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Concentration, Pollution Level, and Sources of Heavy Metals from Household Dust in Ramadi City, Iraq

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Abstract: Researchers and environmental managers have been interested in household dust pollution because exposure to heavy metals has a detrimental effect on health. This study aims to determine heavy metals concentrations (Cd, Cr, Cu, Ni, Pb and Zn), pollution level, and their potential sources in the household dust of Ramadi City, Iraq. The dust was collected from 35 houses. The atomic absorption spectrophotometry method was used to measure concentrations of heavy metals in the dust. The following was the order of the heavy metal mean concentration: Zn > Ni > Cu > Pb > Cr > Cd. These metals' mean concentrations are below background guidelines. The descending order of the EF values for the measured metals is as follows: Ni (6.35) > Cu (5.40) > Pb (1.53 > Cr (1.24) > Zn (1.14) > Cd (0.84). Results of the calculation of CF for metals measured in house dust in Ramadi City showed values of less than 1 (CF < 1 indicating a minimum contamination level. Based on the results of multivariate statistics (correlation matrix, cluster and principle components analysis), sources of Cr, Cu, Ni and Zn are indoor anthropogenic sources while the sources of Cd and Pb are outdoor anthropogenic.

Key words: Metals, pollution, house dust, Iraq.

Introduction

The U.S. Environmental Protection Agency states that internal dust is more polluted than external dust and requires attention (Tan et al., 2016). The accelerated urbanization has resulted in a growing interest in the quality of indoor dust (Shi and Wang, 2021). Approximately 90% of the time that people spend nowadays is in indoor environments (Gonzalez-Martin et al., 2020). One thousand times more likely to be exposed to pollutants indoors than outdoors (Hwang et al., 2008). Dust is defined as tiny powdery particulate matter that precipitates or is suspended in the air in indoor environments and is any particle less than 300 µm (Turner, 2011). The term "household dust" refers to a mixture of organic and inorganic particles produced by atmospheric deposition, human activity, and outdoor dust transmission (Hassan, 2012). Heavy metals, which have drawn a lot of attention owing to their high toxicity, inability to degrade, and adverse impacts on humans, are among the contaminants of hazardous indoor environments. Heavy metals are both sucked into and released from household dust (Arar et al., 2019). Heavy metals tend to settle and accumulate in interior floor dust, regardless of their origin, whether they come from a natural or human source (Clark et al.,

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2020). In addition to internal sources like fuel burning, ornamental materials, cooking, and smoking, heavy metals in dust can also come from exterior sources including soil, mining, smelting, industrial processes, and vehicle emissions (Yadav et al., 2019). As it relates to human health, heavy metal-contaminated house dust has attracted increasing attention in recent years. Several research works have been carried out to assess the metal concentrations in house dust globally, including those in Canada (Al Hejami et al., 2019), China (Wang et al., 2020; Zhao et al., 2020), Egypt (Jadoon et al., 2020), India (Yaparla et al., 2019), Iran (Hashemi et al. 2020; Tashakor et al., 2022), Jordan (Arar et al., 2019), Nepal (Yadav et al., 2019), Saudi Arabia (Albar et al., 2020), Trinidad (Clark et al., 2020), Turkey (Gul et al., 2023), USA (Dietrich et al., 2023; Matt et al., 2021). In Iraq, only one study on the contamination of household dust with heavy metals was carried out in Fallujah City, Anbar governorate (Al-Dulaimi et al., 2021).

The major objectives of this study are to (1) quantify the concentrations of heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) in samples of home dust collected in Ramadi City, Anbar governorate, (2) to evaluate the pollution level, and (3) to determine the source of heavy metals in house dust.

Materials and Methods

Description of the Study Area

The Anbar Governorate's capital is Ramadi City, located at 33° 25' 51.11" N and 43° 17' 42.21" E (Figure 1). The city of Ramadi has a hot and dry desert climate with few precipitations in winter. Ramadi City is characterised by the presence of some industrial factories and workshops in addition to increasing the number of vehicles and the resulting high traffic emissions.

