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Investigation of Heavy Metals in Indoor Dust from Irbid, Jordan

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Abstract

The purpose of this study is to investigate the presence of a variety of heavy metals in the household dust of residents in Irbid, Jordan. Seventy samples of household dust were taken from various parts of the city, digested, and analyzed using flame atomic absorption spectroscopy (FAAS) for the presence of Pb, Cd, Cu, Zn, Co, Ni, Cr, Fe, and Mn. The geometric mean concentrations were 83.4, 2.1, 531.7, 94.8, 36.2, 16.1, 126.4, 141.3, and 9278 mg/kg for Pb, Cd, Zn, Cu, Cr, Co, Ni, Mn, and Fe, respectively. Calculations were done to determine enrichment factors about the abundance of heavy metals in the earth's crust. According to the findings, Cd and Ni are extremely enriched in the dust samples taken from indoor environments, whereas Pb, Cu, and Zn are only moderately so. The incorporation of dust from both indoor and outdoor sources into the environment of the house is thought to be the cause of the enrichment of certain elements. Calculations, based on a factor analysis, revealed that the outdoor dust from a variety of sources, which is typically brought inside by foot traffic, has a significant impact on the quality of the indoor environment.

Keywords: *Heavy metals, Indoor environment, House dust, Atomic absorption.*

1. Introduction

A growing number of researchers have recently become interested in the potential dangers posed by polluted air found inside buildings. The levels of contaminants, found in house dust, particularly heavy metals, have received a significant amount of attention in recent years (Shi and Wang, 2021; Naimabadi et al., 2021; Doyi et al., 2019). Dust in the home is a byproduct of modern living and occurs as a result of the interaction of liquids, solids, and gaseous substances that are produced by a variety of different sources. Aerosol particles, solvents, fungal spores, and soil particles, brought in on people's shoes, are the usual constituents of house dust. The precise composition is determined by multiple factors, including the activity of endogenous and exogenous sources (Gul et al., 2023; Shi and Wang, 2021).

It is possible for airborne particles and dust from nearby highways that contain heavy metals to make their way into the interior of the house through windows or balconies. It has been found that homeowners who regularly vacuum their homes, mop their floors, and dust their furniture have lower levels of metal in their homes (Gul et al., 2023; Tong and Lam, 2000). In addition, the distribution of heavy metals in house dust is affected by the activities that take place inside, the characteristics of the house, the distance that separates the building from the sources of vehicular emissions, and the type of heating that is used (Al-Momani et al., 2015). The mode of heating utilized during the colder months has a significant impact on the concentrations of various heavy metals. The highest concentrations have been found in residential properties that heat their spaces with wood or olive waste. The majority of the lead, zinc, cadmium, and copper are associated with the carbonate phases, whereas the majority of the aluminum, vanadium, manganese, and chromium are associated with the remainder (Al-Momani et al., 2015).

An increase in the levels of heavy metals can have devastating effects on human health, particularly in childhood. Children are at a greater risk than adults because they are more likely to engage in activities that involve hand-to-mouth activity (Tan et al., 2016). Because of this, it is anticipated that higher concentrations will be absorbed by the bodies of children as compared to adults. For example, a great deal of research has been done to determine how Pb intake affects children's total body burden. It was discovered that there is a correlation between the amount of lead that is present in blood and the amount of lead that is present in household dust (Isley et al., 2022).

Several studies on heavy metal levels in Jordanian soil, air, street dust, and water have been published (Tarawneh et al., 2021; Al-Massaedh and Al-Momani 2020; Mashal et al., 2017). However, indoor heavy metal levels have received less attention (Al-Momani et al., 2015; Al-Momani, 2007). The goal of this study is to estimate the levels of Pb, Cd, Cu, Zn, Co, Ni, Cr, Fe, and Mn in indoor dust, collected from 70 homes in Irbid, Jordan.

