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Review Article

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A systematic review on concentration of residential indoor air metals and health risk assessment

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ABSTRACT

This review evaluates metal concentrations in indoor air within residential buildings, focusing on original research published in English from 2010 to 2022. We conducted a comprehensive literature search across Google Scholar, ScienceDirect, and SpringerLink, identifying 34 relevant studies measuring metal concentrations in various residential environments. Data extraction revealed significant regional variations, with urban homes exhibiting higher metal concentrations compared to rural and industrial areas. Chromium (Cr) levels in urban regions reached 116.00±170.00 mg/kg, compared to 63.40±34.80 mg/kg in rural areas and 30.90±16.90 mg/kg in industrial regions. Nickel (Ni) concentrations were also higher in urban homes at 86.10±126.00 mg/kg, versus 27.60±9.08 mg/kg in rural and 20.40±7.65 mg/kg in industrial settings. The living room showed the highest metal concentrations, with lead (Pb) at 170.00±NA mg/kg and nickel (Ni) at 174.00±144.00 mg/kg, significantly higher than in bedrooms and kitchens ($p<0.05$). Seasonal variations indicated elevated warm season metal concentrations, with iron (Fe) measured at 11,200 ± 9830 mg/kg. Health risk assessments highlighted a total cancer risk (CR) of 1.59×10^{-3} in industrial areas, exceeding acceptable limits (10^{-5} to 10^{-6}). The ingestion pathway was the primary route for both cancer and non-cancer risks, with copper (Cu) posing the highest potential cancer risk across all regions. These findings emphasize the need for monitoring and regulation of indoor metal concentrations, particularly in industrial areas.

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Review

People spend a significant amount of their time indoors, with adults spending about 88% of the day and children spending about 71-79% in indoor environments, such as homes, offices, classrooms, laboratories, etc [1]. Daily activities in buildings such as cooking, doing housework and sweeping the house, painting walls, and using heating systems can play an important role in the production of indoor pollutants [2]. One of the other main routes of migration of mineral pollutants into the house is the penetration of outdoor air containing suspended particles (PM) [3]. Many of these pollutants can be absorbed into airborne particles in the indoor air and then settle in the environment as house dust [4]. According to the United States Environmental Protection Agency (USEPA), indoor air pollution is higher than outdoor air pollution [5]. Longer exposure to higher levels of indoor pollutants may increase the chance of exposure to some of these pollutants by up to 1,000 times compared to outdoor exposure [1]. Consequently, there is a growing emphasis on the importance of diligently monitoring indoor environmental conditions to detect and address various pollutants, with particular concern placed on heavy metals due to their detrimental effects on human health and the ecosystem [6, 7].

Indoor dust is recognized as one of the indoor pollutants that contain toxic substances, particularly heavy metals [8]. Heavy metals such as zinc (Zn), lead (Pb), copper (Cu), chromium (Cr), nickel (Ni), arsenic (As), and cadmium (Cd) are present in indoor environments due to their high toxicity and non-degradable properties, which have adverse effects on human health [9]. They occur naturally as trace metals in rocks and soils but are released into the atmosphere due to human activities. Various sources of heavy metals exist in urban areas, such as vehicle emissions, industrial discharges, and other activities [10]. Heavy metals in indoor environments can enter the human body through routes including ingestion, inhalation, and skin contact [9, 11]. The lack of a known mechanism for homeostasis means that elevated concentrations of heavy metals can harm various forms of biological life, including plants, animals, and humans. These toxic substances can build up in ecosystems, disrupting delicate balance and causing long-lasting damage to the health and survival of living organisms [12]. Numerous scientific studies conducted in the field of oncology show that the accumulation of these pollutants in the body tissues and circulatory system affects the central nervous system and the function of internal organs, as well as the role of cofactors, these metals as a trigger or initiation causing carcinogenic processes to act in the body [13].

The main objective of this extensive research is to thoroughly investigate and analyze the concentration of heavy metal found in residential indoor dust. This detailed review article will assess the health risks of these heavy metals in residential indoor dust, including non-carcinogenic and carcinogenic risks. However, it will also explore estimating these risks through various exposure pathways such as ingestion, skin contact, and inhalation. An in-depth exploration of this topic addresses critical gaps in the current understanding of the implications of heavy metals in indoor dust on human health. Furthermore, the findings of this study can serve as a valuable resource for policymakers looking to develop initiatives that prioritize safeguarding both human health and the environment.

Search strategy

We conducted a systematic search of three major databases including: Google Scholar, ScienceDirect, and SpringerLink, to identify relevant studies published between 2010 and 2022. The search targeted original research articles written in English that investigated metal concentrations in residential environments, including bedrooms, kitchens, and living rooms. The search strategy was executed in two phases. In the first phase, we used keywords such as "Environment Tobacco Smoke (ETS)," "Indoor air pollution," "Cigarette," and "Metals," combining them with Boolean operators (e.g., "ETS" OR "Indoor air pollution" OR "Cigarette" AND "Metal"). The second phase utilized additional keywords, including "ETS," "Indoor," "Cigarette," "Waterpipe," and "Heavy metal," using combinations such as "ETS" OR "Indoor" OR "Waterpipe" OR "Cigarette" AND "Heavy metal." To ensure the selection of relevant studies, we focused on those that included "heavy metal" or "metal" in their title, abstract, or keywords.

Selection criteria

Our inclusion criteria targeted studies that measured metal concentrations specifically in residential indoor environments. Articles were excluded if they focused on non-residential settings (e.g., schools, workplaces, outdoor environments), biological fluids, mainstream and sidestream emissions, or tobacco products. Similarly, abstracts, editorials, conference papers, reviews, and meta-analyses were excluded. These criteria ensured that the review concentrated on environmental exposures in residential settings without the influence of tobacco-specific studies.

Fig. 1 illustrates the details of our study selection.

Screening process

Following the removal of duplicate records, two independent reviewers (A.M. and A.R.) screened the titles and abstracts of the remaining studies to assess their relevance. When disagreements occurred, a third Reviewer (R.R.) was consulted for resolution. Additionally, R.R. re-evaluated all excluded studies to verify the accuracy and consistency of the screening process.

Quality assessment

The quality of the included studies was evaluated independently by two reviewers (A.M. and A.R.) to ensure reliability and validity. Each study was assessed based on the following criteria: the reputation and impact of the publishing journal, the rigor and appropriateness of the study's methodology, the precision and reliability of the metal measurement techniques employed, the adequacy and representativeness of the sample size, and the clarity and specificity in defining sampling locations within residential environments. Any disagreements between the two reviewers were addressed through detailed discussions involving a third reviewer (R.R.), who also conducted a comprehensive re-evaluation of all included studies. This multi-step review process ensured that only methodologically robust and scientifically credible studies were incorporated into the final analysis.

Data extraction

Key variables were extracted from the included studies, including geographic region, sampling locations within residential buildings (e.g., bedroom, kitchen), smoking status of the environment, seasonal variations, and the reported concentrations of metals. Additionally, when available, health risk assessments were reviewed, with metal concentrations compared to guidelines from the World Health Organization (WHO) and Environmental Protection Agency (EPA).

