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Source identification and health risk assessments of heavy metals in indoor dusts of Ilorin, North central Nigeria

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Abstract

Background and Purpose Exposure to heavy metals (HMs) in indoor dusts is a serious public concern that is linked to a myriad of deleterious health outcomes. The objectives of this study are to estimate the contamination levels of HMs in indoor dusts of different residential areas in Ilorin, Nigeria; identify HMs sources in different residential areas; and evaluate human health risks of HMs in selected residential areas.

Methods Indoor dust sampling was conducted in ten randomly selected from low, medium and high population density residential areas of Ilorin, Nigeria. Ten HMs concentration levels, their health risk implication and the associated potential ecological risks were evaluated.

Results The mean concentration levels measured for Fe, Pb, Zn, As, Co, Cr, Cu, Cd, Mn and Ni were 38.99, 5.74, 3.99, 0.08, 2.82, 2.13, 0.47, 0.60, 6.45 and 1.09 mg/kg, respectively. Positive Matrix Factorization (PMF) model was applied to ascertain sources of HMs in sampled indoor dust. Percentage contribution from oil-based cooking (29.82%) and transportation (29.77%) represented the highest source to HM concentrations among the six factors identified. The results of the various pollution indices employed showed that Pb, Zn, As, Co, Cr, Cu, Mn and Ni contributed moderately to HMs concentration levels in the sampled dusts. Cd had highest potential ecological risk factor (E_r^i) of between 160 and 320. The average values of Enrichment Factors (EFs) obtained aside from Fe used as the reference metal, ranged between 8.46 (As) and 2521.61 (Cd). Health risk assessment results revealed that children are the most susceptible to the risks associated with HMs bound indoor dust than the adults. The percentage risk contributions of Hazard Quotient via ingestion route (HQ_{ing}) in Hazard Index (HI) for non-cancer risk of indoor HMs were 93.17% and 69.87% in children and adults, respectively. Likewise, the percentage cancer risks contribution through ingestion pathway (CR_{ing}) were higher than cancer risks through inhalation and dermal pathways (CR_{inh} and CR_{dermal}), accounting for 99.84% and 97.04% of lifetime cancer risk in children and adults, respectively. The contamination level of Cd recorded is of great concern and signifies very strong contribution from anthropogenic sources.

Conclusion This study has further revealed the levels of HMs in typical African residential settings that could be used by relevant stakeholders and policy makers in developing lasting control measures.

Keywords Health risk assessment · Heavy metals · Indoor dust · Pollution indicators · Positive matrix factorization · Residential area

Highlights

- Ten heavy metals (HMs) in indoor dusts of residential areas were investigated
- Cd contamination varied from moderate to high potential ecological risk.
- Six sources of HMs in indoor dust were identified using PMF model.
- Health risks of HMs in indoor dust were higher in Children than Adults

Extended author information available on the last page of the article

Introduction

The presence of heavy metals (HMs) in indoor dusts is of great health and ecological concern as people spend about 90% of their time in enclosed residential and workplace environments ([1]; Jamiu Adetayo [2–4]). The exposure risk to indoor dust bound HMs also known as potentially toxic elements (PTEs) requires more attention due to the longer duration of occupants indoor stay and the significant high concentrations discovered in indoor dusts [5–7].

Dust is a complex mixture of many chemical contaminants from different origins and activities [8, 9]. Sources of dusts may include those accumulated from indoor activities and those imported from outdoor sources. Indoor accumulated dust may comprise of contaminants from biological origins (deposited bioaerosols), toxic elements from the use of household chemicals, smoking, burning of incenses deposited aerosols from cooking activities, particles from materials of building such as asbestos and paints, and those from cleaning activities (Jamiu Adetayo [1, 2, 10, 11]). Importation of dust via shoes and infiltration of dust particles from anthropogenic activities such as vehicular traffic, industries and solid wastes burning constitute a higher percentage of indoor settled dusts [12]. Airborne particles from various sources which is comprised of volatile and semi-volatile components penetrate via openings and building cracks and get deposited on surfaces [13].

Contact with toxic metals from indoor dust is a critical public health concern that could trigger deleterious health outcomes in individuals. Heavy metals have been ascertained as important substances of concern on account of their non-degradability and adverse effect they portend due to their high toxicity. Major routes of exposure are through dermal, ingestion and inhalation. Studies have linked to a myriad of health issues ranging from heavy metal poisoning, respiratory diseases to cancers [14–17]. Children have been reported widely to be at higher risk of ingesting heavy metal laden dusts as they play often on ground and thereby frequently ingesting dust particles adhering to their hands and toys [9]. Body size could be a major determinant for dermal exposure pathway. Adults are at higher risk due to their bigger body sizes as compared to children [9]. Socio-economic factors, building type, proximity to major anthropogenic source(s) and regional characteristics are some of the major drivers of types and concentration levels of HMs in residential dusts [17–19].

Quite a few studies have been conducted to evaluate HM concentration levels and human health risks in different countries [5, 7, 16, 20–22]. However, studies conducted in Africa are still insufficient to establish the risks associated to this pernicious threat. Exposure patterns in Africa may differ from other regions that have been extensively studied. It becomes imperative to carry out more studies in different regions and areas of different population density types in Africa, which is the major impetus for this study. This study intends to estimate heavy metals concentration levels in dusts obtained from different population density residential areas. Source identification and health risks to human were also evaluated. This study aimed to: (1) estimate contamination levels of HMs in indoor dusts of different residential areas in Ilorin, Nigeria; (2) identify HMs sources in different residential areas; and (3) evaluate human health risks of HMs in selected residential areas.

Materials and Method

Area of Sampling

Ilorin is the state capital of Kwara in the North-central zone of Nigeria. Ilorin lies between longitudes 8°30'N and 4°33'E and latitudes 8.500°N and 4.550°E, with day-to-day mean temperature varying between 25 °C and 35 °C. The city of Ilorin is the seventh biggest metropolis in Nigeria with a population of 777,667 in the 2006 Census [23]. According to United Nations, the population of Ilorin was projected to reach 974,000 in 2021, a 2.53% growth from 2020 prediction [24]. The typical weather is equatorial with apparent dry period (October–March) and rainy period (April–September). Ilorin has over time undergone upsurge in the population of residents as a result of robust commercial and industrial activities in the city.

Indoor dust sampling was conducted pre-noon in August, 2020 in ten randomly selected one floor houses (sampling sites) chosen from low, medium and high population density residential areas, evenly and spatially distributed within Ilorin as illustrated in Fig. 1. The residences (sampling sites) studied were located at Agbo Fulani (A1), Tanke (A2), Oloje Area (A3), Oladosu street (A4), Tanke, Pakata Area (A5), Ubandawaki (A6), Sawmill/oko-erin (B), Unilorin GRA Quarters (C1), Unilorin PS Senior Staff Quarters (C2) and Offa Garage (D). Supplementary Table S1 presents the geographical information of the selected ten (10) sampling sites in Ilorin metropolis.

Sample Collection and Analytical procedures

Using a modified sampling protocol described by Qi et al. [25], indoor dust subsamples from floors, windows and fans were collected and blended together into about 20 g composite sample at each of the ten residences (sites) within Ilorin metropolis. Samples of indoor dust were gathered by gentle sweeping action using new pre-cleaned polyethylene brushes and plastic dustpans. To ensure that there was no cross-contamination of indoor dust samples, de-ionized distilled water (DDW) was consistently used to pre-clean the brushes and dustpans used for dust sampling. All samples were collected and kept in see-through sealed nylons, cautiously labelled and conveyed to the laboratory.