2. Materials and Methods

2.1. Sampling site

Irbid is Jordan's second-largest city. It is located on flat land, 80 kilometers north of Jordan's capital, Amman. From the north, east, and south, it is surrounded by fertile agricultural lands. In general, Summer in Irbid is exceptionally long, hot, and dry while winter is comparatively brief, cool, and wet. From November to mid-April, the weather is rainy, and the rest of the year is very dry.

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2.2. Sample collection

Samples of house dust were collected from a total of seventy different homes in Irbid City, randomly selected during the winter months. The average age of the homes was twenty years. The vacuum cleaners were utilized in the gathering of the indoor dust samples were carried in plastic bags during transport and storage prior to further preparation and examination of the samples.

2.3. Reagents and Glassware

All of the reagents had an analytical grade purity. HF had an assay of 40% (Union LAR. Supplies), and the HNO3 had a high purity assay of 69-71% (BDH Limited, England). Every solution was made with deionized water, which has an electrical conductivity of 18.2 M. After being cleaned with soap, all of the glassware and plastic bottles were then washed completely with tap water. After that, every bottle was soaked in a solution containing 10% HNO3 (v/v) for 24 hours in order to remove any heavy metal contamination. Before being used, the bottles were washed with deionized water and dried.

2.4. Sample preparation

After being dried, the samples were sieved using a polystyrene screen with a 250 µm opening size. Approximately 0.5 g sample was weighed out and placed in a 250 ml Teflon beaker. After adding approximately 15 ml of HNO3 and 4 ml of HF, the mixture was allowed to sit at room temperature for 24 hours. The digestion procedure is described in detail elsewhere (Al-Momani et al., 2015; Al-Momani 2007). Deionized water was then used to dilute the digest to a volume of 50 mL and then stored in pre-cleaned plastic bottles.

2.5. Chemical Analysis

Concentrations of Pb, Cd, Cu, Zn, Co, Ni, Cr, Fe, and Mn were determined using flame atomic absorption spectrophotometry (Varian Spectra AA, AUSTRALIA). The working standard solutions were prepared using standard stock solutions (BDH Chemicals Ltd. Poole, England). The external calibration curves were used to make quantitative determinations for each element.

2.6. Quality Assurance/Quality Control

Throughout the entirety of the experiment, quality control was kept in check through the frequent analysis of reagent blanks, standard samples, and standard reference materials. Because the concentrations shown by blank solutions were not significant, their values were disregarded. The calculated sample-to-blank concentration ratio for each of the measured elements was greater than 10% for all elements, providing further evidence that these results were accurate.

The reliability of the results of the analysis was confirmed by conducting additional tests on standard reference materials (SRM). There were a total of three SRMs that were utilized, and they were as follows: SRM-1646a, SRM-1633b, and SRM-2702. SRM samples were subjected to the same process of digestion and analysis as regular samples. Overall, the results matched the certified concentrations very closely within a range of 5–10% for all of the elements that were measured.

3. Results and Discussions

3.1. Heavy metals in household dust

A statistical overview of the measured elements is presented in Table 1. The fact that the arithmetic means for the measured elements are higher than the geometric means demonstrates that the concentrations of elements, found in the collected dust samples, are positively skewed. Therefore, to provide a more accurate depiction of the data, the Ryan-Joiner test of normality was carried out. The findings showed that the data are not normally distributed (p-values are less than 0.05). Therefore, geometric means, presented in Table 1, more accurately represent levels rather than arithmetic means.

The geometric mean concentration of Zn was approximately 531 mg/kg, making it the second most abundant metal after Fe. On the contrary, the geometric mean concentration of Cd was 62.1 mg/kg, making it the least abundant metal. The following is a ranking of the heavy metal concentrations found in the dust, collected from the homes that were investigated: Fe > Zn > Mn > Ni > Cu > Pb > Cr > Co > Cd.y

Table 1. Statistical summary of heavy metal concentrations (mg/kg dry weight) in house dust of Irbid residences.