Health risk assessment

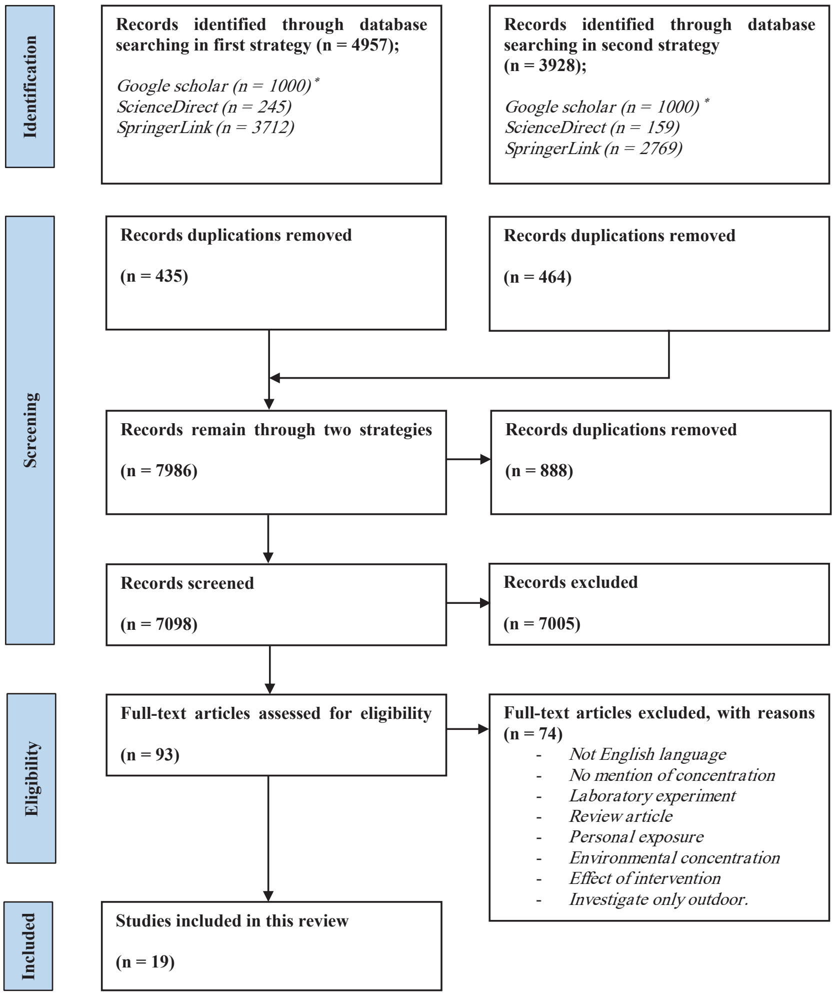
The health risk assessments were conducted to evaluate both cancer and non-cancer risks associated with exposure to certain metals in indoor environments, such as residential buildings. Exposure occurred through three primary pathways: ingestion (oral exposure), inhalation, and dermal absorption. Based on the toxicological properties of the metals in question, we applied the equations recommended by the US Environmental Protection Agency (USEPA) [14] to calculate the non-cancer risk as the Hazard Quotient (HQ) and the Cancer Risk (CR). These calculations were guided by Eq. 1 through 7 (Table 1), and the parameters for these equations are provided in Table 2.

Table 1. The calculation formulas for cancer and non-cancer risk assessment

	Definition	Formula	
D_{ing}	The exposure through ingestion	$D_{ing} = \frac{C \times IngR \times EF \times ED}{BW \times AT} \times CF$	(1)
D_{inh}	The exposure through inhalation	$D_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT}$	(2)
D_{der}	The dermal absorption exposure	$D_{der} = \frac{C \times SL \times SA \times ABS \times EF \times ED}{BW \times AT} \times CF$	(3)
CR	The cancer risk for each exposure	$CR = D \times SF$	(4)
	The total cancer risk from all pathways	$Total\ CR = LCR_{ing} + LCR_{inh} + LCR_{der}$	(5)
HQ	The hazard quotient (non-cancer risk) each exposure	$HQ = {}^{D}/_{RfD}$	(6)
	The total hazard quotient (non-cancer risk) from all pathways	$Total\ HQ = HQ_{ing} + HQ_{inh} + HQ_{der}$	(7)

Table 2. Parameters used in health risk assessment

Factor	Definition	Unit	Value	Reference
C	Metal concentrations in dust	mg/kg	-	
EF	Exposure frequency	days/years	365	
ED	Exposure duration	years	70	
BW	Body weight	kg	70	[15]
AT	Average time	days	365×ED	
$I_{ng}R$	Ingestion rate	mg/day	100	[16]
$I_{nh}R$	Inhalation rate	m^3/day	20	[16]
PEF	Particulate emission factor	m^3/kg	1.36×10^9	[15]
SA	Surface area of skin	cm^2	5700	[16]
SL	Skin adherence factor for dust	Mg/cm^2/h	0.7	[16]
ABS	Dermal absorption factor	n/a	0.001	[17]
CF	Conversion factor	kg/mg	10^{-6}	[18]



*Google scholar only accessed to first 100 relevant pages (86,000 from strategy one, and 23,000 from strategy two), so we access to first 1000 papers.

Fig. 1. The flowchart of search

Statistical analysis

All statistical analyses were conducted using R version 4.3.3. Descriptive statistics summarized the data, while normality tests were performed to evaluate the distribution of metal concentrations. Non-parametric tests, including the Kruskal-Wallis test for comparing multiple groups and the unpaired Wilcoxon test for pairwise comparisons, were used due to the non-normal distribution of data (significant threshold is <0.050). These statistical methods ensured robust and reliable comparisons across groups.

Results

Study characterizes

All of the included studies evaluated the concentration of metals in indoor houses [5, 7, 19-34]. Most included studies were conducted since 2019 (n=13; 72.2%) [7, 20, 21, 23-25, 27, 31-36]. Moreover, most of them were conducted in houses of urban regions (n=14) [7, 20-22, 24-27, 29, 31, 32, 35-37], followed by industrial regions (n=5) [19, 26, 33, 35, 36], and rural regions (n=3) [7, 28, 34]. Few studies were conducted in specific locations of houses; two studies were conducted in living rooms [31, 32], one study was conducted in the kitchen [34], one study was conducted in the bedroom [36], and others were conducted in a mixture of locations of houses. Furthermore, nine studies were conducted during warm seasons (spring and summer) [21, 22, 25-27, 32-34, 36], while three were conducted during cold seasons (fall and winter) [5, 20, 35]. The detailed and characteristics of included studies presents in Table 3.

Table 3. The detailed of included studies

Author	Region	Place in	Smoking status	Season	Quality assessment	Reference
Tashakor et al. (2022)	Industrial			Warm season		[33]
Al-Harbi et al. (2021)	Urban		Non-smoking	Warm season		[21]
Wang et al. (2020)	Rural	Kitchen		Warm season		[34]
Hashemi et al. (2020)	Urban			Warm season		[25]
Hejami et al. (2020)	Urban			Cold season		[20]
Albar et al. (2020)	Urban/Rural					[7]
Cao et al. (2020)	Urban					[23]
Zhou et al. (2019)	Industrial/Urban	Bedroom		Warm season		[36]
Rasmussen et al. (2018)	Urban	Living room	Non-smoking			[31]
He et al. (2017)	Industrial/Urban			Cold season		[35]
Srithawirat et al. (2016)	Urban	Living room		Warm season		[32]
Li et al. (2016)	Urban			Warm season		[27]
Cao et al. (2016)	Urban					[24]
Lin et al. (2015)	Rural					[28]
Altundag et al. (2013)	Urban			Warm season		[22]
Kurt-Karakus et al. (2012)				Cold season		[5]
Abdul-Wahab et al. (2004)	Industrial			Cold season		[19]
Kim et al. (1998)	Industrial/Urban		Smoking/Nonsmoking	Warm season		[26]
Salim Akhtar et al. (1994)	Urban					[29]