Samples of indoor dust weighing 1 g was processed in 50 ml conical flasks at 90 °C for 2 h by adding aqua-regia prepared from analytical reagent (AR) grade (HCl: HNO₃; 3:1) of 10 ml. De-ionized distilled water (DDW) was added to the digested samples up to 50 ml mark in a volumetric flask after cooling and filtering at room

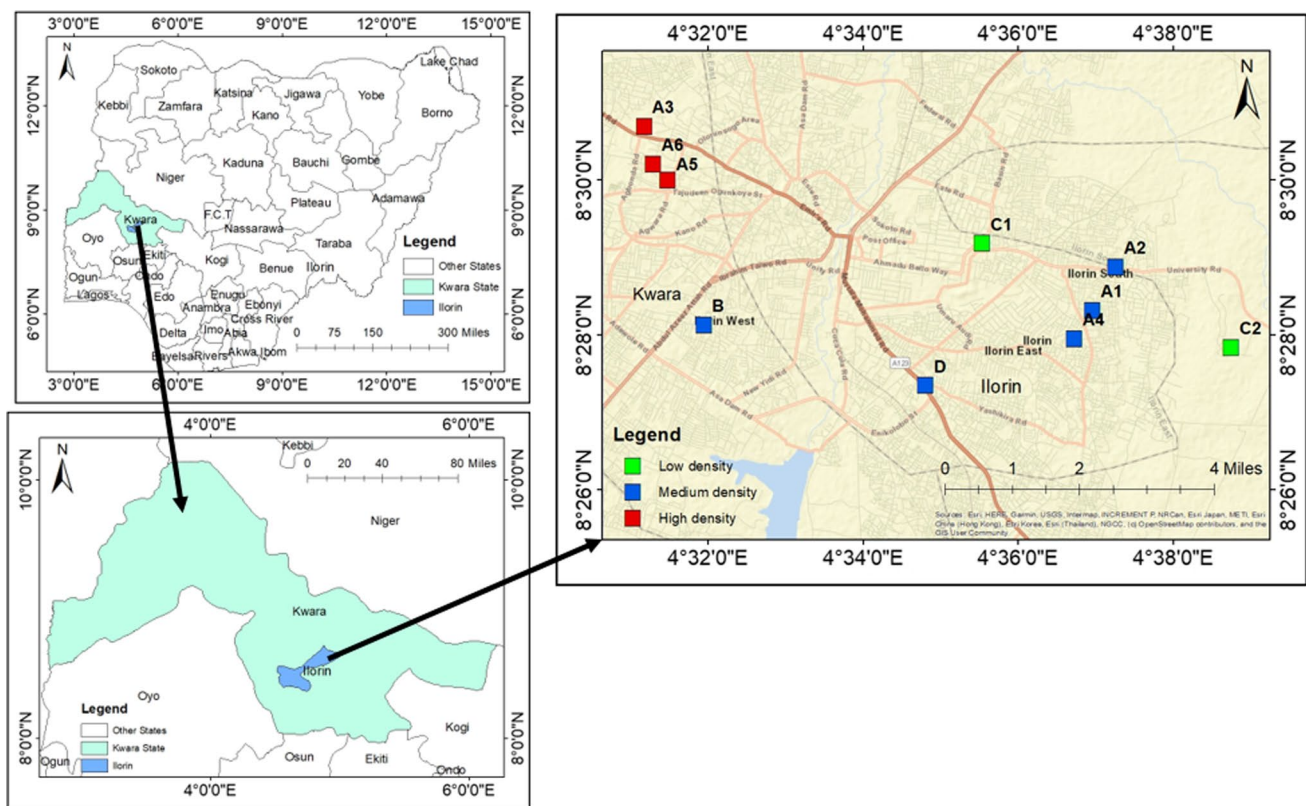


Fig. 1 Location of the study area

temperature. The concentration levels of ten heavy metals [Fe, Pb, Zn, As, Co, Cr, Cu, Mn and Ni] that were established in recent studies to be highly toxic elements in municipal environments [26–32] were determined using atomic absorption spectroscopy (AAS). The method detection limits (MDL) for Fe, Pb, Zn, As, Co, Cr, Cu, Cd, Mn and Ni were 5×10^{-4} , 25×10^{-2} , 12×10^{-2} , 17×10^{-4} , 9×10^{-5} , 4×10^{-2} , 4×10^{-2} , 1×10^{-2} , 4×10^{-2} and 5×10^{-2} , respectively. DDW was used to prepare all standard solutions. Metallic salts (AR grade) were used to prepare 1000 mg/L standard solution of corresponding metals whereas standard solutions of Cu, Ni, and Zn were prepared by using distilled water to dissolve their pure solid forms in either HCl or HNO_3 .

The quality control observed involved the analysis of standard reference material (IDS-1/RDMIL2020), procedure blanks and duplicate samples to authenticate the heavy metals determination precision. Blanks containing filtered and diluted 50 mL aqua-regia prepared for dust samples digestion were validated by attainment of the complete analytical process without samples. Heavy metals of interest were not detected in blank samples, the calibration curve was checked on screen after each investigative run and a graphical inspection was implemented for linearity and replication. The percentage HMs recoveries varied from 87% to

109%, comparative standard deviations of samples analysed in triplicates did not surpass 5%, indicating the accuracy of the procedures employed.

Source Identification- PMF Model

Positive Matrix Factorization (PMF) is a technique used for identifying potential sources of various components in a mixture using multivariate receptor model [12, 33]. PMF model breaks down the sample data matrix into matrices of source profile and source contribution. The type of components sources are determined using profile information acquired and components' inventories data [33, 34]. PMF is considered using Eq. 1 [35]. In this study, PMF 5.0 software was employed to quantitatively examined indoor HMs sources and contributions in Ilorin residences. Additional explanation on PMF model had been reported in other studies [12, 33, 34, 36, 37].

$$x_{ij} = \sum_{k=1}^p g_{ik}f_{kj} + e_{ij} \quad (1)$$

x_{ij} is the measured mass concentration of j^{th} element in sample i , p is sources of pollution in each sample, g_{ik} is the k^{th} pollution source contribution rate in sample i , f_{kj} is

the pollution source characteristic value k to the j^{th} element concentration. The matrix of residual error e_{ij} is determined by minimizing the objective function Q [37, 38]. Q which indicates the goodness of modelling is estimated using Eq. 2.

$$Q = \sum_{i=1}^n \sum_{j=1}^m \left(\frac{e_{ij}}{u_{ij}} \right)^2 \quad (2)$$

In this study, the amount of samples n is 10; Eq. 3 is used to calculate U_{ij} which represents uncertainty of j^{th} element in sample i , [39].

$$U_{ij} = \frac{5}{6} \times MDL, \text{ if } x_{ij} \leq MDL; \text{ or else, } \sqrt{(\sigma_j \times x_{ij})^2 + (MDL)^2}, \text{ if } x_{ij} > MDL \quad (3)$$

x_{ij} is the concentration of j^{th} element in sample i and σ_j is the relative standard deviation of concentration of j^{th} element.

Pollution Assessment Procedures

Evaluation of HMs ecological risks in residential indoor dust samples were achieved using the following contamination indicators: enrichment factor (EF), Geo-accumulation index, contamination factor (contamination degree), Potential Ecological Risk Index (ERI).

EF is a typical method to assess the impact of anthropogenic activities on element distribution in dust or topsoil samples [40, 41]. EF helps to understand the enrichment levels of individual elements over their uncontaminated background estimates [42]. Equation 4 was used to determine the HMs enrichments in Ilorin indoor dust.

$$EF = \frac{[C_n / R_{ref}]_{\text{sample}}}{[B_n / B_{ref}]_{\text{background}}} \quad (4)$$

Where, $[C_n / R_{ref}]_{\text{sample}}$ represents the concentration ratio of target HM and reference element in indoor dust sample and $[B_n / B_{ref}]_{\text{background}}$ represents the background concentration ratio of target HM and the reference element. Zr, Fe, Al, Ti or Mn are commonly picked as standard tracer, reference element to normalize contaminants and to identify natural and anthropogenic sources [43, 44]. In this study, Fe characteristic natural richness, fewer anthropogenic impact and low reactivity with other HMs made it a suitable reference element [30, 40, 45, 46]. Although, there were no evaluated pre-civilization topsoil estimates for Ilorin, the geochemical background estimates of elements adopted for this study were the corresponding continental crust mean of elements investigated by Bradl [47]. Some studies had used similar method to evaluate

EF [12, 48–51]. The five pollution groups of element enrichments are presented in supplementary Table S2.

