_m)_{backround}$ is, obtained from global surface rock averages [23].

Table 3 shows the CF levels that are divided into several levels characterizing the degree of contamination.

Table 3. Contamination factor and contamination level [16]

Contamination Factor (CF)	Contamination Level
CF < 1	Low contamination
1 ≤ CF < 3	Moderate contamination
3 ≤ CF < 6	Considerable contamination
CF ≥ 6	Very high contamination

This classification system enables the recognition of the areas and metals that are most affected by pollution [26]. If the CF value is higher than 1, the concentration of the metal also arises beyond the natural level, which has anthropogenic causes for contamination. The calculated values of the CF higher than 6 are defined as severe levels of contamination, which can cause threats to both the environment and health.

2.4.3 Geo-accumulation Index (Igeo)

The Geo-accumulation Index (Igeo) is one of the common techniques for measuring the level of heavy metal pollution in dust samples based on a comparison of current concentrations to pre-industrial background levels [27]. The Igeo can also be used for categorizing the pollution intensity and identifying the metal contamination in the environment.

The Igeo is computed by the formula as estimated by Müller [27]:

$$I_{geo} = \log_2\left[\frac{(C_m)_{sample}}{1.5 \times (C_m)_{backround}}\right] \tag{3}$$

where, $(C_m)_{sample}$ is the measured concentration of the metal (Me) in the dust sample, and $(C_m)_{backround}$ is the geochemical background value of the metal, derived from global surface rock averages [23]. The factor 1.5 is a correction factor adopted in an attempt to quantify the possible fluctuations of the background values with the lithogenic effects in the background.

The Igeo classification system proposed by Müller divides [28] pollution levels into seven grades, ranging from unpolluted to extremely polluted. These classes are defined as follows (Table 4):

Table 4. Müller classification for geo-accumulation index (Igeo)

Igeo Value	Class	Sediment Quality
Igeo ≤ 0	0	Unpolluted
0 < Igeo ≤ 1	1	Unpolluted to moderately polluted
1 < Igeo ≤ 2	2	Moderately polluted
2 < Igeo ≤ 3	3	Moderately to heavily polluted
3 < Igeo ≤ 4	4	Heavily polluted
4 < Igeo ≤ 5	5	Heavily to extremely polluted
Igeo > 5	6	Extremely polluted

This index is valuable for understanding how much the current concentration of metals in dust deviates from the natural background, providing an assessment of the cumulative effects of human activities on the environment. The Igeo values for more than one element in a site can be added to give a total geo-accumulation index (Itot), which provides a better perspective on the total contamination load of the site [29-31].

2.4.4 Heavy element concentration assessment

To evaluate the magnitude of contamination of the dust samples with heavy metal content, concentrations of five major metals, iron (Fe), manganese (Mn), zinc (Zn), lead (Pb) and copper (Cu) were compared with global permissible limit and natural background levels. Hence, for risk assessment of the environmental pollution, the averages of the global rocks were taken as the reference baseline for computation of the Enrichment Factor (EF), Contamination Factor (CF), and Geo-accumulation Index (Igeo).

Table 5. Global permissible limits and global average of heavy elements and Global rock average

Heavy Metals	Global Rock Average (ppm) [23]	WHO Permissible Limits (ppm) [32]	EPA Permissible Limits (ppm) [33]
Lead (Pb)	16	---	40
Iron (Fe)	35,900	---	30
Manganese (Mn)	750	---	30
Zinc (Zn)	127	123	110
Copper (Cu)	32	25	16

The allowed ranges of these heavy metals were described by the requirements of international organizations like the World Health Organization (WHO) and the U. S Environmental Protection Agency (EPA) to decide whether the concentrations of these elements create threats to human health and the environment.

Table 5 shows the global permissible limits and background concentrations adopted in this study for comparison:

The concentration levels of these metals in the collected dust samples were compared against these values to determine the level of contamination. If the concentration of a certain metal in any of the samples taken surpassed the normative values, the possibility of damaging effects on the environment and human health was deemed high, and more evaluation using the indices of pollution described earlier was needed.

2.5 Statistical analysis of heavy metals

2.5.1 Data preparation

To evaluate the relationships between these variables, the concentrations of Fe, Mn, Zn, and Pb, were extracted from the dataset. The strength and significance of their relationships were quantified by performing pairwise comparisons using the Pearson correlation coefficient, and its associated p-values. This defines a basis on which sources and behaviors of these metals in the environment can be identified.

2.5.2 Statistical methodology

Pearson Correlation Coefficient (r): Pearson correlation coefficient indicates how much two variables are dependent on each other. The formula is used for its calculation:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 . \sum(y_i - \bar{y})^2}}$$

where, x_i and y_i are values of the two variables being compared and $\bar{x}$ and $\bar{y}$ are mean values of the variables.

The p-value is just for testing the null hypothesis (H_0) that there is no correlation between the variable ($r = 0$). For H_0 to be rejected, i.e., to say that the effect is statistically significant, we must have that $p < 0.05$.

3. RESULTS AND DISCUSSION

The concentrations of the five key heavy metals—lead (Pb), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu)—were measured both inside and outside homes across various residential locations in Anbar Governorate. The following subsections discuss the concentrations of these metals and compare indoor and outdoor levels.

3.1 Iron (Fe)

Figure 3 presents the iron concentration in Out-Home and In-Home at different places, with emphasis on USEPA allowable limit of 30 ppm. The data also shows that iron concentrations at all locations in and out of doors exceed the permissible limit by an order of magnitude. The highest outdoor concentration is found at HPO2 (6355.7 ppm) much higher than 200 times the acceptable limit which shows a serious contamination case.

At most of the locations, the outdoor concentrations are consistently higher than the indoor concentrations, indicating that the major source of iron contamination is the external dust brought by dust storms. Locations such as FPO1 (3822.5 ppm) and FPO3 (5593.4 ppm) also display elevated outdoor iron levels.

Indoor concentrations are also concerning, with locations like FPI2 (5427.0 ppm) and HPI2 (6438.4 ppm) exceeding even their respective outdoor levels in certain cases. This suggests that substantial amounts of iron-laden dust are penetrating residential homes, potentially through windows, doors, and air circulation systems.

