Health Risk Assessment of Heavy Metals in Indoor Dust in Erbil City

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***Abstract*—Indoor dust is a significant source of heavy metal exposure, posing potential health risks to residents. This study investigates the concentration and possible health risks of heavy metals in household dust in Erbil City, Kurdistan Region of Iraq, and assesses the associated health risks. 123 indoor dust samples were collected from various residential areas and analyzed using Energy Dispersive X-ray spectroscopy, an advanced technique that enables precise elemental detection. The metals assessed included aluminum (Al), iron (Fe), titanium (Ti), arsenic (As), chromium (Cr), nickel (Ni), cadmium (Cd), and lead (Pb). The highest mean concentrations were observed for aluminum (Al), particularly in the Northwest region (29209 mg/kg), while lead (Pb) exhibited the lowest concentration in the same Northwest region (28 mg/kg). Notably, elevated levels of titanium (Ti) were detected in the northern area, and cadmium (Cd) was most pronounced in the Northeast, reflecting spatial variation potentially linked to traffic emissions, construction activity, and indoor smoking. To evaluate the potential health implications, hazard quotients and hazard indices (HI) are calculated for both children and adults, focusing on non-carcinogenic risks through inhalation exposure in accordance with the United States Environmental Protection Agency guidelines. Although localized HQ values were higher for certain elements, such as Ti and Cd, all calculated HI values remained below the threshold value of 1. This indicates that under current environmental conditions, indoor dust in Erbil City is unlikely to pose significant non-carcinogenic health risks through inhalation.**

***Index Terms*— Hazard index, Hazard quotient, Health risk, Heavy metal, Indoor dust.**

I. Introduction

In the past few years, the focus of scientific research has shifted towards air pollution, as human exposure to air pollution mainly occurs through indoor dust (Zhou, et al., 2019) because humans spend 90% of their time in an indoor environment (Sabzevari and Sobhanardakani, 2018). Household dust is a combination of organic and inorganic particles (Al-Dulaimi, Shartooh, and Al-Heety, 2021) in various shapes and sizes. However, typically 58% of indoor dust particles are in the size range of 44–149 µm and 6%–35% of them are in the size range of 30–63 µm (Naimabadi, Gholami and Ramezani, 2021). These particles are small enough to be absorbed by inhalation (Tashakor, et al., 2022) as the heavy metals effects through the inhalation path are slightly different compared with other exposure paths, especially for children, who have a higher relative inhalation rate per unit of body weight (Hammood, Chamani and Sobhanardakani, 2024). For example, the inhalation of arsenic causes cardiovascular disease and respiratory cancer (Mahmoud, et al., 2023). On the one hand, the exposure to nickel is mainly through inhalation in non-carcinogenic effects, including lung fibrosis, and nervous system damage, in carcinogenic effects including nasal and lung cancer (Sabzevari and Sobhanardakani, 2018); on the other hand, Pb exposure is associated with gastrointestinal, neurological, and cognitive impairment in children, learning disabilities, fainting, and in severe cases, death (Hammood, Chamani and Sobhanardakani, 2024). Cadmium is classified as a carcinogenic element and is also known as a toxic element for kidneys (Jahandari, 2020). Hexavalent chromium is both carcinogenic and genotoxic, particularly affecting lung tissues. In addition, chromium exposure can lead to pulmonary and cardiovascular toxicity (Mahmoud, et al., 2023). The accumulation of Fe in the body tissues results in cirrhosis, liver carcinoma, heart failure, diabetes mellitus, and osteoporosis (Zararsiz and Öztürk, 2020). The International Agency for Research on Cancer has classified aluminum (Al), cobalt (Co), copper (Cu), iron (Fe), nickel (Ni), and zinc (Zn) as non-carcinogenic elements, whereas arsenic (As), cadmium (Cd), chromium (Cr), and lead (Pb) are classified as both carcinogenic and non-carcinogenic elements (Tan, et al., 2016). Those heavy metals in household dust can be classified into endogenic and exogenic sources. The endogenic sources include materials used by residents of the house (Al-Dulaimi, Shartooh and Al-Heety, 2021) (cooking, consumer products, building, and furniture material) daily activities such as cleaning and smoking, incense burning (Darus, et al., 2012). The exogenic sources include road dust, vehicle emissions, and industrial discharges (Al-Khashman, 2007). Hashemi, et al., (2020) reported that the concentration of Pb can be

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due to human activities, including smoking and penetration into indoor environments in response to emission of vehicles. Somsunun, et al., (2023) reported that paint is associated with increasing As, Cu, Pb, and Zn in household dust. Rasmussen, Subramanian and Jessiman, (2001) reported that the indoor dust in electrically heated houses in Canada tends to have both mercury and lead higher than those by oil and gas. Tong and Lam, (2000) found a positive relationship between the yellow dye and Cd and Pb. The main objective of this study is (1) to quantify heavy metal concentrations in indoor dust in Erbil City and (2) to evaluate the potential health risks posed by heavy metal exposure to indoor dust through inhalation.