Sampling and Analysis

Dust samples have been collected in May and June 2023 from 35 randomly selected homes, as shown in Figure 2. Except for the kitchen and bathroom, every surface in the house—including the flooring and window sills—was sampled for dust. Physical properties of the house, such as vicinity to major roads, number of dwellers and the habits of the occupants such as cooking, sweeping and cleaning are listed in Table 1.

Brushes and aluminum paper were used to collect the dust, which was then stored in plastic containers. After being dried, homogenised, and crushed using ceramic mortar (agate), a stainless steel sieve with a diameter of 106 mm was used to sift the dust samples. In a 3:1 ratio, nitric acid and hydrochloric acid were used to make the digesting dust. Then, 1 gram of the dry sample was combined with 10 cc of the prepared citrus combination, which had already been weighed, and mixed. The mixture was then placed in the microwave and digested for 15 minutes at 190 °C to nearly dry, following which it was allowed to cool and then rinsed with deionised water to remove the full sample. A Whitmann (42 Mm) filter was used to filter it after that, and 50 ml of distilled water was added to the mixture to complete the process (Islam et al., 2015). At the Anbar Water Directorate's Central Water Laboratory, the digested samples are examined for Cd, Cr, Cu, Fe, Ni, Pb and Zn using an atomic absorption flame emission spectrometer (ASC.7000).

Pollution Level Assessment

The pollution level in sediment, soil, and dust samples is measured using a variety of indices. The heavy metal pollution level in samples of Ramadi City household dust was determined using the enrichment factor (EF) and contamination factor (CF).

Enrichment Factor (EF)

The enrichment factor (EF), frequently used to compare an element's abundance in a sample medium to its normal natural abundance, reveals how much human activity has contributed to the existence of an element there (Gul et al., 2023). Using the formula suggested by Barbieri (2016), the EF was determined as follows:

$$\mathrm{EF} = \frac{(TE/RE)\ \mathrm{Sample}}{(TE/RE)\ \mathrm{Background\ Value}} \tag{1}$$

where TE is the metal concentration as determined by the dust sample, and RE denotes the standard metal. Iron was selected as the normalising element since natural sources (1.5%) make up the great majority of its input (Tippie, 1984). The enrichment factor categories are in the following order: deficiency to minimal enrichment (EF <2), moderate enrichment (2 < EF < 5), significant enrichment (5 < EF < 20), very high enrichment (20 <EF < 40) and extremely high enrichment (EF > 40) (Mmolawa et al., 2011).

Contamination Factor (CF)

The degree of metal contamination in dust is expressed using the contamination factor (CF), which is calculated as follows:

$$\mathrm{CF} = \frac{(Cm)\ \mathrm{Sample}}{(Cm)\ \mathrm{Background}} \tag{2}$$