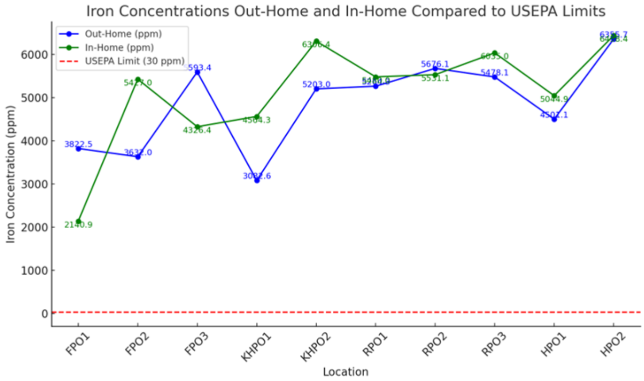

Figure 3. Iron concentrations in outdoor and indoor environments

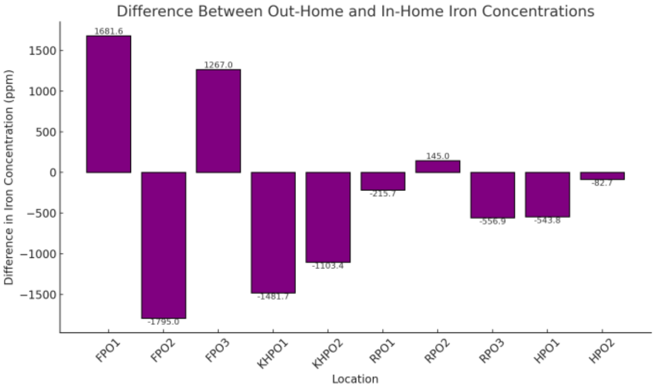

Figure 4. Differences between outdoor and indoor iron concentrations at sampling locations

Figure 4 shows the comparison between Out-Home and In-Home iron concentration. Positive values means that the concentration of the pollutant is higher outdoors while negative values point to a higher concentration indoors.

Certain places like FPO1 and FPO3 make large positive differences that show outdoor iron concentration is 1681.6 ppm more than the indoor iron concentration, and FPO3 makes 1267.0 ppm more than the indoor iron concentration. These results indicated that in these regions, the major source of iron is an external source which has probably come from industries or from transportation leading to the deposition of iron dust through storms.

Interestingly, certain locations, such as FPI2 and HPI2, show negative differences, indicating that indoor iron concentrations are higher than outdoor levels. For instance, at FPI2, the indoor concentration exceeds the outdoor level by 1795.0 ppm. This could be due to indoor sources of iron contamination, such as older infrastructure or furniture that contains iron-based materials, or dust accumulation over time that becomes trapped indoors

The elevated iron concentrations pose significant health risks, especially considering the USEPA limit is set at 30 ppm to protect public health. Chronic exposure to such high levels of iron can lead to various health issues, including respiratory problems, organ damage, and even long-term consequences such as cardiovascular and neurodegenerative diseases. Since the concentrations are especially high indoors, reducing outdoor contact should be complemented by indoor emission control and the prevention of dust from entering homes

3.2 Manganese (Mn)

Figure 5 presents the analysis of Manganese (Mn) concentrations in residential areas, comparing both outdoor (Out-Home) and indoor (In-Home) values against the USEPA permissible limit of 30 ppm. In Figure 1, all measured Mn concentrations exceed the USEPA limit, indicating significant contamination across all sample locations. The highest Mn levels are observed at FPO2, where outdoor concentrations reach 293.5 ppm and indoor concentrations 275.9 ppm, suggesting that external sources of manganese are impacting indoor air quality. Similarly, at FPO3, outdoor concentrations are 223.9 ppm, while indoor levels drop to 165.1 ppm. Although the concentration gap varies, outdoor levels tend to be higher than indoor levels across most locations, except at KHPO2, where indoor concentrations (222.7 ppm) slightly exceed outdoor concentrations (214.7 ppm).

The comparison against the Global Rock Average of 750 ppm reveals that although the concentrations in these residential areas are significantly higher than the USEPA limit, they remain lower than the global average background for manganese in natural environments. This implies that activities such as industries or transportation are also playing a role in increasing manganese concentration but they are not only responsible for contamination. This is because natural background levels can also still contribute to the contamination levels recorded.

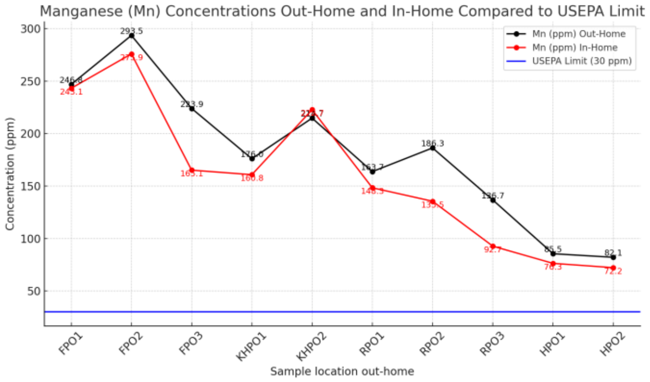

Figure 5. Manganese concentrations in outdoor and indoor environments

A comparison between the Outdoor and Indoor Mn concentrations is depicted in Figure 6. The greatest disparity is noted at FPO3, which should be the result of an increased concentration of outdoor contaminants over indoor contaminants by 58.8 ppm, suggesting the comingling of dust storms or industrial activity with contamination levels in this region. In the same manner, RPO2 of 50.8 ppm and RPO3 of 44.0 ppm display large positive differences, which may be attributed to the contributions from external sources. On the other hand, the indoor concentration of manganese in KHPO2 is 8.0 ppm higher than the outdoor concentration, which indicates that there could be indoor sources of contamination by manganese or poor ventilation in which manganese dust could be trapped.

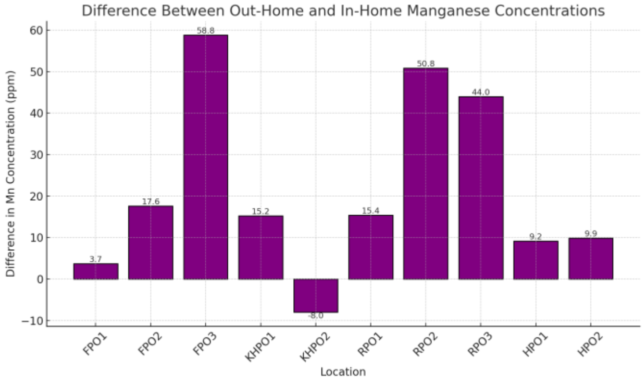

Figure 6. Differences between outdoor and indoor manganese concentrations at sampling locations

3.3 Zinc (Zn)

The concentrations of Zinc (Zn) in Out-Home and In-Home environments as well as the difference between the two are present in Figure 7. Zinc concentrations are then compared to critical benchmarks: the USEPA limit of 110 ppm, the WHO limit of 123 ppm, as well as the Global Rock Average (roughly 127 ppm).