Influence of region on metals concentration

One of the available reservoirs for environmental pollutants is indoor dust, which may accumulate indoors over a long period from both indoor and outdoor sources [1]. Depending on the type of local human activities and location, the concentration of heavy metals in indoor dust can be estimated in different ranges [6]. Also, the natural geological composition of an area can affect the concentration of metals (38). Based on the results within houses in urban regions, the concentration of chromium (Cr) was higher (116.00±170.00 mg/kg) compared to rural (63.40±34.80 mg/kg) and industrial regions (30.90±16.90 mg/kg). Moreover, nickel (Ni) showed higher concertation (86.10±126.00 mg/kg) compared to rural (27.60±9.08 mg/kg) and industrial regions (20.40±7.65 mg/kg). Additionally, the concentration of lead (Pb) (225.00±387.00 mg/kg), arsenic (As) (49.10±47.60 mg/kg), and cobalt (Co) (13.30±10.10 mg/kg) were higher compared to rural (208.00±199.00, 4.46±NA, and 8.03±2.47 mg/kg, respectively), and industrial region (105.00±145.00, 4.30±1.87, and 5.69±5.86 mg/kg, respectively). However, the concertation of zinc (Zn) (976.00±1500.00 mg/kg) and cadmium (Cd) (9.98±25.40 mg/kg) were higher compared to industrial (534.00±268.00 and 1.94±1.60 mg/kg), and rural region (273.00±148.00 and 0.17±0.14 mg/kg). Additionally, the selenium (Se) concentration was higher compared to the rural regions (61.20±104.00 vs. 1.20±0.42 mg/kg), while this metal was not detected in the industrial regions. Urban regions often show a higher concentration of heavy metals due to emissions from industrial activities and urban sewage, traffic [38]. A review by Olujimi et al. (2021) emphasizes the role of housekeeping practices in indoor environments, indicating that inadequate cleaning can lead to the accumulation of dust laden with heavy metals. The study underlines the importance of regular cleaning to mitigate health risks associated with toxic metal exposure from dust [6]. Also, an ineffective ventilation system can lead to the accumulation of dust generated from activities due to limited air flow throughout the area [15].

Within houses in rural regions, the concertation of manganese (Mn) (497.00±220.00 mg/kg) and vanadium (V) (52.90±NA mg/kg) were higher compared to urban (343.00±287.00 and 20.60±2.15 mg/kg), and industrial region (133.00±44.80 and 13.50±3.70 mg/kg). Moreover, the concertation of iron (Fe) (19,000±NA mg/kg) and rubidium (Rb) (16.70±4.81 mg/kg) were higher compared to the urban region (10,800±7150 and 12.00±2.85 mg/kg), while these metals were not detected in an industrial region.

Within houses in industrial regions, the concentration of copper (Cu) (320.00±262.00 mg/kg) was higher compared to urban (165.00±99.80 mg/kg) and rural regions (68.70±29.90 mg/kg). Table 4 presents a concertation of metals in each region.

Table 4. The concentration of metals in different region (mg/kg)

	Industrial (N=6)	Rural (N=4)	Urban (N=21)	P-value*
Ag				
Mean (SD)	NA (NA)	NA (NA)	2.65 (1.06)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	2.65 [1.90, 3.40]	
Ba				
Mean (SD)	NA (NA)	94.3 (36.3)	144 (49.4)	0.266
Median [Min, Max]	NA [NA, NA]	94.3 [68.6, 120]	163 [71.0, 180]	
B				
Mean (SD)	NA (NA)	NA (NA)	122 (29.7)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	122 [101, 143]	

Table 4. Continued

	Industrial (N=6)	Rural (N=4)	Urban (N=21)	P-value*
Cr				
Mean (SD)	30.9 (16.9)	63.4 (34.8)	116 (170)	0.117
Median [Min, Max]	24.3 [17.6, 60.2]	52.7 [34.6, 114]	46.7 [11.0, 749]	
Cu				
Mean (SD)	320 (262)	68.7 (29.9)	165 (99.8)	0.062
Median [Min, Max]	320 [135, 505]	65.4 [36.8, 107]	154 [15.9, 419]	
Fe				
Mean (SD)	NA (NA)	19000 (NA)	10800 (7150)	0.400
Median [Min, Max]	NA [NA, NA]	19000 [19000, 19000]	14100 [144, 15000]	
Mn				
Mean (SD)	133 (44.8)	497 (220)	343 (287)	0.125
Median [Min, Max]	133 [102, 165]	448 [306, 737]	240 [18.8, 1040]	
Mo				
Mean (SD)	NA (NA)	NA (NA)	11.3 (12.3)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	11.3 [2.60, 20.0]	
Ni				
Mean (SD)	20.4 (7.65)	27.6 (9.08)	86.1 (126)	0.043
Median [Min, Max]	18.6 [13.5, 31.0]	25.8 [20.1, 38.9]	38.8 [10.0, 495]	
Pb				
Mean (SD)	105 (145)	208 (199)	225 (387)	0.311
Median [Min, Max]	64.7 [5.79, 392]	208 [67.4, 349]	123 [5.70, 1690]	
Missing	0 (0%)	2 (50.0%)	4 (19.0%)	
Zn				
Mean (SD)	534 (268)	273 (148)	976 (1500)	0.124
Median [Min, Max]	516 [254, 849]	279 [107, 427]	546 [30.9, 6890]	
Cd				
Mean (SD)	1.94 (1.60)	0.170 (0.141)	9.98 (25.4)	0.013
Median [Min, Max]	1.62 [0.490, 4.18]	0.170 [0.0700, 0.270]	3.53 [0.540, 108]	
Al				
Mean (SD)	NA (NA)	NA (NA)	17700 (4310)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	19900 [12700, 20400]	
As				
Mean (SD)	4.30 (1.87)	4.46 (NA)	49.1 (47.6)	0.057
Median [Min, Max]	4.30 [2.98, 5.62]	4.46 [4.46, 4.46]	29.6 [11.3, 142]	
Co				
Mean (SD)	5.69 (5.86)	8.03 (2.47)	13.3 (10.1)	0.304
Median [Min, Max]	5.69 [1.54, 9.83]	8.40 [5.40, 10.3]	11.6 [3.90, 32.1]	
V				
Mean (SD)	13.5 (3.70)	52.9 (NA)	20.6 (2.15)	0.046
Median [Min, Max]	13.5 [10.9, 16.1]	52.9 [52.9, 52.9]	19.6 [19.1, 25.3]	
U				
Mean (SD)	NA (NA)	NA (NA)	0.640 (0.0566)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	0.640 [0.600, 0.680]	
Ti				
Mean (SD)	NA (NA)	NA (NA)	1040 (216)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	1040 [889, 1200]	
Se				
Mean (SD)	NA (NA)	1.20 (0.424)	61.2 (104)	0.800
Median [Min, Max]	NA [NA, NA]	1.20 [0.900, 1.50]	2.00 [0.730, 181]	

Table 4. Continued

	Industrial (N=6)	Rural (N=4)	Urban (N=21)	P-value*
Sb				
Mean (SD)	NA (NA)	NA (NA)	9.31 (3.11)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	9.81 [5.54, 13.0]	
Sr				
Mean (SD)	NA (NA)	NA (NA)	226 (43.8)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	236 [164, 267]	
Sn				
Mean (SD)	NA (NA)	NA (NA)	17.8 (NA)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	17.8 [17.8, 17.8]	
Rb				
Mean (SD)	NA (NA)	16.7 (4.81)	12.0 (2.85)	0.666
Median [Min, Max]	NA [NA, NA]	16.7 [13.3, 20.1]	12.0 [9.97, 14.0]	
Hg				
Mean (SD)	NA (NA)	NA (NA)	3.10 (NA)	n.a
Median [Min, Max]	NA [NA, NA]	NA [NA, NA]	3.10 [3.10, 3.10]	

* The Kruskal-Wallis and Wilcoxon unpaired tests were used (significant value is 0.05).