The geo-accumulation index (I_{geo}) is generally used to quantitatively assess HM contamination of sediments by comparing the HM concentration with its corresponding background concentration in bottom sediments [39, 52]. Similarly, I_{geo} is applicable for evaluating HM pollution in indoor dusts using eq. 5 ([53–55]; L. [56]).

$$I_{\text{geo}} = \log_2 \left(\frac{C_n}{1.5B_n} \right) \quad (5)$$

Where C_n represents the concentration of indoor element n and B_n denotes the concentration of geochemical background of element n in the continental crust. The elemental continental crust mean reported by Bradl [47] were adopted in this study as background estimates of HMs due to the lack of corresponding background values measured in the study area [12, 42, 48, 49, 57–59]. I_{geo} categorisation is shown in supplementary Table S2.

The potential ecological risk index (ERI) of indoor HMs were evaluated using Eqs. 6–8 by Hakanson [60]. Environmental hazard of several elements has been comprehensively assessed using the five ERI categories given in supplementary Table S2 [61, 62].

$$ERI = \sum_{i=1}^n E_r^i \quad (6)$$

$$E_r^i = T_r^i \times C_f^i \quad (7)$$

$$C_f^i = \frac{C_{0-1}^i}{C_n^i} \quad (8)$$

Where C_f^i refers to contamination factor or pollution index-PI of single element; C_{0-1}^i refers to element concentration in sample; the background concentrations (C_n^i) of HMs ($\mu\text{g/g}$) in indoor are the concentrations of upper crust described by Bradl [47] and stated as follows: Pb = 20, Zn = 85, Cu = 50, Cr = 100, Mn = 900 (0.09 wt%), Fe = 51,000 (5.1 wt%), As = 13, Co = 20, Cd = 0.3, Ni = 60.; the toxicity response coefficient (T_r^i) for As = 10; Cd = 30; Mn = Zn = 1; Cr = 2; Cu = Ni = Co = Pb = 5 [63]. ERI equals the addition of potential ecological risk factor (E_r^i) for all elements considered. The level of pollution of elements in topsoil are investigated using C_f^i and contamination degree (C_{deg}) [64, 65]. The four classes of C_f^i and C_{deg} according to [60, 66] are reported in supplementary Table S2. C_{deg} represents the addition of C_f^i of all elements studied as presented in eq. 9.

$$C_{deg} = \sum C_f^i \quad (9)$$

Health Risk Assessment

The methods for estimating the health risk assessment in children and adults are described in supplementary document. Non-carcinogenic and carcinogenic risks via inhalation, dermal contact and ingestion exposure routes were estimated. Factors used for health risk calculations are described in supplementary Tables S3. Supplementary Table S4 shows the cancer slope factor (CSF) and reference doses (RfD) for studied HMs. The average daily doses for children and adults [in mg/(kgday)] through the three exposure routes of ingestion (ADD_{ing}), inhalation (ADD_{inh}) and dermal contact (ADD_{dermal}) were estimated using eqs. 10–12 [67].

$$ADD_{ing} = \frac{C \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (10)$$

$$ADD_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (11)$$

$$ADD_{dermal} = \frac{C \times SA \times AF \times ABF \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (12)$$

The probability risks of non-carcinogenic heavy metals in indoor dusts were determined by estimating the Hazard Quotient (HQ) and Hazard Index (HI) using eqs. 13 and 14, respectively; the carcinogenic risks (CR) assessment were considered using eqs. 15 and 16.

$$HQ = \frac{ADD_i}{R_f D} \quad (13)$$

$$HI = \sum_{i=1}^3 HQ_i \quad (14)$$

$$CR_i = ADD_i \times SF \quad (15)$$

$$CR = \sum_{i=1}^3 CR_i \quad (16)$$

where: HQ is the single pathway non-carcinogenic risk, R_fD [68] is the reference dose in mg kg⁻¹ day⁻¹ which is the highest dose necessary to escape an adverse situation when absorbed, per unit time per unit weight, CR_i is carcinogenic risk for pathway i, SF is the carcinogenic slope factor, and i denotes pathway. The Hazard index (HI) is the non-carcinogenic risk from various routes. HI is equal to the addition of HQ for separate exposure pathways. HI > 1

denotes the possibility that non-carcinogenic risk is significant, whereas HI ≤ 1 shows insignificant non-carcinogenic risk. For regulatory purposes, the international threshold limits permitted by United States Environmental Protection Agency (USEPA) and International Agency for Research on Cancer (IARC) were followed. Cancer risk (CR) values between 1 × 10⁻⁶ to 1 × 10⁻⁴ indicates acceptable or tolerable level. If the CR value is higher than 1 × 10⁻⁴, the risk is unacceptable, whereas values lower than 1 × 10⁻⁶ shows no significant health hazard [39, 69–71]. CR of Fe, Zn, Co, Cu and Mn were not analysed in this study because of the lack of SF values.

Statistical analysis

The SPSS 20, OriginPro 2021 and Microsoft Excel were applied to achieve the statistical analyses of the indoor dust data and human health risk assessment calculations.

Results and Discussion

Concentration Distribution of Heavy Metals

The HMs concentrations (mg/kg) statistics in indoor dust of Ilorin metropolis are described in Table 1. The distribution of HM indoor concentration at ten houses located in residential areas of Ilorin are shown in Fig. S1. Among the ten HMs studies, only Cd indoor concentration was 2 times higher than its background concentration, demonstrating intense impact of anthropogenic operations on Cd concentrations on indoor dust within Ilorin metropolis. All the background concentrations of Fe, Pb, Zn, As, Co, Cr, Cu, Mn and Ni were higher than their respective measured concentrations in indoor dust samples. The mean concentration of HMs were ranked in the declining sequence Fe > Mn > Pb > Zn > Co > Cr > Ni > Cd > Cu > As. Concentrations of HMs in indoor dusts of this study were lower than those found in indoor dusts studies conducted in many metropolitan areas of the world (Table 2).

Positive Matrix Factorization (PMF)

The identification of HM sources in indoor dust of Ilorin was achieved using Positive Matrix Factorization model. Nine of the HMs studied were defined as ‘strong’ having a signal to noise (S/N) ratio varying between 3.4 and 9.0 while Cr was defined ‘weak’ with small S/N ratio of 0.4. The PMF model runs was fixed at 20. A six factor solution gave acceptable absolute scale residual after testing the PMF model with four to eight factors. The six factor simulation was selected as the perfect fit that impacted the deposition of the ten HMs studied as all the residuals were between −3 and +3 and the

Table 1 Descriptive statistics of indoor dust heavy metals concentrations (mg/kg)

Sample Code	Fe	Pb	Zn	As	Co	Cr	Cu	Cd	Mn	Ni
A1	40.79	4.43	3.42	0.03	1.24	2.19	0.31	0.51	5.97	1.32
A2	32.02	5.71	4.06	0.08	1.03	1.39	0.45	0.02	6.83	1.46
A3	41.63	5.38	4.79	0.02	4.17	0.06	0.92	2.47	6.63	1.37
A4	44.29	7.11	3.42	0.08	3.52	4.63	0.62	0.01	5	1.68
A5	38.03	4.47	7.45	0.09	5.6	2.56	0.42	0.04	9.86	0.97
A6	41.42	1.72	5.36	0.11	3.96	0.39	0.31	1.3	3.84	0.1
B	40.63	6.74	2.41	0.14	0.93	3.11	0.52	0.03	8.1	0.005
C1	41.15	8.72	4.27	0.03	4	4.51	0.49	0.09	8.62	1.7
C2	31.42	5.17	4.09	0.06	3.18	1.65	0.26	0.14	4.27	0.69
D	38.52	7.94	0.64	0.19	0.52	0.85	0.4	1.38	5.41	1.6
Mean	38.99	5.74	3.99	0.08	2.82	2.13	0.47	0.60	6.45	1.09
SD	4.20	2.02	1.79	0.05	1.75	1.59	0.19	0.84	1.95	0.63
Median	40.71	5.55	4.08	0.08	3.35	1.92	0.44	0.12	6.30	1.35

Q estimates were at the least value. Figure 2 presented the PMF source profile, factor contribution and fingerprints of HMs in indoor dusts of Ilorin.