Figure 7 shows that most zinc concentrations fall below the Global Rock Average and the WHO limit. However, significant contamination is observed at certain locations, particularly at RPO2 (528 ppm Out-Home, 312.5 ppm In-Home), which greatly exceeds both regulatory standards and natural background levels. Other locations, such as KHPO2 (223.5 ppm Out-Home, 177.5 ppm In-Home), also show concentrations well above the USEPA limit of 110 ppm and the WHO standard. The elevated levels indicate likely substantial contamination, from external sources including those involving industrial activities, traffic emissions and dust storms.

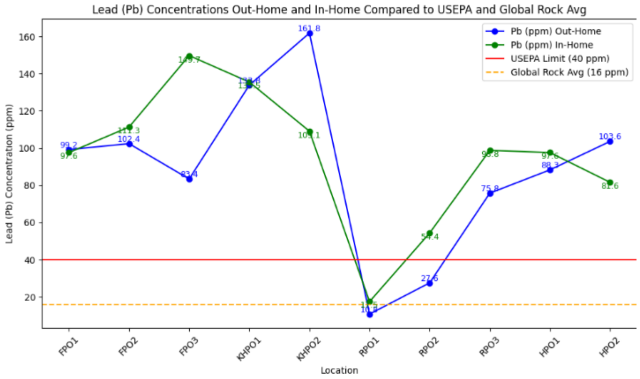

Figure 7. Zinc concentrations in outdoor and indoor environments

Interestingly, while some locations display higher outdoor concentrations, such as RPO2 and KHPO2, other areas show the reverse trend. For example, at KHPO1 and RPO1, the In-Home concentrations are higher than the outdoor levels, potentially indicating that indoor sources or poor air quality management are contributing to the elevated zinc levels indoors. Indoor highs at such places are alarming, since fluctuating high concentrations of zinc inside, especially within closed spaces, are potentially hazardous to health as they cause gastric disorders, weaken the immune defense system and lead to numerous other chronic ailments.

Figure 8 displays the amount of zinc found outdoors and indoors at each site. The highest increase is seen at RPO2 (215. 5 ppm) where outdoor concentrations of CO_2 are markedly higher than indoor ones. This indicates that outdoor sources of zinc pollution like emissions or dust are affecting the region considerably. Likewise, RPO3 (73 ppm) and KHPO2 (46 ppm) have, consequently, evidence of higher outdoor zinc concentration, which in turn indicates that outdoor pollution is contributing significantly to indoor zinc levels.

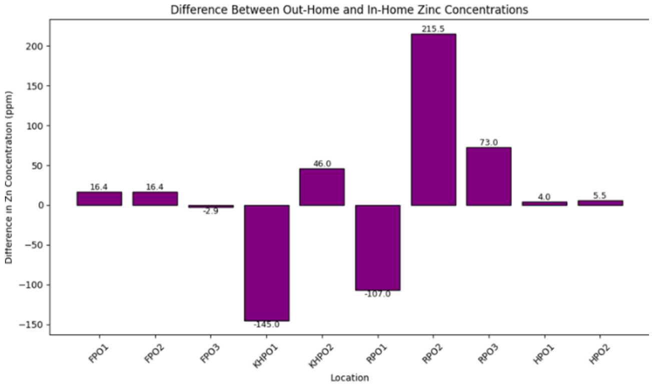

Figure 8. Differences between outdoor and indoor zinc concentrations at sampling locations

On the other hand, places such as KHPO1 and RPO1 are places that have a negative difference of 145 ppm and 107 ppm indicating that the indoor concentration of zinc was higher than the outside concentration. This reversal indicates that there could be indoor sources of zinc for example building materials, dust particles, or even poor indoor air circulation which leads to the accumulation of some compounds indoors. The negative differences highlighted the significance of indoor air quality management, especially in areas where contaminants from outdoor air are deposited within the homes.

3.4 Lead (Pb)

The Out-Home and In-Home Lead (Pb) concentrations for different places are shown in Figure 9, along with USEPA permissible limit for Pb of 40 ppm and Global Rock Average of 16 ppm.

The Pb concentrations in several sites both indoor and outdoor, are higher than the USEPA recommended limit of 40 ppm, suggesting a highly contaminated environment. More specifically, KHPO2 has an outdoor concentration of 161.8 ppm and an indoor concentration of 109.1 ppm, which is higher than either the USEPA limit or the Global Rock Average. Other areas, for instance, KHPO1, has outdoor lead level of 133.8 ppm and indoor level of 135.5 ppm while FPO2 has outdoor lead level of 102.4 ppm and indoor level of 111.3 ppm thus implying that the lead level exceed the regulatory limits and suggests a serious health concerns if people are exposed to it for a long-term.

Such areas which include RPO1 and RPO2, for instance, have relatively lower concentrations measured at 10.8 ppm for the outdoor and 27.6 ppm for the indoor, both of which are well below the USEPA limit. But still, in these areas, indoor concentrations are higher than the outdoor concentrations, implying the possibility of indoor contamination sources.