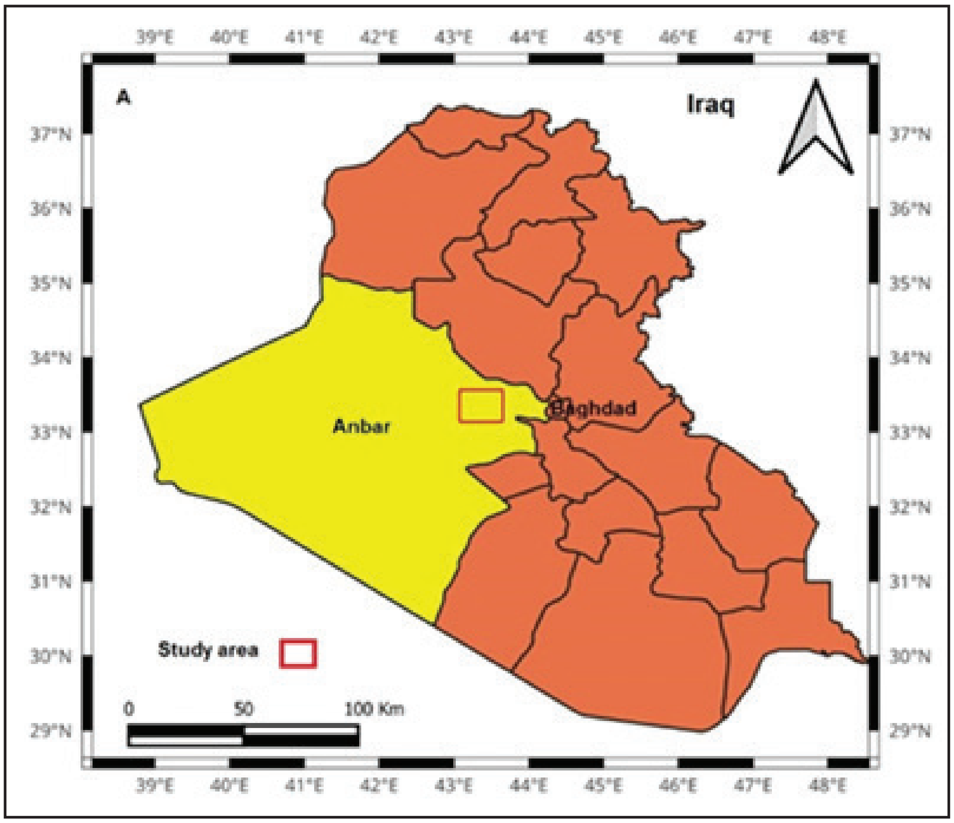

Figure 1: Location map of the study area.

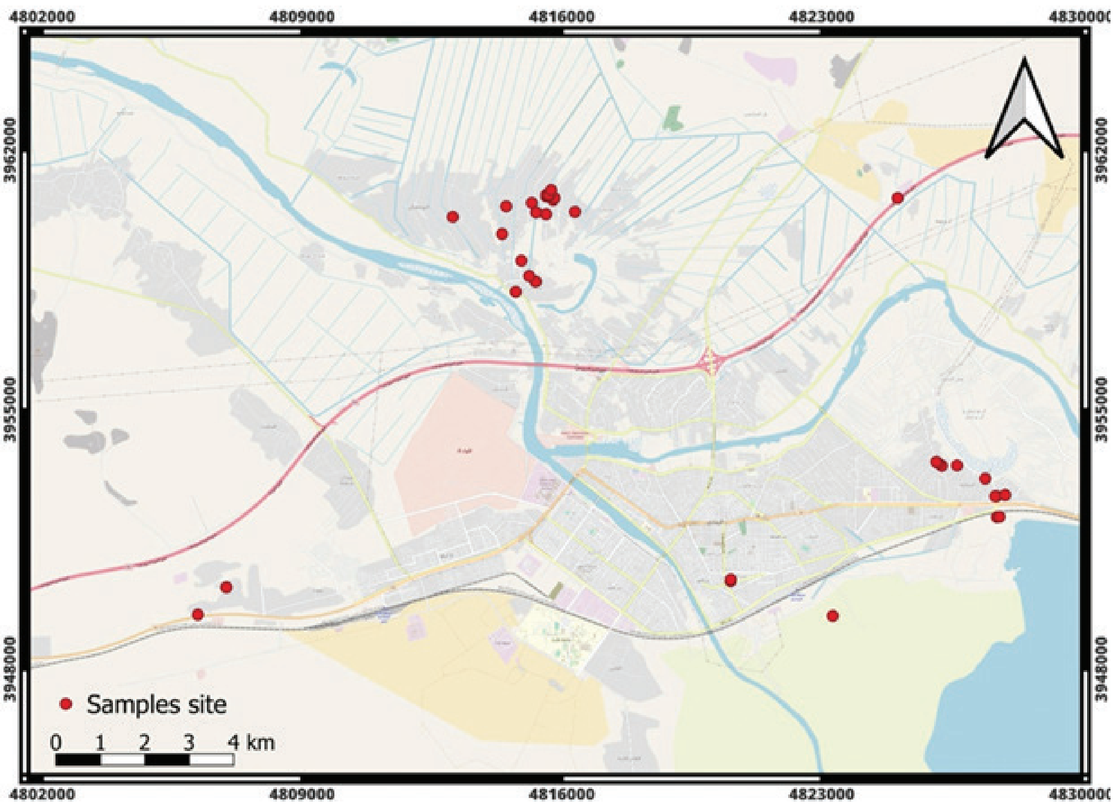

Figure 2: Sampling sites map.