In factor 1, As, Mn and Pb accounted for 72.9%, 16.6%, 21.4% and 19.1%, respectively. As is associated with smoke from meat cooking (charboiling) [90]. Cooking fumes consist of Mn and Pb [91]. Cr is released from utensils made of stainless steel [92]. Taner et al. [93] stated that Cr in high concentration was found in a barbecue canteen. As, Mn, Cr and Pb are released in tobacco smoking microenvironment [94–96]. Pb, Cr and Mn are associated with incense burning used for indoor fragrance and worship purposes in Ilorin [97]. Thus, factor 1 is considered smoke from heating or combustion (cooking) source.

In factor 2, Cd, Cu and Co were predominant, accounting for 81.30%, 31.1% and 15.0%, respectively. Cd and Cu are used in tyres production [98], Cu are released from vehicle brake linings, Co and Cu are related to vehicular body wears [99], Co are emitted from fumes of cooking [91, 100]. Cd are associated with oil combustion, batteries, and plastics [85]. Hence, factor 2 is Cd, Cu and Co considered to be cooking fumes and non-exhaust traffic emission sources.

In factor 3, the proportions of Co, Zn, As, Mn and Ni were 61.3%, 67.1%, 21.4%, 25.7% and 14.2%, respectively. Zn are released during oil frying food preparation [101]. Co, As, Mn and Ni are found in cooking fumes from Oil-based cooking [102]. As is emitted from cooking smoke [101]. Therefore, factor 3 is considered to be emission from Oil frying or Oil-based cooking.

In factor 4, major elements Mn, Cu and Zn contributed 27.8%, 20.9% and 23.1%, respectively. Building construction materials and wall paints consist of Mn, Cu and Zn. Zn is discharged into the atmosphere from indoor construction materials comprising paints, plastic, windows and doors [34, 102]. Yellow wall paint could be connected with Cd, Cu, Pb, and Zn while green colour is linked to Zn (S. T. [77]).

Consequently, factor 4 could be indoor building materials and paint coating source.

In factor 5, Cr, Cu, Pb, Mn and Co in high concentrations are responsible for 70.8%, 40.1%, 31.6%, 23.7% and 12.2%, respectively. HMs such as Cr, Cu, Mn and Pb are discovered in wood which may vary based on the type of forest and climate [103, 104]. Cr is leached into air at high temperature from stainless steel kitchenware. Co and Mn are emitted from kitchenware [102]. Thus, sources of Factor 5 could be emissions from kitchen ware indoor, furniture and paper products.

Factor 6, Ni, Pb, Mn and Cd contributed 76.5%, 35.5%, 15.8% and 10.5%. Ni and Pb are emitted during combustion of leaded gasoline [66, 105]. Pb, Mn and Cd are associated with emissions from vehicle which consist of brake wears, tyre wears and vehicle exhaust [106, 107]. Ni and Pb are characteristic elements of coal combustion (J. [108]). Therefore, sources of Factor 6 could be emissions from coal and leaded fuel combustion.

The six sources of HMs accounted for smoke heating or combustion (0.36%), Cooking fumes and Non-exhaust traffic emission (2.62%), Oil frying emission (Oil-based cooking) (29.82%), Indoor building materials and paint coatings Emission (27.78%), Kitchenware, furniture and paper product emission (9.65%) as well as emissions from coal and leaded fuel combustion (29.77%).

Oil frying emission (29.82%) had the highest percentage source contribution followed closely by coal and leaded fuel combustion (29.77%) while smoke from heating or combustion were responsible for the smallest percentage factor contribution of 0.36%. In this study, cooking and transportation sources were the highest contributors to HM concentrations in residential areas of Ilorin metropolis. Result showed that HMs deposited in indoor dust potentially pose huge human health and ecological risks. In addition to outdoor emissions from transportation (Exhaust and Non-exhaust emissions) in

Table 2 Comparison of heavy metals in indoor dust in Ilorin with other studies around the world

Location	Indoor type	Concentration (mg/kg)										References
		Fe	Pb	Zn	As	Co	Cr	Cu	Cd	Mn	Ni	
Ilorin, Nigeria	House dust	38.99	5.74	3.99	0.08	2.82	2.13	0.47	0.60	6.45	1.09	This Study
Toronto, Canada	House dust	–	190	630	–	–	78	251	2.8	94	29	[20]
Zhejiang, China	House dust (smelting Area)	–	1690	6888.2	141.9	–	142.6	188.6	108.1	1039.3	–	[5]
Neyshabur, Iran	House dust	6288–32,759	13.7–5345	105.8–2958	–	1.3–21.4	28.1–190.4	43.8–640.4	0.5–12.9	135.5–1033	24.7–162.2	[72]
Istanbul, Turkey	office	–	192	1970	–	16	254	513	1.8	655	471	[73]
Istanbul, Turkey	home	–	28	832	–	5	55	156	0.80	136	263	[73]
Istanbul, Turkey	Home+Office	–	30	984	–	7	89	200	0.95	163	282	[73]
Ottawa, Canada	Home	–	222	633	–	8.8	69	157	4.3	267	52	[74]
Sydney, Australia	Home	–	76	372	–	–	65	93	1.6	48	15	[75]
Warsaw, Poland	Home	–	124	1070	–	–	90	109	–	–	30	[76]
Kwun Tong, China	Home	–	308	2120	–	–	–	806	39	283	–	[77]
Hong Kong	School and Child care	–	164	2241	–	–	–	167	4.7	193	–	(Susanna TY [78])
Selangor, Malaysia	House dust	–	850	430	–	–	–	–	190	–	830	[79]
Christchurch, New Zealand	House dust	–	724	21,700	–	–	–	190	5.2	–	–	[80]
Ahvaz, Iran	House dust	–	39.6–124	216–890	–	5.8–11.8	10–26	63–159	0.25–0.65	63–139	5–20	[81]
Plymouth (UK)	House dust	–	169	1.6	–	400	64	565	110	46	–	[82]
Shah Alam, Malaysia	House dust	–	30.19	–	–	–	16.88	148.71	31.24	9	–	[83]
Xi'an, China	House dust	–	180.9	461.5	13.2	43.4	149.2	70.8	–	558.3	34.6	[84]
Sri Serdang, Malaysia	House dust	–	89.05	–	–	–	–	53.27	1.89	–	–	[85]
Ilorin, Nigeria	House dust	26.60–45.40	2.34–10.17	–	–	–	–	0.19–1.99	0.001–0.38	–	0.38–2.19	[86]
Lagos, Nigeria	House dust	108	22.5	295.5	–	–	0.35	–	19	–	–	[87]
Niger Delta, Nigeria	Printing press studios	8900–45,800	26.6–346	182–3000	–	3.5–222	7.8–284	34.5–973	2.08–208	165–2100	13.5–180	[88]
Niger Delta, Nigeria	Car spray painting workshops	15,500–479,000	41–380	169–20,300	–	4.5–223	10.5–123	32–973	0.5–8	87.5–2780	10.5–146	[88]
Niger Delta, Nigeria	Metal design workshops	19,300–661,000	95.5–1530	1750–8460	–	15.5–232	53.8–346	125–973	2.5–8	365–7260	46.5–490	[88]
Lagos, Nigeria	House dust	–	85	54.04	102.89	–	9.23	25.37	–	–	–	[89]