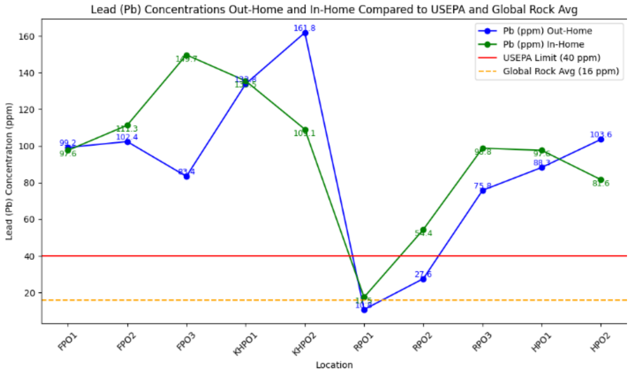

Figure 9. Lead concentrations in outdoor and indoor environments

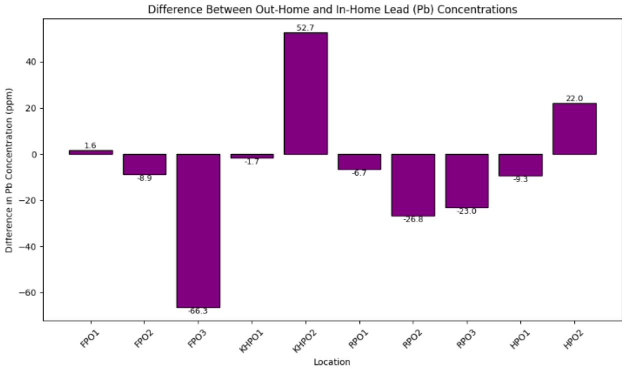

Figure 10. Differences between outdoor and indoor lead concentrations at sampling locations

With respect to the concentration of Pb, the Out-Home concentration is different from the In-Home concentration, as shown in Figure 10. Positive values indicate higher outdoor concentrations, while negative values represent higher indoor levels.

The largest negative difference is observed at FPO3, where the indoor concentration is 66.3 ppm higher than the outdoor concentration. This shows a major route of indoor lead pollution occurrence. Possible sources may include lead-based paints, older building materials, or indoor dust that picks up lead from other sources. Other areas with relatively more indoor contamination include FPO2 (-8.9 ppm) and RPO2 (-26.8 ppm) which indicates that indoor air may be affected more by lead particles in trapped or indoor sources rather than outdoor air.

The maximum positive difference is recorded in KHPO2 with 52.7 ppm of outdoor concentration being higher than that in the indoor environment. This might mean that there is a significant level of outdoor lead exposure from industrial activity, vehicle emissions, or the soil. Any attempt aimed at eliminating lead exposure at this place would have to be directed at minimizing the effects of these outside factors.

Lead exposure indoors is even more critical since people living in these structures, especially children, can be exposed to lead for years despite having low lead concentrations. More differences are observed at FPO3, FPO2 and RPO2 that revealing that indoor concentration surpasses outdoor and hence calls for some measures to address indoor pollution such as airing, eradicating lead-containing materials or dust control. On the other hand, areas such as KHPO2 indicate the importance of tackling sources of contamination outside the building. Measures that could be adopted in such areas could be the reduction of industrial effluence or the emission of traffic related air pollutants.

3.5 Copper (Cu)

Figure 11 shows the Out-Home and In-Home Cu concentration at different places with reference to the benchmark standards such as USEPA permissible limit of 16 ppm, WHO limit of 25 ppm, and Global Rock Average of 32 ppm.

The Out-Home and In-Home copper levels are lower than the USEPA, WHO limits, and the Global Rock Average. Copper is thought not to be a major problem and, therefore, has brought an idea that the concentration of copper varied from 0.1 ppm to 9.6 ppm in that area which is too low than the threshold limits.

A higher concentration relative to this calculation was measured at FPO2 and it was measured to be 9.6 ppm across Out-Home which is still below the USEPA limit of 16 ppm. Also, values for indoor concentration remain very low at all sites, and with the majority of values concentrated around 1 to 5 ppm.

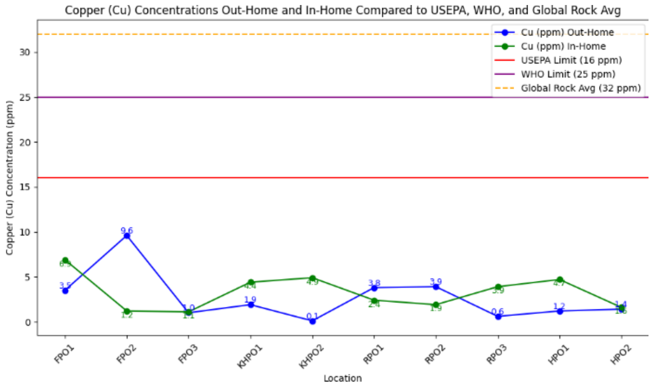

Figure 11. Copper concentrations in outdoor and indoor environments

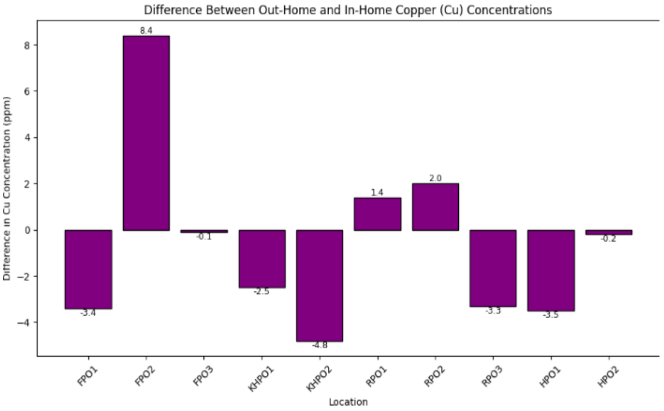

Figure 12. Differences between outdoor and indoor copper concentrations at sampling locations

Figure 12 illustrates the differences between Out-Home and In-Home Cu concentrations, showing whether outdoor levels are higher than indoor ones, or vice versa.

At FPO2, the largest positive difference was found, where Out-Home was 8.4 ppm greater than In-Home. By this reasoning, an external source of copper contamination is indicated, but it is not, at least to the same extent, contaminating indoor air quality. Outdoor sources include copper from industries, from cars on the road or dust from the wind.

The highest negative value, that is 4.8 ppm, was recorded in KHPO2 where the copper concentration indoors was higher than outdoors. This could indicate the possibility of internal sources of copper contamination like copper pipes, dust, or other factors that may lead to high copper levels within the home.

In most other areas, the differences between Out-Home and In-Home concentrations were not significant. For instance, the concentration of copper shown by RPO1 and RPO2 was only up to 1.4 and 2.0 ppm, respectively, showing that both indoor and outdoor copper levels did not have any major sources of contamination.

That the variations of the copper concentrations are relatively small across most of the places suggests that there is a good balance of copper both indoors and outdoors. This supports the earlier assertion that copper is not a significant polluting agent as is seen in this specific area and therefore, it does not appear to pose a significant environmental or public health risk at any of the surveyed locations

Given that all measured concentrations fall far below the established regulatory limits, the risk of health issues related to copper exposure is minimal. Copper is an essential trace element required for various biological functions, but at these low concentrations, there is little concern about toxicity from environmental exposure in both indoor and outdoor environments.