II. Materials and Methods

A. Study Area

Erbil city is the capital of the Kurdistan region of Iraq and is in the northeastern of Iraq, Erbil city, was divided into nine regions (Center, North, East, South, West, Northeast, Northwest, Southeast, Southwest), as shown in Fig. 1.

B. Sample Collection

A total of 123 samples of indoor dust were collected from residential houses between September and October 2024, as shown in Fig. 2, as part of the study, the homeowners were asked about the physical characteristics of their residential houses, and the responses are summarized in Table I. The dust samples were taken from window sills, closets, desks, and bookshelves using polyethylene brushes and pans for general collection and a handheld vacuum cleaner for areas that were difficult to reach, as shown in Fig. 3. Polyethylene brushes and a handheld vacuum cleaner were cleaned between each sample collection to prevent any contamination. Collected dust samples were stored in a sealed polyethylene container, labeled, and then transferred to the laboratory for elemental analysis.

C. Sample Preparation and Instrument Analysis

Collected dust samples were sifted using stainless steel sieves to remove human and pet hair and other visible extraneous particles. Then, the samples were coated with gold using a DSR1 Desk Sputter Coater. This process is done to enhance electrical conductivity, prevent charging caused by the electrical beam, and provide a resolution image. After coating, the samples were transferred to the energy dispersive X-ray spectroscopy (EDX), an analytical technique used to identify materials' elemental composition. It works by directing a beam of high-energy electrons onto a sample, causing the atoms in the material to emit X-rays (Abd Mutalib, et al., 2017). Each element emits X-rays with a unique energy, allowing for the identification and quantification of the elements present (Girão, Caputo and Ferro, 2017). In this study, the EDX analysis was carried out using equipment provided by the Scientific Research Center at Soran University using FEI Quanta 450 scanning electron microscopy (SEM) coupled with EDX detector with accelerating voltage: 200 V to 30 kV, The FEI Quanta 450 SEM, designed for versatile and advanced materials research, operates under three imaging modes–high vacuum, low vacuum, and environmental SEM (ESEM). ESEM allows the imaging of samples in a low-vacuum or variable-pressure environment, enabling the observation of non-conductive, wet, or uncoated samples without the need for

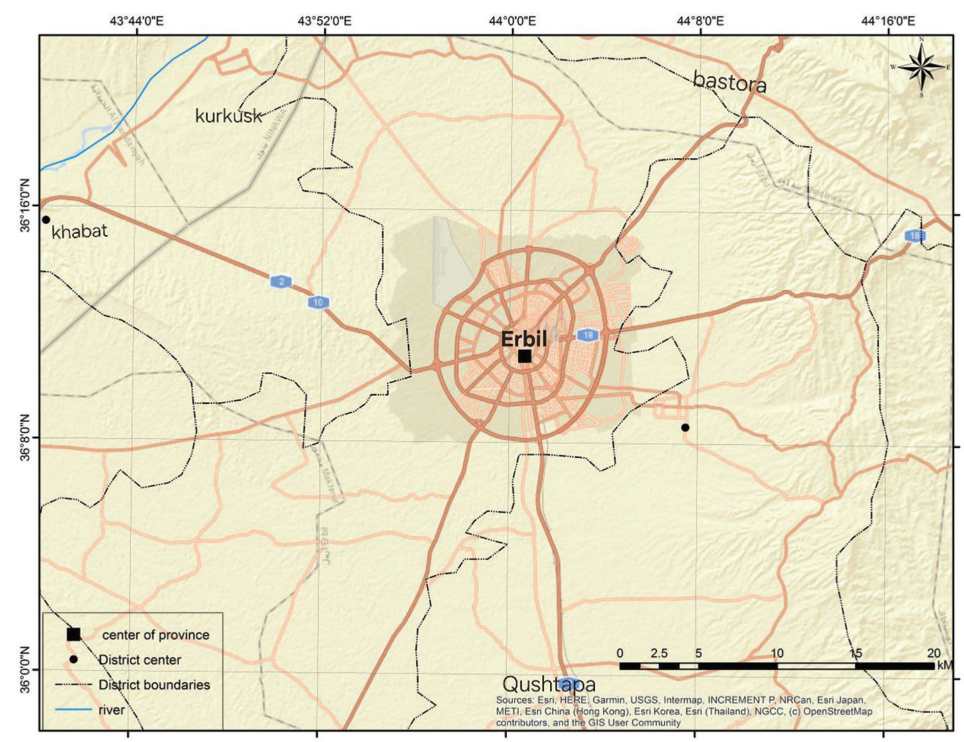

Fig. 1. Location map of the study area, created using ArcGIS.