Table 1: Properties of the sampling sites

Parameters	*Values (number of samples in each class)*
Age of the house (year)	1-10 (8), 10-20 (10), 20-30 (5), 30-40 (5), 40-50(3) , 50-60 (4)
Type of street outside the house	1 lane (22), 2 lane (12), Dead end (1)
Distance of the house from the street (meter)	1-10 (14), 10-20 (12), 20-30 (3), 30-40 (2), 40-50 (2), No street (2)
Stationary pollution source < 10 meters from the house	Yes (1) , No (34)
If the house is attached	Attached (10) , Detached (25)
Time since the house was painted (year)	1-10 (25), 10-20 (6), 20-30 (2), 30-40 (1), 40-50 (1)
Presence of a garage in the house	Yes(21), No (14)
If the garage is attached to the house	Yes (14), No (21)
Age of garage (year)	1-10 (7), 10-20 (10), 20-30 (2), 30-40 (2), No (14)
Distance of the garage lot to the house (meter)	1-10(11), 10-20 (9), 20-30 (1), No (14)
Floor cover	Tiles (8), Cement (12), Ceramic (13), Porcelain (1), Marble (1)
Frequency of sweeping the carpet (No. time/month)	1-5 (11), 5-10 (8), 10-15 (3), 15-20 (3), 20-25 (4), 25-30 (3), No (3)
Frequency of cleaning the carpet (No. time/month)	1-5 (2), 5-10 (2), 10-15 (2), 15-20 (9), 20-25 (5), 25-30 (15)
Open windows time (hour)	Morning(23), evening (7), No (5)
Open windows frequency (No. time/month)	1-5 (0), 5-10 (2), 10-15(8), 15-20 (3), 20-25 (2), 25-30 (15),No (5)
Cooking frequency (No. time/day)	1(0), 2(7) , 3(25), 4(3)
Cooking fuel	Gas (35) , kerosene (0) , wood (0)
Air conditioning	yes (16) , No (19)
Presence of pets in the house	Yes (1), No (34)
Floor level of the house	1 floor (14), 2 floor (21)
Number of occupants	1-5 (15), 5-10 (15), 10-15(4), 15-25 (1)

where Cm Sample represents the level of a particular metal in the dust, and Cm background represents the background value of that metal. Hakanson (1980) classified the CF values into the following four classes: ($CF < 1$) little contamination, ($1 \leq CF < 3$) moderate contamination, ($3 \leq CF < 6$) considerable contamination, and ($CF > 6$) very high contamination.

Identification of Heavy Metals Sources

Because enrichment factor analysis has a weak capacity to discriminate between various sources, it cannot find sources in complex source types (Kaonga et al., 2021). Statistical multivariate techniques including principal component analysis (PCA), cluster analysis (CA), and correlation analysis increase the capacity to distinguish between different sources. Multivariate statistics (correlation matrix analysis, CA and PCA) were carried out using STATISTICA Software - version 13.3 for Windows.

Results and Discussion

Heavy Metals Concentration

Table 2 provides the findings of the statistics analysis on the concentrations of heavy metals in household dust in Ramadi City. The levels of heavy metals in the home dust of the study area are distributed in the following descending order: Zn > Ni > Cu >Pb> Cr > Cd. Metals' spatial variation is explained by the coefficient of variance (CV). The Ni has a CV of 41.51%, indicating limited variability and steady distribution throughout the research region, while the Pb has CV of 196.43%, demonstrating increased change of Pb in house dust. Because there are no heavy metals guidelines for dust, the concentration of heavy metals was compared to soil guidelines for metals. The average concentrations of Cd, Cr, Cu, Ni, Pb, and Zn in house dust in Ramadi were compared with the United States Soil Quality Guidelines (USSQG), (USEPA, 1999) and CCMESQG