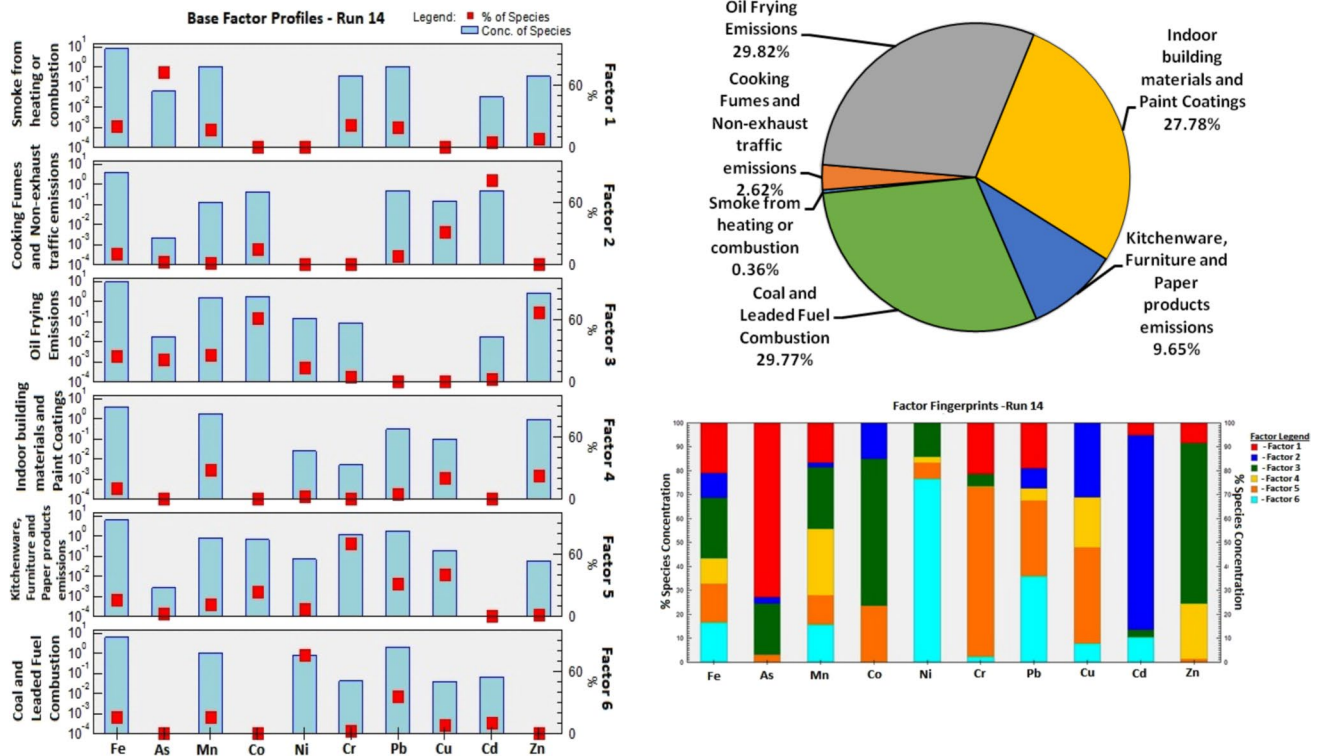


Fig. 2 (a) PMF model source profiles, (b) Percentage factor contributions of heavy metals, and (c) Fingerprints of heavy metals in Ilorin indoor dust

the study area, HMs accumulation in indoor dust of Ilorin may be influenced by lifestyle of inhabitants which encompass incense burning for religious purposes and as perfume, smoking habit, cooking method and type of cooking fuel used such as wood, charcoal, kerosene, liquefied petroleum gas (cooking gas), the type of indoor building materials, furniture, kitchenware and paper products in residences.

Most residences in Ilorin are not air-conditioned, they therefore used fans and open windows for ventilation which may explain the high HM concentrations in indoor dust. Open windows are likely routes of atmospheric metallic particulate from street or road dusts [109], a large proportion of HMs in indoor dust begins from outdoor sources for well aerated houses while some HMs starts from indoor sources with low ventilation. Frequent cleaning of indoor environment could reduce the quantity of HMs ([85, 110]; Susanna TY [78]). By tradition, it was observed that most residents in Ilorin clean their houses every morning using dry cleaning technique. Ground surfaces are swept at least once in a day while fan and windows cleaning might not be regular, this is consistent with report of Praveena et al. [85] that HM concentrations are highest in the windows and least in the building floors. Sweeping in the indoor environment may trigger re-suspension of indoor dusts from floors and furniture [111]. Sweeping and brushing (Dry cleaning

methods) might remove about 91% of indoor dust while mopping (wet cleaning methods) could remove indoor dust completely [112].

One major way to alleviate the indoor dust pollution challenge include: reducing the airborne particulates during cooking by using cleaner fuel; regular housekeeping which include cleaning of indoor surfaces, furniture, walls, floors, windows and doors; improving outdoor environment; ensuring air cross-ventilation in rooms; reducing oil based cooking and production of meat meals. Other ways of reducing indoor dust include trashing of expired kitchenware, furniture and paper products, reducing indoor incense burning and prohibiting tobacco smoking in indoor spaces.

Assessment of heavy metals contamination in indoor dust

Enrichment Factor (EF)

The enrichment level of HMs investigated in residential areas of Ilorin extended from deficiency to extremely high enrichment using the EF classification criteria in supplementary Table S2. EFs of indoor HMs in Ilorin are shown in Table 3, the highest enrichment values of all the HMs were all higher than 2, apart from reference element Fe

Table 3 Enrichment factor (EF) and geoaccumulation index (I_{geo}) of heavy metals from indoor dust

EF										
Sample Code	Fe	Pb	Zn	As	Co	Cr	Cu	Cd	Mn	Ni
A1	1.00	276.94	50.31	2.89	77.52	27.38	7.75	2125.52	8.29	27.51
A2	1.00	454.73	76.08	9.80	82.03	22.14	14.33	106.18	12.09	38.76
A3	1.00	329.55	69.04	1.88	255.43	0.74	22.54	10,086.48	9.02	27.97
A4	1.00	409.36	46.33	7.09	202.66	53.31	14.28	38.38	6.40	32.24
A5	1.00	299.72	117.54	9.28	375.49	34.33	11.26	178.81	14.69	21.68
A6	1.00	105.89	77.64	10.42	243.80	4.80	7.63	5335.59	5.25	2.05
B	1.00	423.01	35.59	13.52	58.37	39.04	13.05	125.52	11.30	0.10
C1	1.00	540.36	62.26	2.86	247.87	55.90	12.15	371.81	11.87	35.12
C2	1.00	419.59	78.10	7.49	258.08	26.78	8.44	757.48	7.70	18.67
D	1.00	525.62	9.97	19.35	34.42	11.25	10.59	6090.34	7.96	35.31
Mean	1.00	378.48	62.29	8.46	183.57	27.57	12.20	2521.61	9.46	23.94
Minimum	1.00	105.89	9.97	1.88	34.42	0.74	7.63	38.38	5.25	0.10
Maximum	1.00	540.36	117.54	19.35	375.49	55.90	22.54	10,086.48	14.69	38.76
I_{geo}										
Sample Code	Fe	Pb	Zn	As	Co	Cr	Cu	Cd	Mn	Ni
A1	-10.87	-2.76	-5.22	-9.34	-4.60	-6.10	-7.92	0.18	-7.82	-6.09
A2	-11.22	-2.39	-4.97	-7.93	-4.86	-6.75	-7.38	-4.49	-7.63	-5.95
A3	-10.84	-2.48	-4.73	-9.93	-2.85	-11.29	-6.35	2.46	-7.67	-6.04
A4	-10.75	-2.08	-5.22	-7.93	-3.09	-5.02	-6.92	-5.49	-8.08	-5.74
A5	-10.97	-2.75	-4.10	-7.76	-2.42	-5.87	-7.48	-3.49	-7.10	-6.54
A6	-10.85	-4.12	-4.57	-7.47	-2.92	-8.59	-7.92	1.53	-8.46	-9.81
B	-10.88	-2.15	-5.73	-7.12	-5.01	-5.59	-7.17	-3.91	-7.38	-14.14
C1	-10.86	-1.78	-4.90	-9.34	-2.91	-5.06	-7.26	-2.32	-7.29	-5.73
C2	-11.25	-2.54	-4.96	-8.34	-3.24	-6.51	-8.17	-1.68	-8.30	-7.03
D	-10.96	-1.92	-7.64	-6.68	-5.85	-7.46	-7.55	1.62	-7.96	-5.81
Mean	-10.95	-2.50	-5.20	-8.19	-3.77	-6.82	-7.41	-1.56	-7.77	-7.29
Minimum	-11.25	-4.12	-7.64	-9.93	-5.85	-11.29	-8.17	-5.49	-8.46	-14.14
Maximum	-10.75	-1.78	-4.10	-6.68	-2.42	-5.02	-6.35	2.46	-7.10	-5.73

Upper crust concentration ($\mu\text{g/g}$) or ppm Pb=20, Zn=85, Cu=50, Cr=100, Mn=900 (0.09 wt%), Fe=51,000 (5.1 wt%), As=13, Co=20, Cd=0.3, Ni=60 [47].

suggesting that they originated from man-made origins [90, 113]. The mean EFs of the nine HMs in Ilorin indoor dust fluctuated between moderate to extremely high enrichment. The maximum enrichments of indoor Pb, Zn, Co, Cr and Cd were extremely high while that of As, Cu, Mn and Ni ranged from significant to very high enrichment (Supplementary Fig. S2a). Mean EFs values of indoor Zn, Pb, Co and Cd were extremely high, raising potential pollution concern and suggesting a close monitoring of their concentrations in Ilorin indoor environment. HM concentrations and pollution indices calculated in this study are presented in Table 4.