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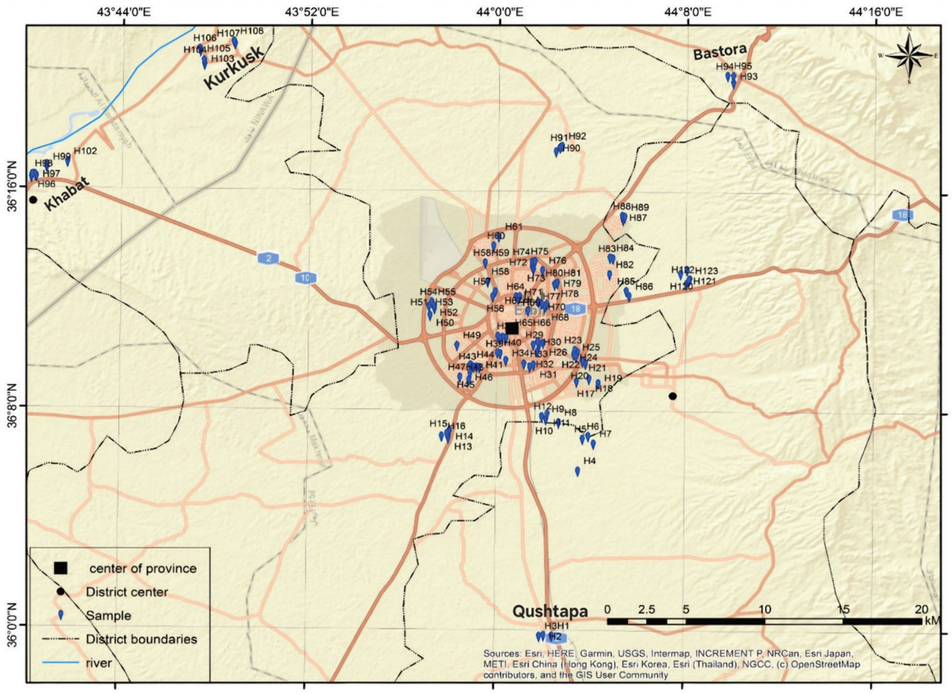

Fig. 2. Distribution of the sample locations in Erbil city, created using ArcGIS.

Fig. 3. A brush and a handheld vacuum used for dust collection.

metal coating (Mazumder, et al., 2018). It is especially useful for examining biological, environmental, and insulating materials in their natural or hydrated state (Ruozi, et al., 2011). These three imaging modes allow the characterization of conductive and non-conductive material. The EDX analysis provides both qualitative (identifies which elements are present in the sample) and quantitative data (measures the amount [concentration] of each element) (Morita, 2018). This technique is useful not only for determining elemental composition but also for mapping the spatial distribution of elements across the sample surface (Carlton, 2011).

D. Health Risk Assessment

The health risk assessment method specified by the United States Environmental Protection Agency (US-EPA) was used in this study to assess the risk resulting from exposure to heavy metals in indoor dust, as humans are mainly exposed to heavy metals through inhalation through the nose and mouth (Gul, et al., 2023). According to the Exposure Factors Handbook (USEPA, 2001), the exposure level is expressed in terms of the average daily dose (ADD) (mg/kg/day) through inhalation and is calculated separately for each heavy metal using the following formula, according to the US-EPA (Tan, et al., 2016) the parameter value of Eq. (1) is listed in Table II.

$$ADD = \frac{C\ \ InhR\ \ EF\ \ ED}{PEF\ \ BW\ \ AT} \quad (1)$$

TABLE I
Description and Characteristics of Sampling Locations

Parameter	Values (number of samples in each category)
Characteristics of the sampling area	Suburban (22) Urban (101)
Houses close to the street/ factories	Yes (58), No (65)
Number of occupants	1 (2), 2 (5), 3 (17), 4 (28), 5 (32), 6 (21), 7 (11), 8 (5), 11 (1), 15 (1).
Asthmatic children	Yes (20), No (103)
Age of the building	1–5 years (12), 6–10 years (30), 11–15 years (28), 16–20 years (27), 21–30 years (21), 31–25 years (5)
Size of the house	100–150 m^2 (50), 200–250 m^2 (50), 300–500 m^2 (22), 1000 m^2 (1)
Floor level	1 (61), 2 (18), 1&2 (44)
Presence of smokers in the household	Yes (55), No (68)
Presence of air conditioner in the house	Yes (108), No (15)
Windows opened during the day	Once or twice per week (64), three to 4 times per week (35), everyday (24)
Type of fuel used for cooking	Gas (120), Electrical (3)
Recent house repairs or painting	No (109), last 6 months (7), last year (3), last 2 years (4)
Pets	Yes (24), No (89)

TABLE II
Exposure Variables used for Non-Carcinogenic Inhalation Add Assessment

Parameters	Child	Adult
InhR	5	15.7
EF	250	250
ED	6	30
PEF	1.36E+09	1.36E+09
BW	15	60
AT NON	2190	10950

EF: The frequency of exposure, ED: The duration of exposure, PEF: The particle emission factor, BW: Body weight, AT: The average time

C: Concentration of heavy metal (mg/kg), InhR: the rate of inhalation (m^3/day), EF: The frequency of exposure (days/y), ED: The duration of exposure (year), PEF: The particle emission factor (m^3/kg), BW: Body weight (kg), AT: The average time (days) (Hassan, et al., 2024).