NA: Not Applicable.

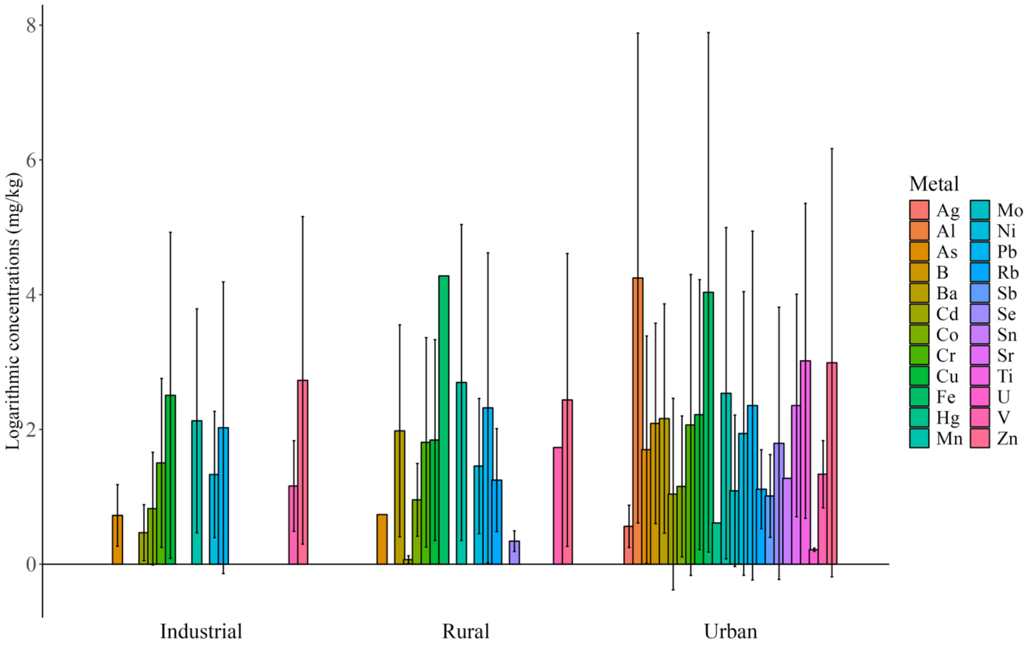


Fig. 2. Distribution of metal concertation in different regions

Furthermore, the urban region showed a higher distribution of certain metals compared to rural and industrial regions (Fig. 2). Some metals were found exclusively in urban areas. The results indicated that silver (Ag), boron (B), molybdenum (Mo), aluminum (Al), uranium (U), titanium (Ti), antimony (Sb), strontium (Sr), tin (Sn), and mercury (Hg) were uniquely present in urban regions (2.65±1.06, 122.00±29.70, 11.30±12.30, 17,700±4310, 0.64±0.05, 1040.00±216.00, 9.31±3.11, 226.00±43.80, 17.80±NA, 3.10±NA mg/kg, respectively).

Additionally, among the metals, only Ni, Cd, and V showed significant differences between regions (Kruskal-Wallis test, $p<0.050$).

Additionally, three studies reported metal concentration as microgram per cube meter (μg/m^3) [24, 30, 32]. Two were conducted in the urban regions [24, 32], and one was conducted in the industrial region [30]. The results showed that the average concertation of Cr, Cu, Ni, Pb, Zn, and Cd in urban region were higher compared to industrial region (0.82±0.73 vs. 0.003±NA, 0.76±0.50 vs. 0.0003±NA, 0.22±0.13 vs. 0.0029±NA, 0.80±0.81 vs. 0.0032±NA, and 0.92±0.66 vs. 0.748±NA μg/m^3, respectively). Furthermore, Cd and Fe only were detected in urban regions (0.14±0.10 and 1.75±1.35 μg/m^3).

Difference of place in a residential building on metals concentration

Heavy metals can be found in various locations due to human activities such as building construction, painting, vehicle traffic, industrial processes, and cooking [25]. The results revealed a significant concentration of metals in the living room of houses, with Ag (2.65±1.06 mg/kg), B (122.00±29.70 mg/kg), Mo (11.30±12.30 mg/kg), Al (20,200.00±356.00 mg/kg), As (13.50±3.04 mg/kg), U (0.64±0.05 mg/kg), Ti (1040.00±216.00 mg/kg), Sb (9.10±3.25 mg/kg), Sr (216.00±72.80 mg/kg), and Sn (17.80±NA mg/kg) being exclusively found in this area.

However, the concertation of Cr was close to significant higher in the living room (437.00±441.00 mg/kg) compared to the kitchen (57.20±NA mg/kg) and bedroom (28.70±4.95 mg/kg) (Kruskal-Wallis test, p=0.052). Additionally, Cu was higher in the living room compared to the kitchen (247.00±NA vs. 74.80±NA mg/kg). In contrast, Fe showed higher concertation in the kitchen compared to the living room (19,000.00±NA vs. 14,400.00±890.00 mg/kg; Wilcoxon unpaired test, p=0.666). The smoke produced from burning solid fuels contains fine and coarse particles that can hang in the air and settle in different areas of a room. This smoke carries pollutants such as heavy metals and organic substances. Additionally, soot generated during cooking can also contain heavy metals [37]. Ibanez et al. (2010) highlight the type of flooring and construction materials used in homes can influence the levels of metals like iron, which are found in high concentrations in household dust [39]. Also, in the results of a study on measuring the concentration of heavy metals in domestic dust in Malaysia, a higher concentration of iron was observed compared to other metals [40]. Moreover, Mn showed close to significant higher concertation in the kitchen (737.00±NA mg/kg) compared to the living room (343.00±12.00 mg/kg) and bedroom (160.00±47.50 mg/kg) (Kruskal-Wallis test, p=0.052). Furthermore, the living room had close to significant higher concertation of Ni (174.00±144.00 mg/kg) compared to the bedroom (25.40±5.20 mg/kg) and kitchen (20.10±NA mg/kg) (Kruskal-Wallis test, p=0.052). Additionally, Pb had higher concertation in the living room (170.00±NA mg/kg) compared to the bedroom (91.40±28.30 mg/kg) and kitchen (67.40±NA mg/kg) (Kruskal-Wallis test, p=0.187). Similarly, Zn showed higher concertation in the living room (1330.00±NA mg/kg) compared to the bedroom (663.00±131.00 mg/kg) and kitchen (363.00±NA mg/kg) (Kruskal-Wallis test, p=0.118). Cd had a higher concentration in the living room compared to the bedroom (5.45±0.91 vs. 4.13±1.99 mg/kg; Wilcoxon test, p=0.333), while this metal was not found in the kitchen. A close to significant higher concentration of metal was observed in the living room compared to the bedroom (23.80±2.12 vs. 17.80±3.37 mg/kg; Wilcoxon test, p=0.055). Moreover, the distribution of type of metals in the living room was higher compared to the kitchen and bedroom (Fig. 3).