3.6 The environmental hazard indicators

The environmental hazard indicators for all studied metals across various sampling sites were evaluated using three key metrics: These include the following; Geo-accumulation Index (Igeo), Enrichment Factor (EF) and Contamination Factor (CF). Comprehensive data on the concentration levels, Geo-accumulation Index (Igeo), Enrichment Factor (EF), and Contamination Factor (CF) for all metals analyzed in this study are available in Appendix (see Tables A1–A4).

3.6.1 Iron (Fe)

The Igeo values of all the sites varied between 0.01197 and 0.03599, and therefore, all the sites fell in class 1 which represents uncontaminated to moderately contaminated environment. From this classification, it is concluded that Iron enrichment in the area is almost zero, and there is no increase of Iron beyond natural content in the samples collected from the region.

The Enrichment Factor (EF), which is employed to compare the contributions of anthropogenic sources to metal concentrations, remained at 1 at all the sampling sites. This comes under the category of Deficiency to Minimal Enrichment, meaning that the Iron levels are more naturally influenced rather than through anthropogenic actions. The comparatively low EF values imply that natural atmospheric processes like soil erosion and natural dust deposition are the primary sources of Iron in Indoor and Outdoor environments.

Likewise, the Contamination Factor (CF) values fell between 0.05964 to 0.17934 and all the sites fell under the Low Contamination Category. The fact that all the calculated CF values are below 1 gives a clear impression that the concentrations of Iron are not raised much above the background level, hence, does not pose a high threat to the environment in the studied areas.

The integration of Igeo, EF, and CF data elucidates that Iron concentrations in all the sites under study can be attributed to natural sources with a negligible level of anthropogenic influence. Hence, the contamination levels and enrichment values in Iron indicate that it is not currently an environmental threat.

3.6.2 Manganese (Mn)

The environmental hazard indicators for Manganese (Mn) across various sampling sites were analyzed using three key metrics: the Geo-accumulation Index (Igeo), Enrichment Factor (EF), and Contamination Factor (CF). The findings shown here reveal that levels of Manganese are generally low but the degree of concentration of this metal in some places is moderate to high.

The Igeo values for Manganese varied from 0.01932 to 0.07854 for all the studied sites, thus falling under Class 1 of uncontaminated to moderately contaminated sites. This indicates that Manganese concentration is relatively low in all the sites under investigation and there is no significant accumulation of Mn to warrant alarm concerning Mn pollution. Thus, even though there are slight variations in the calculated Igeo values, the Manganese concentration remains low.

The anthropogenic contribution to metal concentrations was evaluated through the Enrichment Factor (EF) and ranged at different extents in the investigated sites. Most of the sites including FPO3, KHPI1, and RPO1 presented deficiency to minimal enrichment, this shows that the concentration of Manganese at these places is at its natural environmental level. However, certain sites showed a moderate increase and these include FPO1 (3.09 EF), FPO2 (3.87 EF) and KHPO1 (2.73 EF) for Manganese, indicating that there could be an onset of anthropogenic input to the environment as a result of industrial inputs and or vehicular emissions. Besides, FPI1 was more enriched (EF = 5.44), indicating a higher anthropogenic impact, especially indoors. This could be due to sources that may include dust from the home or construction material.

Due to this, the degree of moderate to significant increase in some concentrations was not reflected in the high Contamination Factor (CF) results which ranged between 0.09627 and 0.39133 in all the sampling sites. All locations are categorized under low contamination, which means Manganese concentrations are not raised to endanger the environment. In those cases where sites are moderately to highly enriched, these low CF values indicate that there is little Manganese, which might pose a threat to the environment or human health.

3.6.3 Zinc (Zn)

The environmental hazard assessment for Zinc (Zn) across various sampling sites was carried out using three key indicators: thus, some of the established indices include the Geo-accumulation Index (Igeo), Enrichment Factor (EF), and Contamination Factor (CF). The study has revealed that overall Zinc is moderately to slightly enriched and contaminated but few sites show moderate to highly enriched and contaminated sites with implication of anthropogenic impact.

The Igeo values for Zinc vary between 0.00316 and 0.834335 for all the sites attributed to Class 1 which represented uncontamined to moderately contaminated environment. This implies that the contamination level of Zinc is not very alarming as most sites had low contamination levels.

The Enrichment Factor (EF) values for Zinc differ significantly and incline in a wide range of enrichment categories, with values ranging from 0.10108 to 26.29509 between the sites. As shown in FPO3 and FPI3, the EF values presented deficiency to minimal enrichment, suggesting that the major source of the fatty acids profile is natural. Nevertheless, FPO1, FPI1, and RPO1 sites show a moderate (EF 2-5) concentration that may be attributed to the efforts by human beings through activities like construction or industries. For instance, sites numbered KHPI1, RPI1, and RPO3 give higher EFs of 5–20, implying that they have more human influence, likely from industries or transport systems. The location RPO2 with an EF of 26.29509 represents very high enrichment, which suggests that there is probably a significant anthropogenic contribution to this location and that it needs further study.

The results of the Contamination Factor (CF) also support the findings of the EFs; CF values for each parameter fluctuated between 0.01575 and 4.15748. The majority of the sites exhibit low contamination including FPI2, FPI3 where the CF is below 1, meaning that Zinc levels at these sites are not a threat to the environment. Nonetheless, four sites, namely KHPO at 1.5 CF and RPI at 2 CF exhibit a moderate level of contamination which could raise the Zn levels in the environment. The high contamination level observed at RPO2 with an overall count of 4.15748 signifies this area as an area of concern as such amount of contamination could lead to further negative ecological effects and health hazards due to the uptake of Zinc in water and soil systems in the long run.

3.6.4 Lead (Pb)

The environmental hazard assessment of Lead (Pb) across various sampling sites, using the Geo-accumulation Index (Igeo), Enrichment Factor (EF), and Contamination Factor (CF), reveals significant Lead contamination, with numerous sites exhibiting high to extremely high levels of enrichment and contamination.