Non-carcinogenic health risks expressed using the hazard quotient (HQ) for both children and adults by dividing the ADD (mg/kg/day) through inhalation exposure by the reference dose (RfD) (mg/kg/day) as shown in Eq (2) is listed in Table III. The HQ from inhalation exposure is summed to calculate the HI as shown in Eq. (3) (USEPA, 2001).

$$HQ = \frac{ADD}{RfD} \quad (2)$$

$$HI = \sum HQ \quad (3)$$

If the HI value is <1, the risk is considered negligible because the estimated exposure is below the safe level set by health guidelines, meaning it is unlikely to cause harm. If the HI value is >1, the non-carcinogenic risk is considered significant (Somsunun, et al., 2023). Currently, there is no established RfD specifically for titanium (Ti) in indoor dust.

III. Results and Discussion

Table IV and Fig. 4 reveal the mean concentrations (mg/kg) of heavy metals in the dust samples collected from different directions in Erbil city (Center, North, East, South, West, Northeast, Northwest, Southeast, and Southwest), which were analyzed by EDX. The data show a significant variability in the concentrations of elements across different directions. For example, aluminum and iron have higher concentrations in the Northwest and West directions compared to the center. Certain directions show consistently higher concentrations of multiple elements. For example, the Northwest direction has high concentrations of aluminum and iron; this could indicate specific sources or pathways of element distribution in these directions, such as prevailing wind patterns or water flow (Amjadian, et al., 2018). This variability could be due to differences in soil composition, industrial activities, or natural geological formations in these directions. Comparing the center with other directions, it generally has lower concentrations for most elements, suggesting it serves as a baseline or control

TABLE III
Reference Dose Concentrations (RfD)

Heavy metals	RfD In (mg/kg/day)
Al	1.43×10^{-3}
As	3.00×10^{-4}
Pb	3.52×10^{-3}
Fe	7.00×10^{-1}
Cr	3.00×10^{-3}
Ni	2.00×10^{-2}
Cd	1.00×10^{-3}
Ti	Generally, considered safe

TABLE IV
Statistical Analysis of Elemental Concentration (Mg/Kg) in Household Dust in Erbil City

Direction	Al	Fe	Ti	As	Cr	Ni	Cd	Pb
Center								
Mean	13876	8239	721	64	42	55	46	0
Standard	2936	2643	127	44	39	77	89	0
Min	10916	5524	525	0	0	0	0	0
Max	19137	11691	903	133	124	218	234	0
North								
Mean	24155	9805	1357	4	133	71	176	27
Standard	5899	3630	1141	14	183	67	113	58
Min	13871	5787	87	0	0	0	0	0
Max	34019	1750.3	4907	56	533	191	379	207
East								
Mean	27290	10161	1194	22	57	73	181	5
Standard	4698	1400	573	47	89	88	73	13
Min	19357	8482	829	0	0	0	129	0
Max	31831	11652	2209	100	205	179	310	30
South								
Mean	26285	8964	1089	6	118	150	191	0.7
Standard	6594	2316	422	26	182	237	162	2.8
Min	13832	4051	443	0	0	0	0	0
Max	33659	13097	1710	104	520	825	452	11
West								
Mean	28256	10444	1326	0	100	106	187	0
Standard	15632	4994	688	0	148	151	226	0
Min	11430	3462	588	0	0	0	0	0
Max	78255	21788	2976	0	466	484	642	0
North East								
Mean	22942	9707	1006	31	63	100	237	22
Standard	7502	3823	445	128	131	106	201	46
Min	6174	2438	216	0	0	0	0	0
Max	36918	19276	1885	641	633	391	721	209
South East								
Mean	25135	9278	1057	15	222	121	190	16
Standard	7902	4737	505	61	295	116	176	34
Min	10370	3731	188	0	0	0	0	0
Max	40849	28261	2308	321	1211	396	732	125
South West								
Mean	26921	10508	1072	0	101	94	83	25
Standard	7141	4013	366	0	111	114	79	43
Min	15617	6084	482	0	0	0	0	0
Max	36538	20923	1658	0	396	329	216	135
North West								
Mean	29209	11821	1247	11	49	135	75	28
Standard	5390	2041	537	33	67	197	118	75
Min	18990	8570	576	0	0	0	0	0
Max	35891	15465	2372	101	164	524	367	229