Geo-accumulation Index (I_{geo})

I_{geo} results (Table 3) showed that Ilorin indoor environment were practically uncontaminated by all the HMs studied except Cd with various contamination levels at A1 (0.18), A3 (2.46) and A6 (1.53) which amounts to 30% of sampling

sites (residences) studied. A1 indicated Cd varied from uncontaminated to moderate contamination, A3 showed Cd fluctuated from moderate to heavy contamination while Cd contamination at A6 had moderately contamination. Supplementary Fig. S2b shows the geo-accumulation indexes of indoor HMs in Ilorin.

Contamination factor (C_f) and Contamination Degree (C_{deg})

The Pollution indices estimates of Ilorin indoor dust HMs presented in supplementary Table S5 shows C_f results were comparable to the I_{geo} outcome. Low contamination was generally observed in the indoor dusts of Ilorin residences with regard to Fe, Pb, Zn, As, Co, Cr, Cu, Mn and Ni except Cd (Table 4). Moderate C_f and very high C_f of Cd was obtained at A1 and A3 sampling sites respectively, although considerable high C_f of Cd were detected in (A6 and D) accounting for 20% residence sampled. The degree of contamination of indoor dust samples studied in Ilorin varied

Table 4 Heavy metal concentrations and pollution indices

Heavy metals	Statistics	Concentration (mg/kg)	Pollution Indicators			
			EF	Igeo	C _f	E _r
Pb	Mean	5.74	378.48	−2.50	0.2870	1.4348
	Minimum	1.72	105.89	−4.12	0.4360	0.4300
	Maximum	8.72	540.36	−1.78	0.0860	2.1800
Zn	Mean	3.99	62.29	−5.20	0.0470	0.0470
	Minimum	0.64	9.97	−7.64	0.0876	0.0075
	Maximum	7.45	117.54	−4.10	0.0075	0.0876
As	Mean	0.08	8.46	−8.19	0.0064	0.0638
	Minimum	0.02	1.88	−9.93	0.0146	0.0154
	Maximum	0.19	19.35	−6.68	0.0015	0.1462
Co	Mean	2.82	183.57	−3.77	0.1408	0.7038
	Minimum	0.52	34.42	−5.85	0.2800	0.1300
	Maximum	5.60	375.49	−2.42	0.0260	1.4000
Cr	Mean	2.13	27.57	−6.82	0.0213	0.0427
	Minimum	0.06	0.74	−11.29	0.0463	0.0012
	Maximum	4.63	55.90	−5.02	0.0006	0.0926
Cu	Mean	0.47	12.20	−7.41	0.0094	0.0470
	Minimum	0.26	7.63	−8.17	0.0184	0.0260
	Maximum	0.92	22.54	−6.35	0.0052	0.0920
Cd	Mean	0.60	2521.61	−1.56	1.9967	59.9000
	Minimum	0.01	38.38	−5.49	8.2333	1.0000
	Maximum	2.47	10,086.48	2.46	0.0333	247.0000
Mn	Mean	6.45	9.46	−7.77	0.0072	0.0072
	Minimum	3.84	5.25	−8.46	0.0110	0.0043
	Maximum	9.86	14.69	−7.10	0.0043	0.0110
Ni	Mean	1.09	23.94	−7.29	0.0182	0.0908
	Minimum	0.01	0.10	−14.14	0.0283	0.0004
	Maximum	1.70	38.76	−5.73	0.0001	0.1417

from low to moderate with the highest and lowest HM contamination degrees of 8.82 (A3) and 0.51 (A2), respectively, the indoor dusts in residential areas of Ilorin are generally classified as having low degrees of HM contamination with mean HM contamination degree of 2.53.

Ecological Risk Index

Ecological Risk Factor (E_r^i) of Pb, Zn, As, Co, Cr, Cu, Mn and Ni were below 40 indicating low ecological risk factor. Only Cd had E_r^i ranging between 160 and 320 at one sampling site (A3)(see supplementary Table S6), suggesting a potential high risk at the sampling sites. 20% (A6 and D) of the sampling sites had E_r^i of Cd between 80 and 160, indicating considerable ecological risk while one site (A1) had moderate potential ecological risk of Cd. 90% of sampled residences had low potential risk with ERI estimates less than 150. The value of Potential ERI were higher than 150 at only one sampling sites (A3) which potentially poses moderate to very high ecological risks. Sampling sites A2

(4.00) and A3 (249.67) had the highest and lowest ERI, respectively.

The estimates of Igeo and E_r^i for Cd were greater than that of other HMs in this study as shown in Table 4. Consequently, Cd indoor concentration should be given more consideration. The elevated concentrations of Cd might be from vehicular traffic in Ilorin. Cd are discharged from motor oil combustion, batteries, and plastics [85]. Cd is associated with tyre wears and lubricating oil leakage [39] signifying the influence of transportation (outdoor) emission on indoor environment.

Pollution Indices evaluation

The outcomes of the various HMs pollution indicators used in this study were comparable (Table 4). The similar outcomes of EF, Igeo, C_f or PI, and PERI of Pb, Zn, As, Co, Cr, Cu, Mn and Ni showed low or no contamination in indoor dust of Ilorin residences. Mean EFs of Cd revealed extremely high enrichments. Igeo estimates signified that

only Cd fluctuated from moderate to heavy contamination. C_f or PI values of Cd only ranged from very moderate to high. Similarly, ERI of only Cd varied from moderate to very high in Ilorin indoor dust. In this study, the various pollution indicators applied revealed that out of the ten HMs studied in the indoor dusts of Ilorin, only Cd pollution showed varying levels of contamination and requires great concern.

Human Health Risk Assessment

Human exposure risks of residents (Adults and Children) to HMs in indoor dusts via the three contact routes were considered using Eqs. 10–16. Out of ten HMs investigated, nine HMs (Pb, Zn, As, Co, Cr, Cu, Cd, Mn and Ni) were considered as non-carcinogenic while five (Pb, As, Cr, Cd and Ni) were classified as cancer-causing HMs.

Non cancer risks

The percentage of HQing in HI of indoor HMs were 93.17% and 69.87% in Children and Adults, respectively (supplementary Tables S7 and S8). This shows that the foremost exposure route of indoor HMs in Children and Adults in this study were through ingestion pathway, then dermal contact and inhalation routes. Comparable trends were described by Dashtizadeh et al. [114], Jafarzadeh et al. [115] and Praveena et al. [85]. The non-cancer risks of indoor HMs in Ilorin residents are shown in Fig. 3a.

The $HQ_{children}$ via ingestion, dermal and inhalation routes were 9.33, 0.49 and 2.78 times that of HQ_{Adult} , respectively throughout this study. Supplementary Fig. S3 presents the box plots of Ilorin indoor HIs. The $HI_{children}$ were higher than HI_{Adults} in this study. The indoor HIs for children and adults for all indoor HMs studied in residential areas of Ilorin were

insignificant ($HI < 1$). Moreover, $HI_{children}$ of Pb, Cr and Cd as well as HI_{adult} of Cd exceeded 0.01 at some sampling sites (residences). The HI exceeding 0.01 implied that Adults and Children over a long interval may amass HMs in their body systems due to exposure to indoor dust in the city, which could result in health ailment. Cd toxicity damages the kidney, high Cr body accrual causes neurological disorder, renal infection and developmental illness. Thus, the emerging potential HMs non-cancer risks in indoor dusts of Ilorin cannot be overlooked.