The Igeo values for Lead ranged from 0.13546 to 2.02944, classifying most sites in Class 2 (moderately contaminated), with a few locations, such as KHPO2, falling into Class 3 (moderately to heavily contaminated). This classification suggests that Lead has accumulated to concerning levels in some areas, particularly at KHPO2, indicating the need for further investigation and potential remediation. In contrast, sites like RPO1 and RPI1, which are classified in Class 1, demonstrate low levels of Lead contamination, with limited environmental impact.

The Enrichment Factor (EF) values for Lead show a wide range, with many sites falling under extremely high enrichment. Sites such as FPI1 (EF = 102.28876), KHPO1 (EF = 97.38978), and KHPI1 (EF = 66.61002) highlight substantial anthropogenic contributions to Lead concentrations, likely stemming from industrial emissions, traffic, or other human activities. Several other sites, including RPO3 and KHPI2, are highly enriched (EF 5–20), which further supports the human contribution to the increased Lead concentration. Even in the sites that registered moderate enrichment (2–5 EF), such as RPI1, it indicates that human activities are still partly contributing to the pollution.

Lead Contamination is further confirmed by the Contamination Factor (CF) which ranges between 0.675 and

10.1125, which highlights the extent of the problem in most of the sites. However, KHPO2, FPI3 and KHPI1 with CF = 10.1125, 9.35625 and 8.46875, respectively reveal very high contamination, which shows that the Lead concentration at these sites is still a serious environmental problem. On the other hand, RPO1 (CF = 0.675) and RPI1 (CF = 1.09375) show low to moderate contamination hence showing that Lead levels are still tolerable in these areas. Nevertheless, it found a very high contamination level was prevalent both indoors and outdoors, which underlined the immediate importance of intervention measures that would help to control the adverse effects of these pollutants on the environment and health in the future.

3.6.5 Copper (Cu)

The Igeo, EF, and CF analysis of the potential environmental risk of copper (Cu) across the different sampling stations indicates that Copper poses a relatively low threat to the environment in the area. The Igeo values vary between 0.0006271 and 0.06021, and put all sites in Class 1, which implies that the areas are relatively unpolluted to moderately polluted. This implies that copper accumulation is minimal and does not have any negative impacts on the environment in the regions that were analyzed.

The Enrichment Factor (EF) values for copper vary from 0.02156 to 3.61574 but most of the sites are deficient or have very low enrichment. This points out that natural sources dominate the contribution of copper concentrations with minimal interferences from human beings. Nevertheless, there are a few stations, FPI1 (EF = 3.61574) and FPO2 (EF = 2.96531), which show relatively moderately enriched Copper levels which may be attributed to anthropogenic activities such as human motion, urban impact, vehicle exhaust emissions, and industrial occurrences. Nevertheless, the enrichment stays moderate and does not lead to the pollution of the environment.

The value of the Contamination Factor (CF) is between 0.00313 and 0.3 for copper, which indicates that the Copper contamination is low in all sites. All the CF values are below 1, which rules out the possibility of copper being toxic to the environment. Hence, moderate levels of enrichment disturb the concentrations of copper only slightly and do not affect the environment and health of the people.

3.7 Correlation analysis of heavy metals and contamination factors

The calibration between heavy metals (Fe, Mn, Zn, Pb) concentration and their corresponding contamination factor (CF) is presented in Figure 13. The analysis of the correlation of heavy metals and contamination factors sheds more light on their relationship and sources of contamination. The concentrations of Fe, Mn, Zn, and Pb showed a strong positive correlation (1.00) with their respective contamination factors (CF), indicating a direct proportionality between metal concentrations and CF as an indicator of environmental impact. This indicates that a highly localized enrichment pattern is involved, and that this likely relates to anthropogenic or geogenic sources. In addition, Mn and Pb concentrations were moderately positively correlated (*r* = 0.31), indicating common sources or modes of deposition for these elements. On the contrary, Zn displayed a moderately negative correlation (-0.56) with Mn concentrations and a lesser negative correlation (-0.39) with Pb concentrations, indicating different behaviors or different sources of origin for these metals. Furthermore, Fe and Mn concentrations were also anti-correlated weakly (-0.27), which supports the presence of minor inverse relationships possibly driven by competitive environmental processes. These results highlight the inherent complexity of heavy metal distributions and their interaction and call for more study on their sources, deposition mechanisms and environmental dynamics.

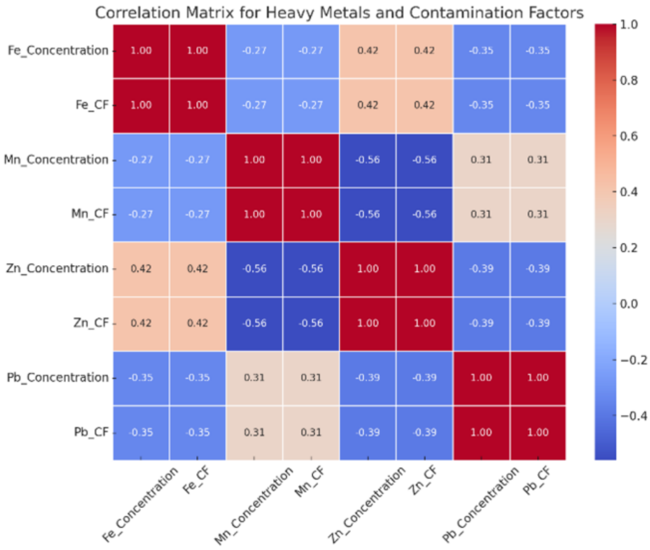

Figure 13. shows the heatmap which illustrates the correlation between the concentrations of heavy metals (Fe, Mn, Zn, Pb) and their respective contamination factors (CF)

Table 6. Pearson correlation coefficients (*r*) and p-values for relationships between heavy metal concentrations

Variable Pair	Pearson Correlation (*r*)	p-value	Interpretation
Fe Concentration - Mn Concentration	-0.270	0.350	Weak negative correlation, not statistically significant.
Fe Concentration - Zn Concentration	0.419	0.136	Moderate positive correlation, not statistically significant.
Fe Concentration - Pb Concentration	-0.346	0.225	Moderate negative correlation, not statistically significant.
Mn Concentration - Zn Concentration	-0.560	0.037	Moderate negative correlation, statistically significant.
Mn Concentration - Pb Concentration	0.310	0.280	Weak positive correlation, not statistically significant.