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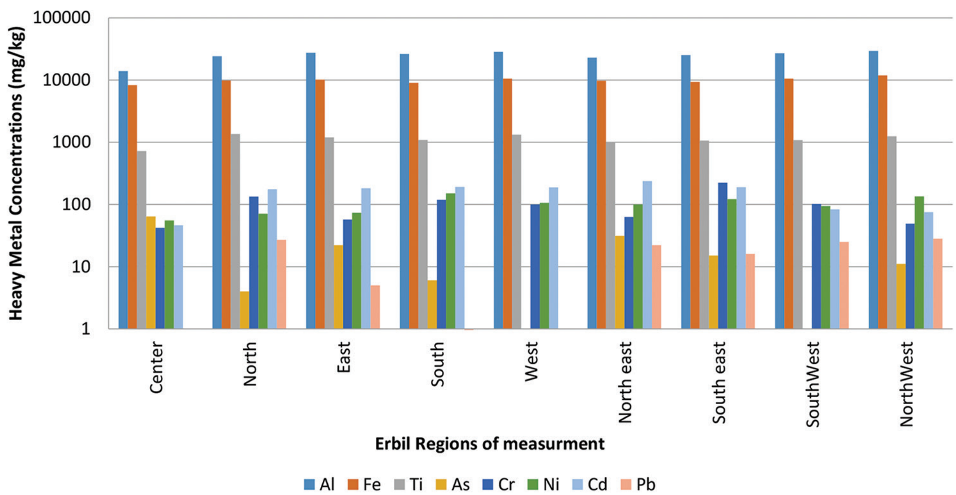

Fig. 4. Heavy metal concentration (mg/kg) in indoor dust at various locations in Erbil city.

area. The higher concentrations in other directions are likely influenced by external factors such as industrial emissions, traffic pollution, and agricultural runoff, or natural mineral deposits (Al-Sarhan et al., 2023). Specifically, the data show that aluminum (Al) had the highest mean concentration (29209 mg/kg, Northwest) followed by Fe (11,821 mg/kg, Northwest), Ti (1357 mg/kg, North), As (64 mg/kg, Center), Cr (222 mg/kg, Southeast), Ni (150 mg/kg, Northwest), Cd (237 mg/kg, Northeast), and Pb (28 mg/kg, Northwest). The mean concentrations of elements followed this order: Al (29,209 mg/kg) >Fe (11,821 mg/kg) >Ti (1357 mg/kg) >Cd (237 mg/kg) >Cr (222 mg/kg) >Ni (150 mg/kg) > As (64 mg/kg) > Pb (28 mg/kg). In addition to environmental and geographical factors, house characteristics also influence the presence of heavy metals in household dust such as proximity to the main street, presence of pets, presence of smokers, and number of occupants (Gul, et al., 2023) can affect contamination levels inside houses, those metals may enter homes through suspended particles from outdoor air, as well as street dust or soil carried on by clothes, bags, pets, and other means (Gad, et al., 2022). Iron and aluminum are major component of the Earth's crust and can enter indoor environments through the infiltration of outdoor soil and dust particles (Hassan, et al., 2024). It has been suggested that the main source of aluminum (Al) in indoor dust samples might be from construction materials, including window frames and siding, which can degrade over time and contribute to indoor dust (Hassan, 2012). In addition, it has been reported that Cr, Ni, and Cd come from tobacco smoke and paints (Roy, et al., 2024). Heavy metals such as Pb and as, along with Cd in indoor dust might result from vehicle emissions, traffic emissions, and industrial activities (Alghamdi et al., 2022). It is crucial to assess whether heavy metals in dust threaten human life. Since Kurdistan's quality control department lacks guidelines on heavy metals in dust and soil, the results were compared with studies from neighboring countries and around the world to evaluate potential health risks (Hassan, et al., 2024). Many of these studies used inductively coupled plasma mass spectrometry (ICP-MS), a highly sensitive analytical technique capable of detecting trace levels of metals and some non-metals in environmental samples. It works by using plasma to ionize the sample and a mass spectrometer to identify and quantify the elements based on their mass-to-charge ratios (Labutin, et al., 2016). In Turkey, ICP-MS was used to determine the concentrations of heavy metals in indoor dust. The study reported median concentrations rather than mean values, with zinc showing the highest median concentration (984 mg/kg) followed by Ni (282 mg/kg), Cu (200 mg/kg), Mn (163 mg/kg), Cr (89 mg/kg), Pb (30 mg/kg), Co (7.0 mg/kg), and Cd (0.95 mg/kg) (Kurt-Karakus, 2012). In Iran, mean concentrations of Zn, Cu, Pb, Cd, Cr, and Ni in indoor dust samples were found to be 567.18 mg/kg, 186.09 mg/kg, 209.01 mg/kg, mg/kg, 143.20 mg/kg, and 57.09 mg/kg, respectively, based on ICP-MS analysis. The mean concentrations of elements followed this order: Zn > Pb > Cu > Cr > Cd > Ni (Hashemi, et al., 2020). In Thailand, the indoor dust samples were also analyzed using ICP-MS. The mean concentrations were as follows: Mn (577.6 mg/kg) > Zn (408.7 mg/kg) > Cu (107.3 mg/kg) > Pb (62.1 mg/kg) > Cr (38.5 mg/kg) > Ni (34.9 mg/kg) > As (12.5 mg/kg) > Cd (2.2 mg/kg) (Somsunun, et al., 2023). In Dhaka, Bangladesh, a different technique–X-ray Fluorescence (XRF) was used to analyze indoor dust. The mean concentrations of Zn, Cu, Pb, and As in the indoor dust samples were 317.87 mg/kg > 104.29 mg/kg > 46.06 mg/kg > 2.63 mg/kg, respectively (Rahman, et al., 2021). Compared to those studies, the concentrations of heavy metals detected in indoor dust samples from Erbil city, particularly cadmium (Cd), chromium (Cr), and arsenic (As) were found to be higher compared to those reported in similar studies conducted in Iran, Turkey, Thailand, and Bangladesh, respectively. Nickel levels, on the other hand, were higher than those observed in Iran and Thailand, but lower than those reported in Turkey and Bangladesh. Several factors may have contributed to these elevated concentrations. For instance, cadmium (Cd) was found in higher concentrations in houses where indoor smoking occurs, while the proximity of many sampled houses to busy roads and active construction sites may have contributed to elevated levels of nickel and chromium through vehicular emissions. In addition, arsenic concentrations were notably higher in samples collected from the city center of Erbil, which could be associated with increased population density, the presence of older building materials, and ongoing construction work in that area.