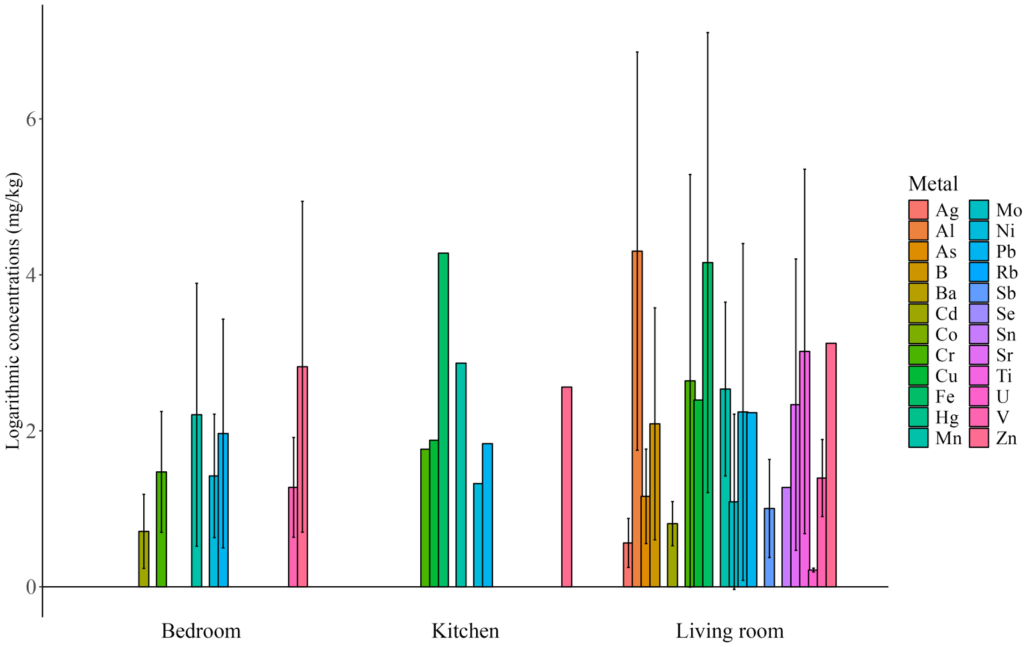


Fig. 3. Distribution of metal concertation in different place of residential buildings

Influence of seasonal variation on metal concentration

With the change of seasons, the principles and ways of human life such as tourism, temperature regulation in residential areas, consumption of fertilizers and pesticides in agricultural areas and even energy and other raw materials also change [41]. Based on the results, the distribution of metals in warm season was higher compared to cold season (Fig. 4). In this line, Fe, Al, As, V, Sb, and Sr were found only in the warm season (11,200±9830, 12,700±NA, 21.60±22.20, 17.80±3.37, 9.27±5.28, and 236.00±6.36 mg/kg, respectively). Additionally, Ba, Cr, Mn, Zn, Cd, and Co showed higher concentrations during warm season than cold season; however, these differences were not statistically significant (Wilcoxon unpaired test, $p>0.05$). The increase in the concentration of these metals in the warm season can be related to transportation and industrial activities, because during the warm season, the volume of cultural activities, tourism, and the milling industry is greater, which can lead to more traffic [42].

In contrast, Cu, Ni, and Pb showed higher concentrations during cold season than warm season; however, these differences were not statistically significant (Wilcoxon unpaired test, $p>0.050$). The increase in the concentration of the mentioned metals in the cold season season can be attributed to the release of car pollutants, corrosion of alloys used in car components, thermal power plants, home heating and coal combustion sources in the studied areas [42]. Pb is anthropogenic in origin and can be emitted from potential sources including coal, motor vehicles and industrial operations, and its levels can change in different seasons [43]. Table 5 presents details of the concentration of metals in each season.

Table 5. The concentration of metals in different season (mg/kg)

	Warm season (N=18)	Cold season (N=4)	P-value*
Ba			
Mean (SD)	164 (NA)	71.0 (NA)	n.a
Median [Min, Max]	164 [164, 164]	71.0 [71.0, 71.0]	
Cr			
Mean (SD)	68.6 (78.7)	42.0 (10.5)	0.736
Median [Min, Max]	33.1 [17.6, 315]	41.8 [29.4, 55.0]	
Cu			
Mean (SD)	162 (113)	258 (170)	0.198
Median [Min, Max]	135 [15.9, 419]	196 [136, 505]	
Fe			
Mean (SD)	11200 (9830)	NA (NA)	n.a
Median [Min, Max]	14500 [144, 19000]	NA [NA, NA]	
Mn			
Mean (SD)	317 (280)	97.0 (55.2)	0.197
Median [Min, Max]	188 [18.8, 879]	97.0 [58.0, 136]	
Ni			
Mean (SD)	64.6 (125)	143 (170)	0.500
Median [Min, Max]	24.2 [13.5, 495]	143 [23.0, 263]	
Pb			
Mean (SD)	115 (84.2)	168 (173)	0.829
Median [Min, Max]	94.5 [5.79, 366]	125 [28.0, 392]	
Zn			
Mean (SD)	720 (588)	413 (292)	0.248
Median [Min, Max]	607 [30.9, 2630]	320 [180, 832]	
Cd			
Mean (SD)	3.88 (2.51)	2.28 (1.43)	0.316
Median [Min, Max]	3.28 [0.490, 8.31]	2.08 [0.800, 4.18]	
Al			
Mean (SD)	12700 (NA)	NA (NA)	n.a
Median [Min, Max]	12700 [12700, 12700]	NA [NA, NA]	
As			
Mean (SD)	21.6 (22.2)	NA (NA)	
Median [Min, Max]	13.0 [2.98, 56.7]	NA [NA, NA]	n.a
Co			
Mean (SD)	14.2 (11.2)	5.00 (NA)	0.666
Median [Min, Max]	12.5 [1.54, 32.1]	5.00 [5.00, 5.00]	
V			
Mean (SD)	17.8 (3.37)	NA (NA)	n.a
Median [Min, Max]	19.2 [10.9, 20.6]	NA [NA, NA]	
Sb			
Mean (SD)	9.27 (5.28)	NA (NA)	n.a
Median [Min, Max]	9.27 [5.54, 13.0]	NA [NA, NA]	
Sr			
Mean (SD)	236 (6.36)	NA (NA)	n.a
Median [Min, Max]	236 [231, 240]	NA [NA, NA]	

* The Wilcoxon unpaired tests were used (significant value is 0.05).

NA: Not Applicable.