Element	Avg.	SD	G-Mean	Min	Max
Cu	103.8	42.6	94.8	32.7	191.6
Ni	227.7	345.4	126.4	38.7	1499.8
Zn	539.7	84.7	531.7	228.6	729.8
Mn	150.0	49.8	141.3	56.7	316.4
Co	18.9	9.6	16.1	0.9	48.0
Pb	102.1	56.6	83.4	3.2	273.3
Cd	2.6	1.4	2.1	0.1	6.5
Cr	40.3	17.5	36.2	3.7	83.0
Fe	10459	3931	9278	133	20879

3.2. Comparison with literature data

In all environmental studies, one of the most important steps that must be taken into account in order to determine the level of contamination by various metals is to compare the data with the literature. Although houses from different countries differ in their designs, structural materials, ventilation, and building codes, the inside activities and the contribution of the indoor environment are still common. In addition, comparing the data with those from relevant regions would help detect the outliers that could indicate analytical errors. Therefore, the results of this study are compared with those reported by other researchers in various cities and are presented in Table 2.

Careful inspection of the data reveals that the levels of major anthropogenic elements (Cu, Pb, Cr, and Cd) are lower than those reported in Table 2. The lead levels are five times lower than those reported for Ottawa, and they are two to three times lower than those for Sydney and Amman, respectively (Rasmussen et al., 2001; Doyi et al., 2019; Al-Momani 2007). It is possible that the age of the house is to blame for the high levels of lead, found in some of the homes that were investigated. Older homes have more damaged interior surfaces and warped windows and doors, which can trap heavy metal particulate (Kim and Fergusson, 1993; Cheng et al., 2018; Shi and Wang, 2021).

The second group of elements is comprised of Zn, Co, and Mn. These elements have levels that are approximately in the middle of the range as shown in Table 2. The geometric mean concentration of Zn was found to be 532 mg/kg, which is higher than what was reported for Sydney, but lower than what was reported for Amman and Ottawa. The proximity of the houses to the main road, which has heavy traffic, may have contributed to the presence of Zn in the dust. The increased Zn content could have been caused by wear and tear of vulcanized vehicle tires as well as corrosion of galvanized roofs (Al-Momani 2007; Cheng et al., 2018).

This study found significantly higher levels of Ni and Fe than any of those reported in Table 2. The concentration of Ni can range from 38.7 to 1499.8 mg/kg while the concentration of Fe ranges from 133.2 to 20879.2 mg/kg. Anthropogenic sources, such as emissions from vehicles and street dust, are the origins of the elements of Ni and Fe found in dust. This includes sources originating from automobile components, such as tire abrasion, brushing, bearing metals, and brake dust (Al-Momani et al., 2015; Doyi et al., 2019; Isley et al., 2022).

Table 2. Comparison of the trace metals concentrations in indoor vacuum dust with global concentration distribution of trace metals in indoor dust (mg/Kg).

	Pb	Cd	Zn	Cu	Cr	Co	Ni	Mn	Reference
Irbid, Jordan	83.4	2.1	531.8	94.8	36.2	16.1	126.4	141.3	This Study
Ottawa, Canada	406	6.46	717	206	86.7	8.92	63	267	Rasmussen et al., 2001
Amman, Jordan	169	2.92	1985	133	66.5	20.5	47	283.6	Al-Momani 2007
Istanbul, Turkey	28	0.8	832	156	55	5	263	136	Kurt-Karakus, 2012
Canada	210	6	833	279	117		102		Rasmussen et al., 2013
Japan	57.9	1.02	920	304	67.8	4.69	59.6	266	Yoshinaga et al., 2014
Al-Karak, Jordan	51.9			90.4	72.5		70	243.2	Al-Madanat et al., 2017
Chengdu, China	123	2.37	657	161	82.7		52.6		Cheng et al., 2018
Sydney, Australia	299		1876	272	90		50.9	220	Doyi et al., 2019
Neyshabur, Iran	56	1.93	513	158	67	9.7	92	332	Naimabadi et al., 2021