Health risk assessments

USEPA health risk assessment technique HQ and Hazard Index, were used to determine inhalation pathway to both children and adults (Faisal, et al., 2021). The statistical data in Table V show the HQ and HI for (Cd, Ni, Cr, Ti, Pb, Al, Fe, and As) for both children and adults based on the indoor dust samples collected from various locations in Erbil city. For children, the highest HQ values in the current study were: Cd – 3.978×10^{-5} Northwest, Ni – 1.259×10^{-6} South, Cr – 1.242×10^{-5} South East, Ti – 7.593×10^{-4} North, Pb – 1.34×10^{-6} North West, Al – 2.451×10^{-4} North West, Fe – 4.314×10^{-6} North West, as – 3.581×10^{-6} center. For adults, the highest HQ value followed: Cd – 3.123×10^{-5} Northwest, Ni – 9.883×10^{-7} South, Cr – 9.751×10^{-6} South East, Ti – 5.960×10^{-4} North, Pb – 1.05×10^{-6} North West, Al – 1.924×10^{-4} North West, Fe – 3.38×10^{-6} North West, and as – 2.811×10^{-5} center. The HQ values followed this order Ti > Al > Cd > As > Cr > Fe > Pb > Ni, for both the age groups. The HQ value for children was slightly higher than for adults since the HQ for children and adults were <1, indicating no significant risk of non-carcinogenic effects. (Hashemi, et al., 2020) reported similar non-carcinogenic results for inhalation exposure to heavy metals through indoor dust in Iran. The HQ values for children were as follows: Pb – 1.6×10^{-4} > Zn 8.5×10^{-6} > Cd 3.3×10^{-6} > Cu (2.15×10^{-6}) > Cr (4.1×10^{-7}) > Ni (6.9×10^{-8}). For adults: Pb 1.01×10^{-4} > Zn (6×10^{-6} > Cd (1.7×10^{-6} > Cu 4.5×10^{-7} > Cr 3.9×10^{-7} > Ni 7×10^{-8}. In the present study, the HQ value for the Zn was not detected. Pb has the lowest HQ value for both ages, as shown in the Table V. Lead (Pb) exhibited the lowest HQ value for both age groups, as presented in Table V. However, the HQ values for Cd, Cr, and Ni were higher in both adults and children compared to the Iranian study. In Turkey, Kurt-Karakus, (2012) reported HQ values for children through inhalation in the following descending order: Pb (1.4×10^{-6}) > Ni (1.1×10^{-6}) > Cu (1.1×10^{-6}) > Zn (3.5×10^{-7}) > Cd (3.3×10^{-7}) > Cr (2.9×10^{-7}) > Co (2.2×10^{-7}) > Mn (1.2×10^{-7}). For adults: Pb (1.1×10^{-6}) > Ni (8.9×10^{-7}) > Cu (6.4×10^{-7}) > Cr (2.8×10^{-7}) > Zn (2.4×10^{-7}) > Cd (1.7×10^{-7}) > Co (1.3×10^{-7}) > Mn (1.3×10^{-7}). Compared to the current study, the HQ values for Pb and Ni were lower, whereas those for Cr and Cd were higher in Erbil City. Zn, Mn, and Cu were not detected in the present study. Rahman, et al., (2021) reported HQ values for children in Dhaka, Bangladesh as follows: Pb (6.9×10^{-6}) > As (2×10^{-6}) > Cu (2.7×10^{-7}) > Zn (2.5×10^{-7}), for adults: Pb (3.91×10^{-6}) > As (1.15×10^{-6}) > Cu (1.52×10^{-7}) > Zn (1.4×10^{-7}) In comparison to the current study, the HQ value for Pb is lower, whereas the value for As is higher in Erbil City. In addition, Cu and Zn were not detected in this study. Furthermore, the HQ values obtained in this study were also compared to those reported by Somsunun, et al., (2023. In their study, the descending order of HQ values for adults were as follows: Mn (4.1×10^{-3}) > Cd (2.29×10^{-4}) > As (1.49×10^{-4}) > Cr (6.99×10^{-5}) > Cu (3.47×10^{-5}) > Pb (3.19×10^{-6}) > Ni (3.13×10^{-7}) > Zn (2.53×10^{-7}), for the children: Mn (4.1×10^{-3}) > Cd (4.48×10^{-4}) > As (2.91×10^{-4}) > Cr (1.33×10^{-4}) > Cu (6.79×10^{-5}) > Pb (6.25×10^{-6}) > Ni (6.12×10^{-7}) > Zn ($4{,}96 \times 10^{-7}$), Their findings indicate that HQ value for inhalation exposure to indoor dust in Chiang Mai City in Thailand for both ages were found to be higher than in Erbil City. The risk of non-carcinogenic effects appears when the values are >1. In the case of the indoor dust in Erbil city, as shown in Fig. 5, for the children, the highest HI value 0.000102 was