Heavy metal concentrations have been statistically analyzed, which showed several correlations between studied variables as shown in Table 6. Statistically significant moderate negative correlation was found within pairs of the variable, where there was a correlation between Mn and Zn concentrations ($r = -0.560$; $p = 0.037$). An inverse relationship is indicated by this result, which implies that these metals may come from different environmental sources, or have different deposition behaviors in this region. Despite that, other variable pairs tend to be statistically weak to moderate correlations such as between Fe and Mn ($r = -0.270$, $p = 0.350$), Fe and Zn ($r = 0.419$, $p = 0.136$). These results suggest that the observed associations may be due more to chance than because of an actual relationship between the two variables. For most variable pairs, there are refractory relationships, which imply complicated interactions between heavy metals themselves and their sources, owing to simultaneous action of both natural and anthropogenic influences. Ultimately, additional lines of investigation using multivariate statistical techniques (e.g., PCA, or hierarchical clustering) could be used to identify general sources or pathways leading to heavy metals in the environment.

4. CONCLUSIONS

The contamination levels of five heavy metals which include iron (Fe), manganese (Mn), zinc (Zn), lead (Pb) and copper (Cu) were assessed in dust samples from indoor and outdoor sources in residential areas of Anbar Governorate, Iraq. Based on the hazard indices the studied elements are principally Fe and Mn with contamination greater than the permissible limits and mainly of natural origin, which implies a low environmental risk. Industrial emissions, vehicular activity and natural sources like soil erosion may be behind the elevated iron and manganese levels seen in this study. Localized spikes in concentrations may be explained by the fact that some sampling locations were close to industrial zones. Moreover, the presence of manganese may be influenced by agricultural practices in the region, confirming that a complex interplay of natural and anthropogenic factors in the region may control its distribution.

The range of Zinc (Zn) contamination varied from moderate to high in outdoor settings and implied an anthropogenic input. Treatment of Indoor Zinc contamination is also important because of the long-term exposure effects that it poses.

Of all the studied pollutants, the degree of Lead (Pb) contamination was the highest with greatly enriched and very high levels of contamination recorded – primarily indoor environments. The overall Pb concentration was beyond the WHO and USEPA recommendations raising concerns about the health implications which require appropriate intervention and control measures.

Copper (Cu) enrichment was deficient to minimal and no environmental hazard observed all through all the sites.

The findings of the study suggest the need to develop specific measures for decontamination to decrease Pb and Zn levels in dwellings and especially indoors where people are most vulnerable to admixtures of heavy metals. To control accumulation of such heavy metals in the long run and for the safety of life, special cavities with proper and frequent monitoring and regular precautionary measures should be taken.

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APPENDIX

Comprehensive data on metal concentrations, Igeo, EF, and CF.

Table A1. Environmental hazard indicators for of Fe

Sampling Site	Concentration ppm	Igeo	Degree of Igeo	EF	Degree of EF	CF	Degree of CF
FPO1	3822.5	0.02137	Class 1	1	Deficiency to minimal enrichment	0.10648	Low contamination
FPI1	2140.9	0.01197	Class 1	1	Deficiency to minimal enrichment	0.05964	Low contamination
FPO2	3632	0.0203	Class 1	1	Deficiency to minimal enrichment	0.10117	Low contamination
FPI2	5427	0.03034	Class 1	1	Deficiency to minimal enrichment	0.15117	Low contamination
FPO3	5593.4	0.03127	Class 1	1	Deficiency to minimal enrichment	0.15581	Low contamination
FPI3	4326.4	0.02419	Class 1	1	Deficiency to minimal enrichment	0.12051	Low contamination
KHPO1	3082.6	0.01723	Class 1	1	Deficiency to minimal enrichment	0.08587	Low contamination
KHPI1	4564.3	0.02552	Class 1	1	Deficiency to minimal enrichment	0.12714	Low contamination
KHPO2	5203	0.02909	Class 1	1	Deficiency to minimal enrichment	0.14493	Low contamination
KHPI2	6306.4	0.03525	Class 1	1	Deficiency to minimal enrichment	0.17567	Low contamination

RPO1	5264.3	0.02943	Class 1	1	Deficiency to minimal enrichment	0.14664	Low contamination
RPI1	5480	0.03063	Class 1	1	Deficiency to minimal enrichment	0.15265	Low contamination
RPO2	5676.1	0.03173	Class 1	1	Deficiency to minimal enrichment	0.15811	Low contamination
RPI2	5531.1	0.03092	Class 1	1	Deficiency to minimal enrichment	0.15407	Low contamination
RPO3	5478.1	0.03062	Class 1	1	Deficiency to minimal enrichment	0.15259	Low contamination
RPI3	6035	0.03374	Class 1	1	Deficiency to minimal enrichment	0.16811	Low contamination
HPO1	4501.1	0.02516	Class 1	1	Deficiency to minimal enrichment	0.12538	Low contamination
HPI1	5044.9	0.0282	Class 1	1	Deficiency to minimal enrichment	0.14053	Low contamination
HPO2	6355.7	0.03553	Class 1	1	Deficiency to minimal enrichment	0.17704	Low contamination
HPI2	6438.4	0.03599	Class 1	1	Deficiency to minimal enrichment	0.17934	Low contamination