3.3. Enrichment of measured elements

The aluminosilicate material is the primary component of elements that can be found in sediments. It is expected that this source will explain the observed concentrations if there were no anthropogenic sources. However, because of the contributions from a variety of man-made sources, the composition of house dust is altered. In studies of atmospheric aerosols (Al-Momani et al., 2005) and soil (Isley et al., 2022; Khudhur et al., 2018; Al-Omari et al, 2012; Tong and Lam 2000; Kim and Fergusson, 1993), it is common practice to employ crustal enrichment factors (EFc) in order to ascertain the degree to which the soil composition has been altered. Iron was chosen as the element to serve as a reference because it is predominately found in the crust (Al-Momani et al., 2015; Al-Omari et al, 2012; Alghamdi et al., 2022; Madadi et al., 2022). The following formula can be used to determine the value of EFc:

$$EF_c = \frac{(C_x / C_{Fe})_{sample}}{(C_x / C_{Fe})_{crust}}$$

where $(C_x/C_{Fe})_{sample}$ is the element X concentration ratio in the sample, and $(C_x/C_{Fe})_{crust}$ is the same ratio in crustal material obtained from the compilation of trace elements in the earth's crust by Rudnick and Gao (Rudnick and Gao 2003). Enrichment factors that are greater than one indicate that crustal dust is not the only source. In general, EF values that are lower than 5.0 are not considered to be significant. Minor enrichments may result from differences in local soil composition and the reference soil used in EF calculations.

Figure 1 displays the crustal enrichment factors of the various elements that were measured. According to the findings, the concentrations of many elements are higher than their natural concentrations. The selective importation of small particles and the preferential removal of the coarser fractions during cleaning are two possible mechanisms for the occurrence of this phenomenon (Tong and Lam 2000). Both of these mechanisms have been proposed as potential explanations of the enrichment of elements in house dust.

It has been observed that the values of the EF for the same element can vary greatly from one house to the next. One possible explanation for this difference is that the strength of the various sources changes to varying degrees. The level of outdoor dust from a variety of sources, which is typically brought inside by foot traffic, has a significant impact on the quality of the environment inside buildings. There are also other dust sources in the indoor environment, such as skin, hair, mites, the rubber of carpet underlays, fibers from clothing and furniture, cooking emissions, heating emissions, and cigarette smoke (Gul et al., 2023; Morawska and Salthammer 2003). As a consequence, the large variation in the EF values could be explained by the incorporation of dust from both inside and outside the house into the environment of the home.

More than 30 enrichment factors were found for Pb, Cd, Zn, Ni, and Cu in samples taken from house dust. These results must be taken as evidence of widespread contamination. The previously used leaded gasoline, former use of lead-based paint, lead solder, and lead pipe are typically thought to be the primary contributors to the accumulation of lead in house dust (Kim and Fergusson, 1993). This is because these activities left a legacy of contamination over a long time. However, the most significant contributor to the presence of lead in the air around the world is the combustion of leaded gasoline by motor vehicles. Recent years have seen an increase in Jordan's adoption of unleaded gasoline for widespread use. As a result, one should anticipate that the fine particles emitted from motor vehicles that contain lead compounds will be dispersed throughout the environment (Al-Omari et al 2012; Yoshinaga et al., 2014).

It is well established that an increase in the levels of certain elements can be attributed to contributions from a variety of different sources. For example, the presence of carpet and the use of galvanized iron roofing are two of the significant sources that contribute to the high levels of Zn that have been found in house dust. Zinc compounds are put to use in the vulcanization step of the manufacturing process for rubber (Cheng et al., 2018; Daru et al., 2012). In addition, homes situated close to roads are likely to have elevated concentrations of the heavy metals of Zn, Pb, and Cd because of the constant abrasion caused by passing vehicles. Ni and Cr are widely used in residential areas to prevent corrosion in office furniture and metal plating (Naimabadi et al., 2021; Doyi et al., 2019, Cheng et al., 2018).