Table 2: Descriptive statistics of total concentration (mg/kg) of heavy metals in household dust in Ramadi City with USEPA and CCME guidelines

Metal	*Mean*	*Minimum*	*Maximum*	*Std. Dev.*	*Coef. Var. (CV)%*	*USEPA SQG*	*CCME SQG*
Cd	0.0072	0.000600	0.0225	0.0052	72.20	0.6	10
Cr	0.5052	0.029000	1.1366	0.2679	53.03	25	64
Cu	1.2486	0.184200	4.4540	0.9544	76.43	16	63
Ni	1.4879	0.059300	2.4173	0.6176	41.51	16	50
Pb	0.9212	0.067600	10.6753	1.8096	196.43	40	140
Zn	1.9098	0.005500	2.8830	0.8613	45.09	110	200

Table 3: Concentrations of heavy metals in household dust from Ramadi City, Iraq and other cities around the world

Country	*No of samples*	*Concentration mean (mg/kg)*						*Reference*
		Cd	*Cr*	*Cu*	*Ni*	*Pb*	*Zn*	
Ramadi, Iraq	35	0.007	0.505	1.248	1.488	0.921	1.901	This study
Sydney, Australia	82	1.64	64.5	93.3	15.1	76.2	372	Chattopadhyay et al. (2003)
Chengdu, China	90	2.37	82.7	161	52.6	123	657	Cheng et al. (2018)
Bushehr, Iran	19	5.31	143.20	186.09	57.09	209.1	567.18	Hashemi et al.2020
Toronto, Canda	67	1.7	42	136	23	36	386	Al Hejami et al.(2019)
Jeddah, Saudi Arabia	20	0.54	46.7	94.1	32.2	n.a	489	Albar et al. (2020)
Alexandria, Egypt	24	0.77	29.2	141	25.1	260	771	Jadoon et al. (2020)
Istanbul, Turkey	31	0.80	54.9	156	263	28.1	832	Kurt-Karakus (2012)
Al-Fallujah, Iraq	50	14.77	289.45	65.03	105.72	75.57	292.85	Al-Dulaimi (2021)
Ankara, Turkey	85	0.400	23.8	65.8	32.3	27.5	264	Gul et al. (2023)

Guidelines (CCCM, 2014). The mean concentrations of the measured metals in house dust in Ramadi City did not exceed the guidelines. The results of the current study were compared with the findings of a number of studies conducted throughout the world because of the scarcity of investigations on the concentration of heavy metals in household dust in Iraqi cities, except for the study of Al-Dulaimi (2021), Table 3. The results of comparing heavy metal concentrations' averages in house dust in Ramadi with that in house dust in a number of cities around the world showed that they were lower than those recorded in those cities. This conclusion may be explained in terms of the numerous internal sources of metals identified in indoor particles and the multiple external sources of metals delivered into the dwellings.

Pollution Levels Assessment

The level of house dust contamination with heavy metals in Ramadi City was determined using two indices, the enrichment factor (EF) and the contamination factor (CF). The mean values of the EF and CF for Cd, Cr, Cu, Ni, Pb and Zn in house dust in the city of Ramadi are shown in Figures 3 and 4, respectively. The obtained results show that the descending order of the EF values for the measured metals is as follows: Ni (6.35) > Cu (5.40)>Pb (1.53> Cr (1.24)> Zn (1.14)> Cd (0.84). Generally, EF< 2 denotes the presence of natural factors, whereas EF > 2 denotes the presence of anthropogenic factors (Barbieri, 2016). While Ni and Cu in house dust of Ramadi City are significantly enriched, reflecting the impact of human activities, Cd, Cr, Pb and Zn are not enriched or minimum enriched. The stainless steel and alloy efflorescence are enrichment sources for Ni in home dust (Yoshinaga et al., 2014; Cheng et al., 2018) and tobacco-filled cigarettes for indoor smokers (Matt et al., 2021). The vehicles, traffic pollutants, emissions from burning lubricating oil, vehicle lubricants, and wear and tear on the engine and tires all contribute to the enrichment of Cu in house dust (Al-Khashman,