TABLE V
Hazard Quotient (hq) and Hazard Index (hi) of Different Studied Metals According to Various Locations

Direction	HQ	Cd	Ni	Cr	Ti	Pb	Al	Fe	As	HI all metals
Center	Adult	6.06E−06	3.62E−07	1.84E−06	3.16E−04	0	9.14E−05	2.36E−06	2.81E−06	4.46E−04
	Child	7.72E−06	4.61E−07	2.35E−06	4.03E−04	0	1.16E−04	3.00E−06	3.58E−05	5.69E−04
North	Adult	2.32E−05	4.68E−07	5.84E−06	5.96E−04	1.01E−06	1.59E−04	2.80E−06	1.75E−06	7.90E−04
	Child	2.95E−05	5.95E−07	7.44E−06	7.59E−04	1.29E−06	2.02E−04	3.57E−06	2.23E−06	0.00100
East	Adult	2.39E−05	4.81E−07	2.50E−06	5.24E−04	1.01E−06	1.79E−04	2.91E−06	9.66E−06	7.43E−04
	Child	3.03E−05	6.12E−07	3.18E−06	6.68E−04	1.29E−06	2.29E−04	3.70E−06	1.23E−05	9.47E−04
South	Adult	2.52E−05	9.88E−07	5.18E−06	4.78E−04	2.63E−08	1.73E−04	2.56E−06	2.63E−06	6.88E−04
	Child	3.20E−05	1.25E−06	6.60E−06	6.09E−04	3.35E−08	2.20E−04	3.27E−06	3.35E−06	8.76E−04
West	Adult	2.46E−05	6.98E−07	4.39E−06	5.82E−04	0	1.86E−04	2.99E−06	0	8.01E−04
	Child	3.13E−05	8.89E−07	5.59E−06	7.42E−04	0	2.37E−04	3.81E−06	0	0.00102
North east	Adult	3.12E−05	6.59E−07	2.76E−06	4.41E−04	8.28E−07	1.51E−04	2.78E−06	1.36E−06	6.44E−04
	Child	3.97E−05	8.39E−07	3.52E−05	5.62E−04	1.05E−06	1.92E−04	3.54E−06	1.73E−05	8.21E−04
North West	Adult	9.88E−06	8.90E−07	2.15E−06	5.47E−04	1.05E−06	1.92E−04	3.38E−06	4.83E−06	7.62E−04
	Child	1.25E−05	1.13E−06	2.74E−06	6.97E−04	1.34E−06	2.45E−04	4.31E−06	6.15E−06	9.71E−04
South east	Adult	2.50E−05	7.97E−07	9.75E−06	4.64E−04	6.02E−07	1.65E−04	2.65E−06	6.58E−06	7.62E−04
	Child	3.18E−05	1.01E−06	1.24E−05	5.91E−04	7.67E−07	2.10E−04	3.38E−06	8.39E−06	9.71E−04
South West	Adult	1.09E−05	6.19E−07	4.43E−06	4.70E−04	9.41E−07	1.77E−04	3.01E−06	0	6.68E−04
	Child	1.39E−05	7.89E−07	5.65E−06	5.99E−04	1.19E−06	2.25E−04	3.83E−06	0	8.51E−04
HI metal	Adult	1.80E−04	5.96E−06	3.89E−06	4.42E−04	4.65E−06	1.48E−03	2.55E−05	6.72E−05	
	Children	2.29E−04	7.60E−06	4.95E−05	5.63E−05	5.93E−06	1.88E−0	3.25E−05	8.56E−05	