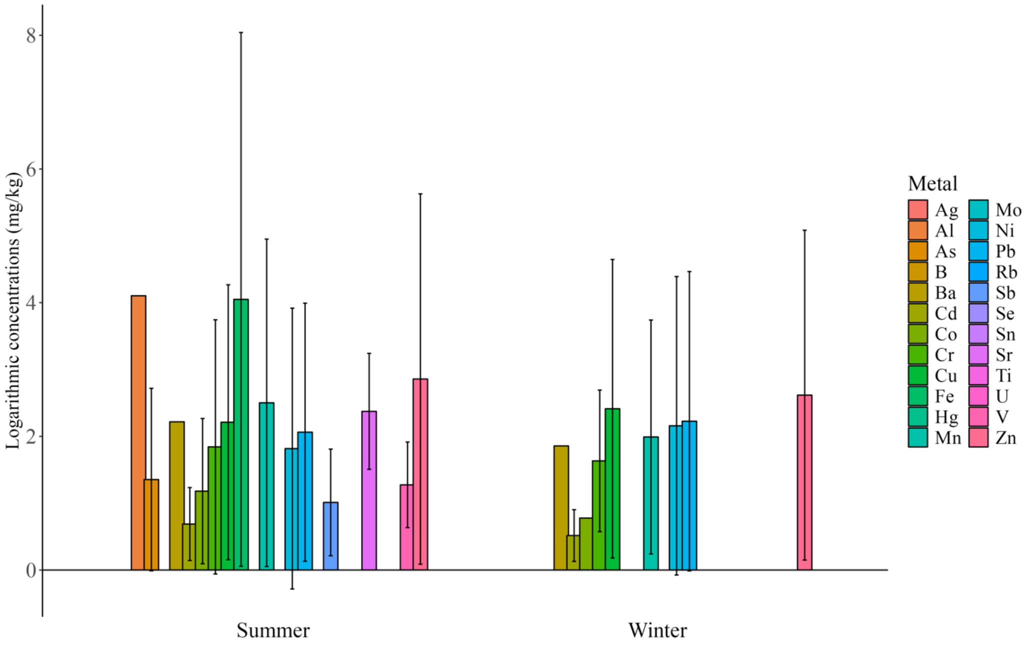


Fig. 4. Distribution of metals concertation in different seasons

Health risk assessment

Today, heavy metal pollution of indoor dust from indoor activities and outdoor sources is considered as an important environmental issue due to the potential adverse effects of toxic heavy metals on health [44]. The health risk assessment showed that the ingestion pathway's daily intake (D) was higher than the other pathways in the three regions. In this line, the ingestion pathway's Cancer Risk (CR) and Hazard Quotient (HQ) were higher than the others.

The findings revealed a stark reality: the total CR of houses in the industrial region was higher (1.59×10^{-3}) than those in urban (1.59×10^{-3}) and rural regions (3.94×10^{-4}). Furthermore, the CR of houses in each region exceeded the permissible limit (10^{-5}-10^{-6}) [45], and posing a potential cancer risk. The total HQ of houses in the industrial region was also higher (2.30) than those in rural (1.26) and urban regions (7.81×10^{-1}). However, the results showed the industrial and rural regions also exceeded the permissible limit (1) [45] for non-cancer risk.

Moreover, the results showed that Cu had the highest potential for cancer risk among metals with ingestion and dermal pathways, while Se had the highest potential for inhalation pathways in three regions. Furthermore, within urban areas, As had the highest HQ among metals with ingestion pathways, while within rural and industrial regions, Pb had the highest HQ. Moreover, with the inhalation pathway, Mn had the highest HQ among metals within the urban region, while within rural and industrial regions, Pb had the highest HQ. Additionally, within urban and rural regions, Cr had the highest HQ among the metals with dermal pathways, while within industrial regions, Cu had the highest HQ. Tables 6 and 7 present the details of each region's CR, and HQ.

Furthermore, the results showed that the total CR of houses during cold season had a higher value compared to warm season (1.29×10^{-3} vs. 8.95×10^{-4}); however, the total CR of houses surpassed the permission limit (10^{-5}-10^{-6}) (45). In contrast, the total HQ of houses during warm season had a higher value than in cold season (4.54×10^{-1} vs. 2.14×10^{-1}), while the total HQ did not surpass the permission limit (1) [45]. Tables 8 and 9 present the details of each season's CR, and HQ.

Table 6. The cancer risk (CR) of metals based on the different regions

	Region								
	Urban			**Rural**			**Industrial**		
	CR_{ing}	CR_{inh}	CR_{der}	CR_{ing}	CR_{inh}	CR_{der}	CR_{ing}	CR_{inh}	CR_{der}
Sb									
As	1.05×10^{-04}	1.55×10^{-07}	4.20×10^{-06}	9.56×10^{-06}	1.41×10^{-08}	3.81×10^{-07}	9.21×10^{-06}	1.36×10^{-08}	3.68×10^{-07}
Ba									
B									
Cd	7.14×10^{-06}		1.14×10^{-05}	1.22×10^{-07}	2.25×10^{-10}	1.94×10^{-07}	1.39×10^{-06}	2.57×10^{-09}	2.21×10^{-06}
Cr	8.29×10^{-05}	1.32×10^{-08}	3.31×10^{-06}	4.53×10^{-05}	5.59×10^{-07}	1.81×10^{-06}	2.21×10^{-05}	2.73×10^{-07}	8.81×10^{-07}
Mn		1.02×10^{-06}							
Mo									
Ni					4.87×10^{-07}			3.60×10^{-07}	
Se		1.52×10^{-06}							
Ag									
Sr									
Zn									
Fe									
Al									
Cu	4.01×10^{-04}		4.00×10^{-04}	1.67×10^{-04}		1.66×10^{-04}	7.77×10^{-04}		7.75×10^{-04}
Pb	2.73×10^{-06}			2.53×10^{-06}	1.84×10^{-09}		1.28×10^{-06}	9.26×10^{-10}	
Co		1.99×10^{-09}			1.65×10^{-08}			1.17×10^{-08}	
Sum	5.99×10^{-04}	2.74×10^{-06}	4.19×10^{-04}	2.24×10^{-04}	1.08×10^{-06}	1.69×10^{-04}	8.11×10^{-04}	6.61×10^{-07}	7.79×10^{-04}
'otal CR		1.02×10^{-03}			3.94×10^{-04}			1.59×10^{-03}	

Table 7. The Hazard quotient (HQ) of metals based on the different regions

	Region								
		Urban			Rural			Industrial	
	HQ_{ing}	HQ_{inh}	HQ_{der}	HQ_{ing}	HQ_{inh}	HQ_{der}	HQ_{ing}	HQ_{inh}	HQ_{der}
Sb	3.33×10^{-02}			3.33×10^{-02}			3.33×10^{-02}		
As	2.34×10^{-01}			2.12×10^{-02}			2.34×10^{-01}		
Ba	1.03×10^{-03}			6.74×10^{-04}			1.03×10^{-03}		
B	8.71×10^{-04}						8.71×10^{-04}		
Cd	1.43×10^{-02}	2.10×10^{-06}	5.69×10^{-02}	2.43×10^{-04}	3.57×10^{-08}	9.69×10^{-04}	1.43×10^{-02}	4.08×10^{-07}	1.11×10^{-02}
Cr	5.52×10^{-02}	8.52×10^{-04}	1.10×10^{-01}	3.02×10^{-02}	4.66×10^{-04}	6.02×10^{-02}	5.52×10^{-02}	2.27×10^{-04}	2.94×10^{-02}
Mn	3.50×10^{-03}	1.44×10^{-03}		5.07×10^{-03}	2.09×10^{-03}		3.50×10^{-03}	5.59×10^{-04}	
Mo	3.23×10^{-03}	4.80×10^{-07}	3.39×10^{-04}				3.23×10^{-03}		
Ni	6.15×10^{-03}	8.78×10^{-07}	9.09×10^{-04}	1.97×10^{-03}	2.81×10^{-07}	2.91×10^{-04}	6.15×10^{-03}	2.08×10^{-07}	2.15×10^{-04}
Se	1.75×10^{-02}			3.43×10^{-04}			1.75×10^{-02}		
Ag	7.57×10^{-04}						7.57×10^{-04}		
Sr	5.38×10^{-04}						5.38×10^{-04}		
Zn	4.65×10^{-03}	6.83×10^{-07}	9.27×10^{-04}	5.57×10^{-04}	8.19×10^{-08}	1.95×10^{-05}	1.99×10^{-03}	1.63×10^{-07}	3.87×10^{-05}
Fe	2.20×10^{-02}	3.24×10^{-06}	7.70×10^{-04}	2.71×10^{-02}			1.54×10^{-02}		
Al	2.53×10^{-02}						6.32×10^{-01}		
Cu	5.89×10^{-03}	8.62×10^{-07}	7.84×10^{-04}	2.80×10^{-02}	4.10×10^{-06}	7.46×10^{-03}	6.73×10^{-02}	1.91×10^{-05}	3.47×10^{-02}
Pb	9.18×10^{-02}	1.34×10^{-05}	2.44×10^{-02}	9.90×10^{-01}	7.65×10^{-03}	7.41×10^{-04}	1.07	3.86×10^{-03}	3.74×10^{-04}
Co	6.33×10^{-02}	4.89×10^{-04}	4.74×10^{-05}	3.82×10^{-02}	2.95×10^{-04}	2.86×10^{-05}	6.33×10^{-02}	2.09×10^{-04}	2.03×10^{-05}
Sum	5.83×10^{-01}	2.80×10^{-03}	1.95×10^{-01}	1.18	1.05×10^{-02}	6.97×10^{-02}	2.22	4.88×10^{-03}	7.58×10^{-02}
Total HQ		7.81×10^{-01}			1.26			2.30	