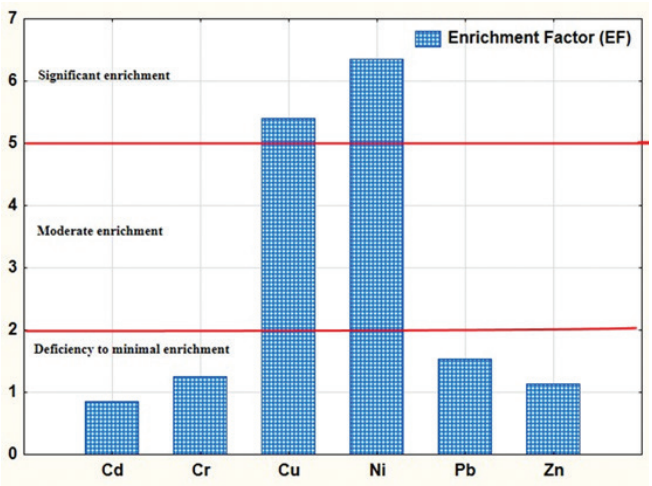

Figure 3: The mean values of EF for the measured heavy metals in household dust in Ramadi City.

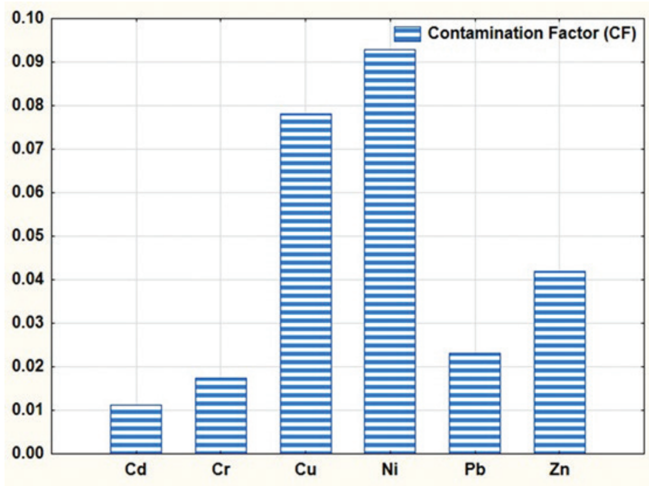

Figure 4: The mean values of CF for the measured heavy metals in household dust in Ramadi City.

2007; Jin et al., 2019; Men et al., 2018). Results of the calculation of CF for metals measured in house dust in Ramadi City showed values of less than 1 (CF< 1 indicating a minimum contamination level.

Identification of Heavy Metals Potential Sources

Findings of the correlation analysis were utilised to look into the correlations between the heavy metals found in residential dust in Ramadi City and their possible sources or origins. Table 4 shows Pearson's correlation coefficients for the heavy metal concentrations in Ramadi City's household dust. Significant positive correlations were shown by the correlation matrix analysis between Cr–Cu (R=0.42), Cr–Ni (R=0.69), Cr-Zn (R=0.52), Zn-Cd (R=0.55), Zn-Cu (R=0.45), Zn-Ni (R=0.68), and Ni-Cu (R=0.43). The common sources/origins might be used to interpret these positive significant correlation associations.

By integrating varimax rotation with Kaiser Normalisation, PCA was utilised for identifying the origins of heavy metals in residential dust in Ramadi City. Table 5 summarises the PCA results. Two significant components that together accounted for 67.60% of the total variance were identified with eigenvalues greater than 1. The metals with the largest positive loadings were Ni (0.89), Cr (0.86), Zn (0.72), and Cu (0.64), with factor 1 accounting for 48.53% of the variance in the metal data. Stainless steel and the efflorescence of alloy are the sources of Crand Ni in house dust (Cheng et al., 2018). The significant correlations between Cr, Ni, Cu, and Zn correspond to similar sources, specifically anthropogenic ones, which confirm the PCA results. Positive great loadings on Cd (0.86) and Pb (0.71) and a total variance of 19.07 were both explained by factor 2. The sources of Pb and

Table 4: Pearson correlation coefficient of heavy metals in households dust in Ramadi City

Metal	*Cd*	*Cr*	*Cu*	*Ni*	*Pb*	*Zn*
Cd	1.00	1.00				
Cr	0.13					
Cu	0.23	0.42	1.00	1.00		
Ni	0.15	0.69	0.43		1.00	
Pb	0.32	0.14	0.18	0.21		
Zn	**0.55**	0.52	0.45	0.68	0.24	1.00

Marked correlations are significant at $P < 0.05$.