Table A2. Environmental hazard indicators for of Mn

Sampling Site	Concentration ppm	Igeo	Degree of Igeo	EF	Degree of EF	CF	Degree of CF
FPO1	246.8	0.06604	Class 1	3.09051	Moderate enrichment	0.32907	Low contamination
FPI1	243.1	0.06505	Class 1	5.43528	Significant enrichment	0.32413	Low contamination
FPO2	293.5	0.07854	Class 1	3.86808	Moderate enrichment	0.39133	Low contamination
FPI2	275.9	0.07383	Class 1	2.43346	Moderate enrichment	0.36787	Low contamination
FPO3	223.9	0.05991	Class 1	1.91607	Deficiency to minimal enrichment	0.29853	Low contamination
FPI3	165.1	0.04418	Class 1	1.82664	Deficiency to minimal enrichment	0.22013	Low contamination
KHPO1	176	0.04709	Class 1	2.73293	Moderate enrichment	0.23467	Low contamination
KHPI1	160.8	0.04303	Class 1	1.68634	Deficiency to minimal enrichment	0.2144	Low contamination
KHPO2	214.7	0.05745	Class 1	1.9752	Deficiency to minimal enrichment	0.28627	Low contamination
KHPI2	222.7	0.05959	Class 1	1.69033	Deficiency to minimal enrichment	0.29693	Low contamination
RPO1	163.7	0.0438	Class 1	1.48847	Deficiency to minimal enrichment	0.21827	Low contamination
RPI1	148.3	0.03968	Class 1	1.29537	Deficiency to minimal enrichment	0.19773	Low contamination
RPO2	186.3	0.04985	Class 1	1.57107	Deficiency to minimal enrichment	0.2484	Low contamination
RPI2	135.5	0.03626	Class 1	1.17263	Deficiency to minimal enrichment	0.18067	Low contamination
RPO3	136.7	0.03658	Class 1	1.19446	Deficiency to minimal enrichment	0.18227	Low contamination
RPI3	92.7	0.0248	Class 1	0.73525	Deficiency to minimal enrichment	0.1236	Low contamination
HPO1	85.5	0.02288	Class 1	0.90924	Deficiency to minimal enrichment	0.114	Low contamination
HPI1	76.3	0.02042	Class 1	0.72394	Deficiency to minimal enrichment	0.10173	Low contamination
HPO2	82.1	0.02197	Class 1	0.61832	Deficiency to minimal enrichment	0.10947	Low contamination
HPI2	72.2	0.01932	Class 1	0.53678	Deficiency to minimal enrichment	0.09627	Low contamination

Table A3. Environmental hazard indicators for lead

Sampling Site	Concentration ppm	Igeo	Degree of Igeo	EF	Degree of EF	CF	Degree of CF
FPO1	99.2	1.24426	Class 2	58.22891	Extremely high enrichment	6.2	Very high contamination
FPI1	97.6	1.22419	Class 2	102.28876	Extremely high enrichment	6.1	Very high contamination
FPO2	102.4	1.28439	Class 2	63.25991	Extremely high enrichment	6.4	Very high contamination
FPI2	111.3	1.39603	Class 2	46.0161	Extremely high enrichment	6.95625	Very high contamination
FPO3	83.4	1.04608	Class 2	33.45528	Very high enrichment	5.2125	Considerable contamination
FPI3	149.7	1.87767	Class 2	77.63715	Extremely high enrichment	9.35625	Very high contamination
KHPO1	133.8	1.67824	Class 2	97.38978	Extremely high enrichment	8.3625	Very high contamination
KHPI1	135.5	1.69957	Class 2	66.61002	Extremely high enrichment	8.46875	Very high contamination
KHPO2	161.8	2.02944	Class 3	69.77489	Extremely high enrichment	10.1125	Very high contamination
KHPI2	109.1	1.36843	Class 2	38.81662	Very high enrichment	6.81875	Very high contamination
RPO1	10.8	0.13546	Class 1	4.60318	Moderate enrichment	0.675	Low contamination
RPI1	17.5	0.2195	Class 1	7.16526	Significant enrichment	1.09375	Moderate contamination
RPO2	27.6	0.34618	Class 1	10.91022	Significant enrichment	1.725	Moderate contamination
RPI2	54.4	0.68233	Class 1	22.06794	Very high enrichment	3.4	Considerable contamination
RPO3	75.8	0.95075	Class 1	31.04658	Very high enrichment	4.7375	Considerable contamination
RPI3	98.8	1.23924	Class 2	36.73281	Very high enrichment	6.175	Very high contamination
HPO1	88.3	1.10754	Class 2	44.0166	Extremely high enrichment	5.51875	Considerable contamination
HPI1	97.6	1.22419	Class 2	43.40819	Extremely high enrichment	6.1	Very high contamination
HPO2	103.6	1.29945	Class 2	36.57386	Very high enrichment	6.475	Very high contamination
HPI2	81.6	1.0235	Class 2	28.43719	Very high enrichment	5.1	Considerable contamination

Table A4. Environmental hazard indicators for copper

Sampling Site	Concentration ppm	Igeo	Degree of Igeo	EF	Degree of EF	CF	Degree of CF
FPO1	3.5	0.02195	Class 1	1.02722	Deficiency to minimal enrichment	0.10938	Low contamination
FPI1	6.9	0.04327	Class 1	3.61574	Moderate enrichment	0.21563	Low contamination
FPO2	9.6	0.06021	Class 1	2.96531	Moderate enrichment	0.3	Low contamination
FPI2	1.2	0.00753	Class 1	0.24807	Deficiency to minimal enrichment	0.0375	Low contamination
FPO3	1	0.00627	Class 1	0.20057	Deficiency to minimal enrichment	0.03125	Low contamination
FPI3	1.1	0.0069	Class 1	0.28524	Deficiency to minimal enrichment	0.03438	Low contamination
KHPO1	1.9	0.01192	Class 1	0.69148	Deficiency to minimal enrichment	0.05938	Low contamination
KHPI1	4.4	0.02759	Class 1	1.08149	Deficiency to minimal enrichment	0.1375	Low contamination
KHPO2	0.1	6.27146E-4	Class 1	0.02156	Deficiency to minimal enrichment	0.00313	Low contamination
KHPI2	4.9	0.03073	Class 1	0.87168	Deficiency to minimal enrichment	0.15313	Low contamination
RPO1	3.8	0.02383	Class 1	0.80982	Deficiency to minimal enrichment	0.11875	Low contamination
RPI1	2.4	0.01505	Class 1	0.49133	Deficiency to minimal	0.075	Low

					enrichment		contamination
RPO2	3.9	0.02446	Class 1	0.77083	Deficiency to minimal enrichment	0.12188	Low contamination
RPI2	1.9	0.01192	Class 1	0.38538	Deficiency to minimal enrichment	0.05938	Low contamination
RPO3	0.6	0.00376	Class 1	0.12288	Deficiency to minimal enrichment	0.01875	Low contamination
RPI3	3.9	0.02446	Class 1	0.72499	Deficiency to minimal enrichment	0.12188	Low contamination
HPO1	1.2	0.00753	Class 1	0.29909	Deficiency to minimal enrichment	0.0375	Low contamination
HPI1	4.7	0.02948	Class 1	1.04518	Deficiency to minimal enrichment	0.14688	Low contamination
HPO2	1.4	0.00878	Class 1	0.24712	Deficiency to minimal enrichment	0.04375	Low contamination
HPI2	1.6	0.01003	Class 1	0.2788	Deficiency to minimal enrichment	0.05	Low contamination