Table 8. The cancer risk (CR) of metals based on the different season

	Season					
	Warm season			**Cold season**		
	CR_{ing}	CR_{ing}	CR_{der}	CR_{ing}	CR_{ing}	CR_{der}
Sb						
As	4.63×10^{-05}	6.81×10^{-08}	1.85×10^{-06}			
Ba						
Cd	2.78×10^{-06}	5.14×10^{-09}	4.42×10^{-06}	1.63×10^{-06}	3.02×10^{-09}	2.60×10^{-06}
Cr	4.90×10^{-05}	6.05×10^{-07}	1.96×10^{-06}	3.00×10^{-05}	3.71×10^{-07}	1.20×10^{-06}
Mn						
Ni		1.14×10^{-06}			2.52×10^{-06}	
Sr						
Zn						
Fe						
Al						
Cu	3.93×10^{-04}		3.92×10^{-04}	6.27×10^{-04}		6.25×10^{-04}
Pb	1.40×10^{-06}	1.01×10^{-09}		2.04×10^{-06}	1.48×10^{-09}	
Co		2.92×10^{-08}			1.03×10^{-08}	
Sum	4.93×10^{-04}	1.85×10^{-06}	4.01×10^{-04}	6.60×10^{-04}	2.91×10^{-06}	6.29×10^{-04}
Total CR		8.95×10^{-04}			1.29×10^{-03}	

Table 9. The Hazard quotient (HQ) of metals based on the different season

	Season					
	Warm season			Cold season		
	HQ_{ing}	HQ_{ing}	HQ_{der}	HQ_{ing}	HQ_{ing}	HQ_{der}
Sb	3.31×10^{-02}					
As	1.03×10^{-01}					
Ba	1.17×10^{-03}			5.07×10^{-04}		
Cd	5.54×10^{-03}	8.15×10^{-07}	2.21×10^{-02}	3.26×10^{-03}	4.79×10^{-07}	1.30×10^{-02}
Cr	3.27×10^{-02}	5.04×10^{-04}	6.52×10^{-02}	2.00×10^{-02}	3.09×10^{-04}	3.99×10^{-02}
Mn	3.23×10^{-03}	1.33×10^{-03}		9.90×10^{-04}	4.08×10^{-04}	
Ni	4.61×10^{-03}	6.59×10^{-07}	6.82×10^{-04}	1.02×10^{-02}	1.46×10^{-06}	1.51×10^{-03}
Sr	5.62×10^{-04}					
Zn	3.43×10^{-03}	5.04×10^{-07}	6.84×10^{-04}	1.97×10^{-03}	2.89×10^{-07}	3.92×10^{-04}
Fe	2.29×10^{-02}	3.36×10^{-06}	7.98×10^{-04}			
Al	1.81×10^{-02}					
Cu	5.79×10^{-03}	8.47×10^{-07}	7.70×10^{-04}	9.21×10^{-03}	1.35×10^{-06}	1.23×10^{-03}
Pb	4.69×10^{-02}	6.86×10^{-06}	1.25×10^{-02}	6.86×10^{-02}	1.00×10^{-05}	1.82×10^{-02}
Co	6.76×10^{-02}	5.22×10^{-04}	5.06×10^{-05}	2.38×10^{-02}	1.84×10^{-04}	1.78×10^{-05}
Sum	3.49×10^{-01}	2.37×10^{-03}	1.03×10^{-01}	1.39×10^{-01}	9.14×10^{-04}	7.43×10^{-02}
Total HQ		4.54×10^{-01}			2.14×10^{-01}	

Conclusion

The results indicated that region and season could have an impact on metals concentrations in indoor places. The variety and distribution of metals in the urban region were higher than in other regions, while the potential of cancer and non-cancer risks showed that the industrial region had the highest value. Thus, the concentration of metals with potential cancer or non-cancer risk showed higher value in the industrial region compared to the urban region. Moreover, a significant difference was only observed for Ni, Cd, and V between the regions.

Within houses, the living room had the highest variety and distribution of metals compared to the bedroom and kitchen.

Furthermore, seasonal variations could affect the concertation of metals in indoor houses; however, none of the metals showed significant differences. Warm seasons had higher metals compared to cold seasons, and the distribution of metals during warm seasons was higher compared to cold seasons. However, both warm and cold seasons had the potential for cancer risk.

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Competing interests

It is not applicable in this research. All experimented results are presented in the manuscript.

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Ethical considerations

“Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely ob-served by the authors.”

References

1. Shi T, Wang Y. Heavy metals in indoor dust: Spatial distribution, influencing factors, and potential health risks. Science of the Total Environment. 2021;755:142367.

2. Tran VV, Park D, Lee Y-C. Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality. International journal of environmental research and public health. 2020;17(8):2927.

3. Hunt A, Johnson DL, Griffith DA. Mass transfer of soil indoors by track-in on footwear. Science of the Total Environment. 2006;370(2-3):360-71.

4. Sabzevari E, Sobhanardakani S. Analysis of Selected Heavy Metals in Indoor Dust Collected from City of Khorramabad, Iran: A Case Study. Jundishapur J Health Sci. 2018;10(3):e67382.

5. Kurt-Karakus PB. Determination of heavy metals in indoor dust from Istanbul, Turkey: estimation of the health risk. Environment international. 2012;50:47-55.

6. Tan SY, Praveena SM, Abidin EZ, Cheema MS. A review of heavy metals in indoor dust and its human health-risk implications. Reviews on Environmental Health. 2016;31(4):447-56.

7. Albar HMSA, Ali N, Eqani SAMAS, Alhakamy NA, Nazar E, Rashid MI, et al. Trace metals in different socioeconomic indoor residential settings, implications for human health via dust exposure. Ecotoxicology and environmental safety. 2020;189:109927.

8. Morawska L, Salthammer T. Indoor environment: airborne particles and settled dust: John Wiley & Sons; 2006.

9. Meza-Figueroa D, De la O-Villanueva M, De la Parra ML. Heavy metal distribution in dust from elementary schools in Hermosillo, Sonora, México. Atmospheric Environment. 2007;41(2):276-88.

10. Thornton I. Metal contamination of soils in urban areas. 1991.

11. Yang Q, Chen H, Li B. Source identification and health risk assessment of metals in indoor dust in the vicinity of phosphorus mining, Guizhou Province, China. Archives of environmental contamination and toxicology. 2015;68:20-30.