Cancer risks

The HMs cancer risks in Ilorin indoor dust for residents are shown in Fig. 3b. The cancer risks of only five HMs (Pb, As, Cr, Cd and Ni) were calculated and presented in supplementary Table S9 using Eqs. 15 and 16. Out of the five HMs examined for risk of cancer, Cd had the uppermost value (Fig. 3b). Cancer risk via ingestion pathway (CR_{ing}) accounted for 99.84% and 97.04% of total cancer risk (CR) in children and adults, respectively. CR_{ing} , CR_{dermal} and CR_{inh} in children were observed to be 9.33, 0.49 and 2.78 times that of Adults in this studied. The box plots of indoor CRs in Ilorin are demonstrated in supplementary Fig. S4. Using the international standard endorsed by USEPA and International Agency for Research on Cancer (IARC) [69–71], the indoor lifetime cancer risks of the five HMs studied in residential areas of Ilorin were either acceptable or insignificant with CR ranging between 10^{-4} and 10^{-6} or below 10^{-6} respectively for both children and adults (supplementary Table S10).

Furthermore, the human health hazard contribution through ingestion HQ_{ing} and CR_{ing} to overall HI and CR in

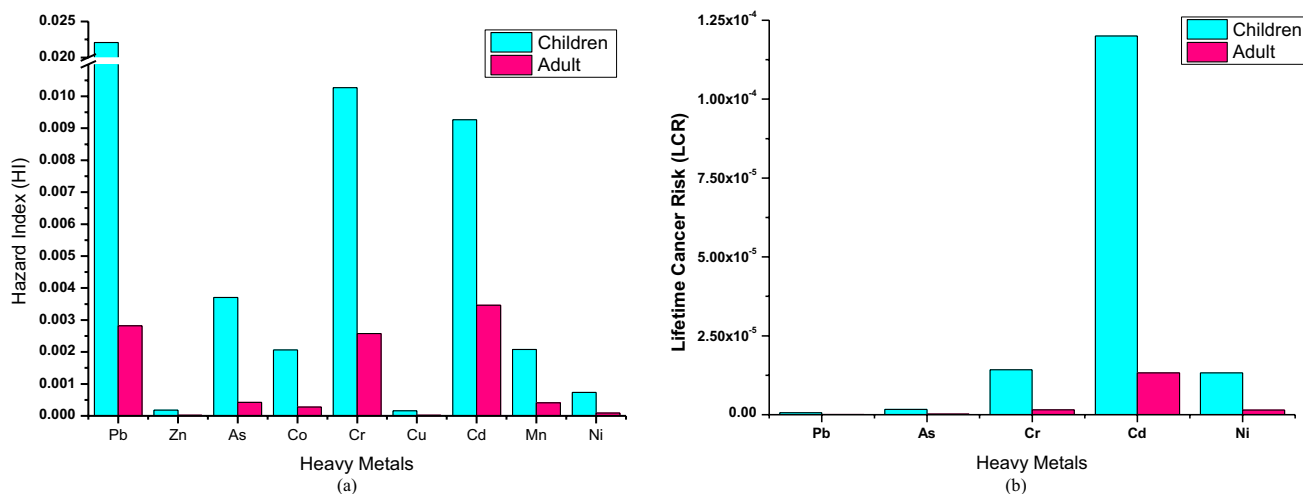


Fig. 3 Health assessment risks of heavy metals for adults and children (a) Non- cancer risk and (b) Cancer risk

this study were 81.52% and 98.44%, respectively, signifying generally that ingestion route contributed more to cancer risk than non-cancer risk in this study. Risk assessment result revealed that children are exposed to greater indoor HM health risks (cancer and non-cancer risks) from indoor dust of Ilorin than adults (Fig. 3a and b). Similar outcomes of children susceptibility to exposure hazards of HMs in indoor dust have been described in several cities [14, 53, 81, 85]. Children are habitually involved in various plays indoor and outdoor, which are typically hand to mouth deeds, causing their rate of respiration per unit body weight to increase. Children possibly inhale indoor particles containing significant HMs into their respiratory systems ensuing in exposure hazards.

Conclusion

This study investigated contamination levels, sources, health and potential ecological risks of 10 major heavy metals (HMs) in indoor dusts of low, medium and high population density residential areas in Ilorin, a major city in central region of Nigeria. The mean concentration of HMs were in the decreasing sequence of $\text{Fe} > \text{Mn} > \text{Pb} > \text{Zn} > \text{Co} > \text{Cr} > \text{Ni} > \text{Cd} > \text{Cu} > \text{As}$. All HMs concentration were all lower than their respective concentrations in the background except for Cd whose concentration is in two folds of the background value. The outcome of EF, Igeo, C_f or PI, and potential ERI of Pb, Zn, As, Co, Cr, Cu, Mn and Ni were similar showing low or no contamination in indoor dust of Ilorin residences. Cd mean EF estimates revealed extremely high enrichments. EFs of indoor sampled dust indicated that Pb, Zn, Co and Cd were extremely high, raising potential pollution concern. Nine of the HMs studied were defined as ‘strong’ having a signal to noise (S/N) ratio varying between 3.4 and 9.0 while Cr was weak with small S/N ratio of 0.4. Apart from reference element Fe, the maximum EF values of the remaining nine HMs were all higher than 2. Low contamination was observed in the indoor dusts as the mean contamination degree of 2.53 was estimated. E_r^i of Pb, Zn, As, Co, Cr, Cu, Mn and Ni were under 40 except for Cd which has a high ecological risk factor. The contamination level of Cd measured is of great concern and calls for concerted mitigation efforts. The $\text{HI}_{\text{children}}$ and $\text{HQ}_{\text{children}}$ exceeded the values obtained for adults in manifolds. $\text{HQ}_{\text{children}}$ via ingestion, dermal and inhalation routes were 9.33, 0.49 and 2.78 multiples of HQ_{Adult} . Estimated overall risk via ingestion HQ_{ing} and CR_{ing} to HI and CR were 81.52% and 98.44%, respectively, thus, Ingestion pathway contributed more to cancer risk than non-cancer risk than pathways of dermal contact and inhalation. The result obtained has raised attention and understanding of the populace on the possible concentration levels and human exposure levels of HM in indoor dusts

continuous monitoring of air pollutants and risks assessment would play an important role in reducing exposure and formulating control strategies that could mitigate the identified negative impacts. Nevertheless, it is necessary to further study the impacts of meteorology, air trajectories and indoor activities on HMs concentrations in residential buildings of Ilorin.

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Data Availability Additional data provided in the supplementary material.

Authors Contributions MOA, JAA, and HAA conceived and designed the study. MOA, HAA, MNOY, ETO and JAA collected the data. JAA and ETO performed the analysis. MOA, HAA, MNOY, ETO, KAA, and JAA wrote and revised the paper. All authors wrote and approved the final draft of the manuscript.

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Declarations

Ethical Approval This is not applicable for this manuscript.