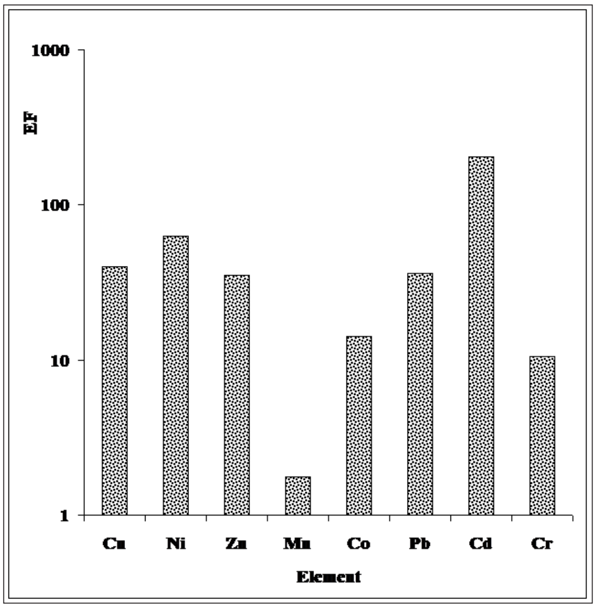

Figure 1. Crustal enrichment factors of measured elements in house dust samples.

3.4. Principal component analysis

Factor analysis was performed using the SPSS program package with varimax rotation to improve the orthogonality of resolved factors. The varimax rotated principal factor patterns for the four-factor groups (Eigenvalues > 1) explained 72.4% of the total variance (Table 2). The last column in the Table contains the communalities for the observed concentrations. The communality for an element reflects the percentage of the observed concentration that has been explained by the specific factors (sources).

The first component consists of the elements Co, Pb, and Cd. All of these elements are anthropogenic in nature. Pb, on the other hand, is commonly used as a marker element for motor vehicle emissions, so this factor has been designated as the automobile emissions factor. The second is heavily laden with Fe and Mn. These two elements are typically regarded as crustal sources. The communality for these two elements was approximately 90%, implying that approximately 10% of the observed Fe and Mn could not be explained by this system. Zn and Cu were heavily loaded on the third factor. Many smelting processes emit these two elements simultaneously. Furthermore, Cu and Zn are the primary constituents of Cu-Zn brass alloys. Thus, this factor may be interpreted as an anthropogenic factor related to the Cu and Zn industries (Isley et al., 2022).

The fourth factor had a significant loading by both Ni and Cr. These two elements are commonly found in residential areas due to their widespread use in the manufacture of office furniture and metal plating for corrosion prevention. Thus this factor is related to stainless steel (Yoshinaga et al., 2014).

4. Conclusion

According to the findings of this study, the indoor house dust found in Irbid City does not contain a high level of contamination. Heavy metals were found to be present in higher concentrations in and around highly populated areas with heavy traffic. According to the results of the enrichment factor, the levels of the following elements: Co, Ni, Zn, Co, and Cd are significantly enriched in house dust in comparison to their concentrations in nature. The combination of dust from inside and outside is the reason for the elevated levels of these elements. Calculations based on a factor analysis revealed that the outdoor dust from a variety of sources, which is typically brought inside by foot traffic, has a significant impact on the quality of the indoor environment.

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Table 3. Rotated component matrix for house dust samples.

Variable	Factor1	Factor2	Factor3	Factor4	Communality
Cu	0.11	-0.17	**0.83**	-0.11	0.75
Ni	0.19	0.22	-0.03	**0.81**	0.74
Zn	-0.20	0.18	**0.79**	0.04	0.66
Mn	0.21	**0.89**	-0.09	-0.13	0.86
Co	**0.82**	-0.06	-0.33	-0.18	0.74
Pb	**0.79**	-0.20	0.14	0.17	0.70
Cd	**0.74**	-0.12	-0.02	-0.01	0.63
Cr	-0.35	0.32	0.16	**0.73**	0.73
Fe	0.14	**0.91**	0.07	0.17	0.86
%Variance	23.0	17.7	16.0	14.0	
Total Variance Explained, (%)					**73.0**

Conflict of Interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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