12. Jeleńska M, Górka-Kostrubiec B, Werner T, Kądziałko-Hofmokl M, Szczepaniak-Wnuk I, Gonet T, et al. Evaluation of indoor/outdoor urban air pollution by magnetic, chemical and microscopic studies. Atmospheric Pollution Research. 2017;8(4):754-66.

13. Mitchell CS, Zhang J, Sigsgaard T, Jantunen M, Lioy PJ, Samson R, et al. Current state of the science: health effects and indoor environmental quality. Environmental health perspectives. 2007;115(6):958-64.

14. EPA U. Soil screening guidance: Technical background document| Superfund| US EPA. Washington, DC: US Environmental Protection Agency[Accessed 7 March 2018]. 1996.

15. Clarke CE, Mohammed FK, Hamid A, Bent G-A. Quantification and health risk assessment of heavy metals in residual floor dust at an indoor firing range: A case study in Trinidad, WI. International Journal of Environmental Health Research. 2022;32(3):652-64.

16. EPA U. Supplemental guidance for developing soil screening levels for superfund sites. Peer Review Draft, OSWER. 2001;9355:4-24.

17. risk assessment information system [Internet]. 2004. Available from: http://rais.ornl.gov/

18. Assessment PR. Risk Assessment guidance for superfund: volume III-part a. Process for Conducting Probabilistic Risk Assessment Unites States Environmental Protection Agency Washington. 2001.

19. Abdul-Wahab SA, Yaghi B. Total suspended dust and heavy metal levels emitted from a workplace compared with nearby residential houses. Atmospheric Environment. 2004;38(5):745-50.

20. Al Hejami A, Davis M, Prete D, Lu J, Wang S. Heavy metals in indoor settled dusts in Toronto, Canada. Science of the Total Environment. 2020;703:134895.

21. Al-Harbi M, Alhajri I, Whalen JK. Characteristics and health risk assessment of heavy metal contamination from dust collected on household HVAC air filters. Chemosphere. 2021;277:130276.

22. Altundag H, Dundar MS, Dogancı S, Celik M, Tuzen M. The use of a sequential extraction procedure for heavy metal analysis of house dusts by atomic absorption spectrometry. Journal of AOAC International. 2013;96(1):166-70.

23. Cao S, Chen X, Zhang L, Xing X, Wen D, Wang B, et al. Quantificational exposure, sources, and health risks posed by heavy metals in indoor and outdoor household dust in a typical smelting area in China. Indoor Air. 2020;30(5):872-84.

24. Cao S, Duan X, Zhao X, Chen Y, Wang B, Sun C, et al. Health risks of children's cumulative and aggregative exposure to metals and metalloids in a typical urban environment in China. Chemosphere. 2016;147:404-11.

25. Hashemi SE, Fazlzadeh M, Ahmadi E, Parand M, Ramavandi B, Taghizadeh F, et al. Occurrence, potential sources, in vitro bioaccessibility and health risk assessment of heavy metal in indoor dust from different microenvironment of Bushehr, Iran. Environmental geochemistry and health. 2020;42:3641-58.

26. Kim K-W, Myung J-H, Ahn J, Chon H-T. Heavy metal contamination in dusts and stream sediments in the Taejon area, Korea. Journal of Geochemical Exploration. 1998;64(1-3):409-19.

27. Li Y, Pi L, Hu W, Chen M, Luo Y, Li Z, et al. Concentrations and health risk assessment of metal (loid) s in indoor dust from two typical cities of China. Environmental Science and Pollution Research. 2016;23:9082-92.

28. Lin Y, Fang F, Wang F, Xu M. Pollution distribution and health risk assessment of heavy metals in indoor dust in Anhui rural, China. Environmental monitoring and assessment.

2015;187:1-9.

29. Madany IM, Akhter MS, Al Jowder O. The correlations between heavy metals in residential indoor dust and outdoor street dust in Bahrain. Environment international. 1994;20(4):483-92.

30. Meyer I, Heinrich J, Lippold U. Factors affecting lead and cadmium levels in house dust in industrial areas of eastern Germany. Science of the total environment. 1999;234(1-3):25-36.

31. Rasmussen PE, Levesque C, Chénier M, Gardner HD. Contribution of metals in resuspended dust to indoor and personal inhalation exposures: Relationships between PM10 and settled dust. Building and Environment. 2018;143:513-22.

32. Srithawirat T, Latif MT, Sulaiman FR. Indoor PM 10 and its heavy metal composition at a roadside residential environment, Phitsanulok, Thailand. Atmósfera. 2016;29(4):311-22.

33. Tashakor M, Behrooz RD, Asvad SR, Kaskaoutis DG. Tracing of heavy metals embedded in indoor dust particles from the industrial city of Asaluyeh, South of Iran. International Journal of Environmental Research and Public Health. 2022;19(13):7905.

34. Wang Y, Fang F, Lin Y, Cai J, Zhang C, Ge Y. Pollution and influencing factors of heavy metals from rural kitchen dust in Anhui Province, China. Atmospheric Pollution Research. 2020;11(7):1211-6.

35. He C-T, Zheng X-B, Yan X, Zheng J, Wang M-H, Tan X, et al. Organic contaminants and heavy metals in indoor dust from e-waste recycling, rural, and urban areas in South China: spatial characteristics and implications for human exposure. Ecotoxicology and Environmental Safety. 2017;140:109-15.

36. Zhou L, Liu G, Shen M, Hu R, Sun M, Liu Y. Characteristics and health risk assessment of heavy metals in indoor dust from different functional areas in Hefei, China. Environmental pollution. 2019;251:839-49.

37. Li Y-C, Shu M, Ho SSH, Wang C, Cao J-J, Wang G-H, et al. Characteristics of PM2. 5 emitted from different cooking activities in China. Atmospheric Research. 2015;166:83-91.

38. Sulistyowati L, Nurhasanah N, Riani E, Cordova MR. Heavy metals concentration in the sediment of the aquatic environment caused by the leachate discharge from a landfill. Global Journal of Environmental Science and Management. 2023;9(2):323-36.

39. Ibanez Y, Le Bot B, Glorennec P. House-dust metal content and bioaccessibility: a review. European journal of mineralogy. 2010;22(5):629-37.

40. Sulaiman FR, Bakri NIF, Nazmi N, Latif MT. Assessment of heavy metals in indoor dust of a university in a tropical environment. Environmental forensics. 2017;18(1):74-82.

41. Duan T, Liu S, Wang D, Feng J, Song N, Yu Y, et al. Seasonal variation and sources of heavy metals in urban street dusts and river sediments of Dongluo River Watershed in Ji'nan City, China. KSCE Journal of Civil Engineering. 2020;24:1400-10.

42. Škrbić BD, Buljovčić M, Jovanović G, Antić I. Seasonal, spatial variations and risk assessment of heavy elements in street dust from Novi Sad, Serbia. Chemosphere. 2018;205:452-62.

43. Cui L, Wu Z, Han P, Taira Y, Wang H, Meng Q, et al. Chemical content and source apportionment of 36 heavy metal analysis and health risk assessment in aerosol of Beijing. Environmental Science and Pollution Research. 2020;27:7005-14.

44. Sabzevari E, Sobhanardakani S. Analysis of selected heavy metals in indoor dust collected from city of Khorramabad, Iran: A case study. Jundishapur Journal of Health Sciences. 2018;10(3).

45. Rostami R, Kalan ME, Ghaffari HR, Saranjam B, Ward KD, Ghobadi H, et al. Characteristics and health risk assessment of heavy metals in indoor air of waterpipe cafés. Building and Environment. 2021;190:107557.