Table 5: Factor loadings (varimax rotation) of heavy metals total concentrations in household dust in Ramadi City

Metal	*Factor 1*	*Factor 2*
Cd	0.12	0.86
Cr	0.86	-0.01
Cu	0.64	0.21
Ni	0.89	0.08
Pb	0.09	0.71
Zn	0.72	0.49
Eigenvalue	2.91	1.14
% Total variance	48.53	19.07
Cumulative %	48.53	67.60

Marked loadings are >0.60.

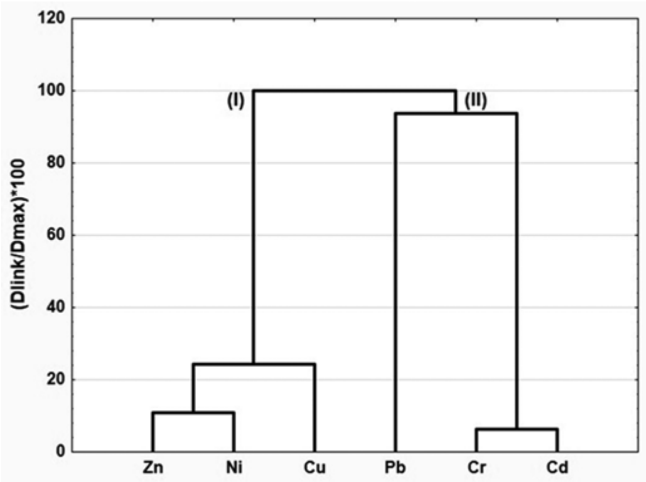

Figure 5: Cluster analysis dendrogram for metals in households dust in Ramadi City.

Cd in the exterior and internal dust included vehicles, traffic emissions, and emissions from the burning of lubricating oil, vehicle lubricants, tire wear, and engine wear and tear (Jin et al., 2019; Men et al., 2018; Zgobicki et al., 2018). In the case of Pb and Cd, factor 2 refers to outdoor anthropogenic sources.

On the standardised data set, the hierarchical cluster analysis (HCA) was performed utilising Ward's approach. The HCA findings for heavy metals in household dust in Ramadi City are shown in Figure 5. Two clusters were identified: the cluster (I) includes Zn-Ni –Cu and the cluster (II) consists of Pb-Cr-Cd. The results of CA and PCA may or may not be completely consistent.

Based on the results of multivariate statistics (correlation matrix, cluster and principle components analysis), sources of Cr, Cu, Ni and Zn are indoor anthropogenic sources, while the sources of Cd and Pb are outdoor anthropogenic. Dust from homes has been attributed to both endogenic and exogenic sources of heavy metals. In addition to commonly occurring home activities (such as smoking, burning incense, vacuuming, cleaning, and external pollutant leakage), endogenic sources include domestic products used by inhabitants (such as stoves, heaters, consumer goods, furniture, and building materials) (Kabata-Penias, 2011). Exogenic sources include tire wear-related releases of certain heavy elements, road dust, traffic pollution, and corrosion of vehicle metal parts (Lavado et al., 2007).

Conclusions

The average concentrations of Cd, Cr, Cu, Ni, Pb, and Zn in Ramadi City's houses dust are less than background levels, proving that it is not contaminated with heavy metals. The enrichment of Ni and Cu in the house dust of Ramadi City is significantly enriched, reflecting the impact of human activities, while that for Cd, Cr, Pb and Zn is deficiency to minimum. Indoor/ or outdoor anthropogenic sources are possible sources of heavy metals.

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Contents