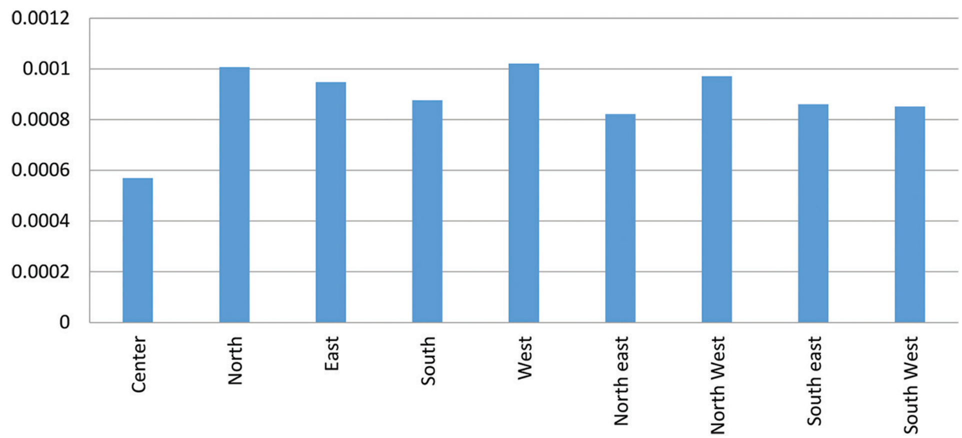

Fig. 5. Hazard Index for children's inhalation of indoor dust at various locations in Erbil City.

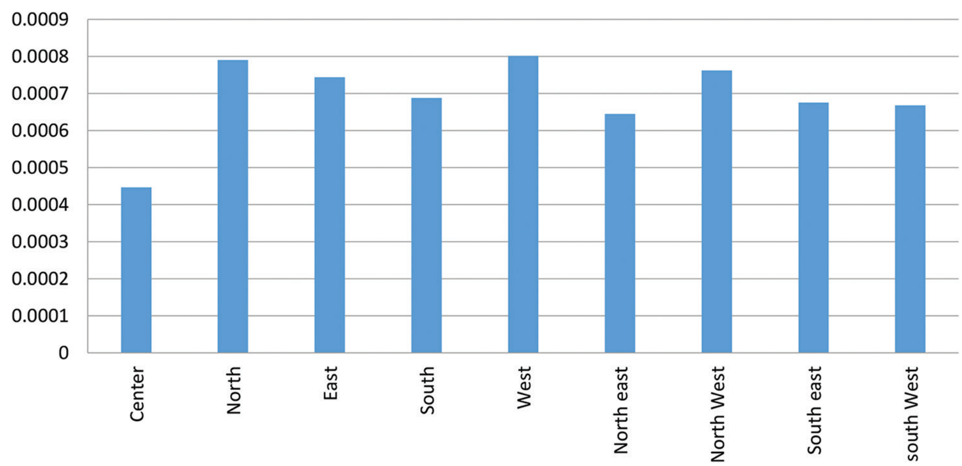

Fig. 6. Hazard Index of adult inhalation of indoor dust at various locations in Erbil City.

observed in the Western region, whereas the lowest HI value was 5.692×10^{-5} was at the center, for adults, the highest value was 8.0139×10^{-7} in the Western region, the lowest value was 4.468×10^{-7} at the center, as shown in Fig. 6, which indicates that children are exposed to the risk of heavy metals more than adults. For both ages, all the values were HI <1, this means that the indoor dust in Erbil city in all directions is no hazard to people and should not pose a risk of non-carcinogenic effect.

IV. Conclusion

This study investigated the presence and potential health risks of indoor pollutants, particularly heavy metals, in Erbil City, where children and women are most vulnerable due to prolonged time spent indoors. Health risk assessment was carried out based on USEPA guidelines for non-carcinogenic effects through inhalation exposure. The highest HQ values for both children and adults were recorded for titanium (Ti) in the North direction, highlighting localized sources or environmental factors. Although Ti lacks an established RfD, its elevated HQ values warrant attention for future assessments. In contrast, lead (Pb) consistently showed the lowest HQ values across all regions, suggesting minimal risk from Pb through inhalation. The highest non-carcinogenic hazard index (HI) for both age groups was observed in the Western region. Although certain locations exhibited elevated concentrations of elements such as Cd, Cr, and As compared to international studies, all calculated HI values remained below the threshold of 1, indicating no significant non-carcinogenic risk from inhalation exposure. The findings confirm that indoor dust in Erbil City does not pose a notable inhalation-related health risk under current conditions. However, ongoing monitoring and public awareness are recommended, especially in areas with higher metal concentrations or susceptible populations such as children.

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