Consent to Participate Yes

Consent to Publish Yes

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References

- Adeniran JA, Araromi DO, Yusuf RO, Jimoda LA, Oke EO, Sonibare JA. Analytical modeling of human exposure from short-term point source releases of aerosols from household spray products. *Sci Technol Built Environ*. 2019a;25(1):83–90. <https://doi.org/10.1080/23744731.2018.1499383>.
- Adeniran JA, Yusuf RO, Abdulkadir MO, Yusuf M-NO, Abdulraheem KA, Adeoye BK, et al. Evaporation rates and pollutants emission from heated cooking oils and influencing factors. *Environ Pollut*. 2020;266:115169. <https://doi.org/10.1016/j.envpol.2020.115169>.
- Phongphetkul P, Mangkang S, Praditsmanont A, Intrachooto S, Choruengwiat J, Treesubuntorn C, Thiravetyan P. Evaluation of indoor air quality in high-rise residential

- buildings in Bangkok and factor analysis. *Environ Monit Assess.* 2021;193(1):1–11.
4. Zhou, L., Liu, G., Shen, M., Liu, Y., & Lam, P. K. (2021). Characteristics of Indoor Dust in an Industrial City: Comparison with Outdoor Dust and Atmospheric Particulates. *Chemosphere*, 129952.
 5. 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. <https://doi.org/10.1111/ina.12683>.
 6. Lu X, Cheng Y, Xiang M, Liu T, Guo Y, Wang F. Size-fractionated particle-bound heavy metals and perfluoroalkyl substances in dust from different indoor air. *Environ Sci Pollut Res.* 2019;26(36):36720–31.
 7. Shi T, Wang Y. Heavy metals in indoor dust: Spatial distribution, influencing factors, and potential health risks. *Sci Total Environ.* 2021;755:142367.
 8. Doyi IN, Isley CF, Soltani NS, Taylor MP. Human exposure and risk associated with trace element concentrations in indoor dust from Australian homes. *Environ Int.* 2019;133:105125.
 9. Melymuk L, Demirtepe H, Jílková SR. Indoor dust and associated chemical exposures. *Curr Opin Environ Sci Health.* 2020;15:1–6.
 10. Adeniran JA, Mohammed IA, Muniru OI, Oloyede T, Sonibare OO, Yusuf M-NO, et al. Indoor transmission dynamics of expired SARS-CoV-2 virus in a model African hospital ward. *J Environ Health Sci Eng.* 2021:1–11.
 11. Adeniran JA, Sonibare JA, Jimoda LA. Statistical approach for determining the effects of microclimatic parameters on household spray products aerosol deposition. *Atmos Pollut Res.* 2015;6(1):21–8.
 12. Odediran, E. T., Adeniran, J. A., Yusuf, R. O., Abdullaheem, K. A., Adesina, O. A., Sonibare, J. A., & Du, M. (2021). Contamination Levels, Health Risks and Source Apportionment of Potentially Toxic Elements in Road Dusts of a Densely Populated African City. *Environmental Nanotechnology, Monitoring & Management*, 100445. doi:<https://doi.org/10.1016/j.enmm.2021.100445>.
 13. Goldstein AH, Nazaroff WW, Weschler CJ, Williams J. How Do Indoor Environments Affect Air Pollution Exposure? *Environ Sci Technol.* 2021;55(1):100–8. <https://doi.org/10.1021/acs.est.0c05727>.
 14. Kurt-Karakus PB. Determination of heavy metals in indoor dust from Istanbul, Turkey: estimation of the health risk. *Environ Int.* 2012a;50:47–55.
 15. McDuffie EE, Martin RV, Spadaro JV, Burnett R, Smith SJ, O'Rourke P, et al. Source sector and fuel contributions to ambient PM_{2.5} and attributable mortality across multiple spatial scales. *Nat Commun.* 2021;12(1):3594. <https://doi.org/10.1038/s41467-021-23853-y>.
 16. Tan SY, Praveena SM, Abidin EZ, Cheema MS. A review of heavy metals in indoor dust and its human health-risk implications. *Rev Environ Health.* 2016;31(4):447–56.
 17. Zhao X, Li Z, Wang D, Tao Y, Qiao F, Lei L, et al. Characteristics, source apportionment and health risk assessment of heavy metals exposure via household dust from six cities in China. *Sci Total Environ.* 2021;762:143126.
 18. 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. *Ecotoxicol Environ Saf.* 2020;189:109927.
 19. Khan SA, Muhammad S, Nazir S, Shah FA. Heavy metals bounded to particulate matter in the residential and industrial sites of Islamabad, Pakistan: implications for non-cancer and cancer risks. *Environ Technol Innov.* 2020;19:100822.
 20. Al Hejani A, Davis M, Prete D, Lu J, Wang S. Heavy metals in indoor settled dusts in Toronto, Canada. *Sci Total Environ.* 2020;703:134895.
 21. Mostafaii G, Bakhtyari Z, Atoof F, Baziar M, Fouladi-Fard R, Rezaali M, Mirzaei N. Health risk assessment and source apportionment of heavy metals in atmospheric dust-fall in a city of Khuzestan Province, Iran. *J Environ Health Sci Eng.* 2021;19(1):585–601. <https://doi.org/10.1007/s40201-021-00630-z>.
 22. Rafiee A, Delgado-Saborit JM, Sly PD, Quémerais B, Hashemi F, Akbari S, Hoseini M. Environmental chronic exposure to metals and effects on attention and executive function in the general population. *Sci Total Environ.* 2020;705:135911.
 23. NPC. (2006). National Population Commission (2006). Federal Republic of Nigeria Official Gazette, 96(2).
 24. UN. (2019). United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition. Rev. 1. Retrieved from <https://population.un.org/wpp/Download/Standard/Population/>
 25. Qi H, Li WL, Zhu NZ, Ma WL, Liu LY, Zhang F, Li YF. Concentrations and sources of polycyclic aromatic hydrocarbons in indoor dust in China. *Sci Total Environ.* 2014;491–492:100–7. <https://doi.org/10.1016/j.scitotenv.2014.01.119>.
 26. Adimalla N. Heavy metals contamination in urban surface soils of Medak province, India, and its risk assessment and spatial distribution. *Environ Geochem Health.* 2020;42(1):59–75. <https://doi.org/10.1007/s10653-019-00270-1>.
 27. Cai LM, Jiang HH, Luo J. Metals in soils from a typical rapidly developing county, Southern China: levels, distribution, and source apportionment. *Environ Sci Pollut Res Int.* 2019;26(19):19282–93. <https://doi.org/10.1007/s11356-019-05329-1>.
 28. Han D, Cheng J, Hu X, Jiang Z, Mo L, Xu H, et al. Spatial distribution, risk assessment and source identification of heavy metals in sediments of the Yangtze River Estuary, China. *Mar Pollut Bull.* 2017;115(1–2):141–8. <https://doi.org/10.1016/j.marpolbul.2016.11.062>.
 29. Jiang HH, Cai LM, Wen HH, Hu GC, Chen LG, Luo J. An integrated approach to quantifying ecological and human health risks from different sources of soil heavy metals. *Sci Total Environ.* 2020a;701:134466. <https://doi.org/10.1016/j.scitotenv.2019.134466>.
 30. Jiang HH, Cai LM, Wen HH, Luo J. Characterizing pollution and source identification of heavy metals in soils using geochemical baseline and PMF approach. *Sci Rep.* 2020b;10(1):6460. <https://doi.org/10.1038/s41598-020-63604-5>.
 31. Maeaba W, Prasad S, Chandra S. First Assessment of Metals Contamination in Road Dust and Roadside Soil of Suva City, Fiji. *Arch Environ Contam Toxicol.* 2019;77(2):249–62. <https://doi.org/10.1007/s00244-019-00635-8>.
 32. Men C, Liu R, Xu L, Wang Q, Guo L, Miao Y, Shen Z. Source-specific ecological risk analysis and critical source identification of heavy metals in road dust in Beijing, China. *J Hazard Mater.* 2020;388:121763. <https://doi.org/10.1016/j.jhazmat.2019.121763>.
 33. Yu Y, Li Q, Wang H, Wang B, Wang X, Ren A, Tao S. Risk of human exposure to polycyclic aromatic hydrocarbons: A case study in Beijing, China. *Environ Pollut.* 2015;205:70–7. <https://doi.org/10.1016/j.envpol.2015.05.022>.
 34. Niu Y, Wang F, Liu S, Zhang W. Source analysis of heavy metal elements of PM_{2.5} in canteen in a university in winter. *Atmos Environ.* 2021;244:117879.
 35. Manousakas M, Papaefthymiou H, Diapoulis E, Migliori A, Karydas AG, Bogdanovic-Radovic I, Eleftheriadis K. Assessment of PM_{2.5} sources and their corresponding level of uncertainty in a coastal urban area using EPA PMF 5.0 enhanced diagnostics.

- Sci Total Environ. 2017;574:155–64. <https://doi.org/10.1016/j.scitotenv.2016.09.047>.
36. Ogundele LT, Owoade OK, Olise FS, Hopke PK. Source identification and apportionment of PM_{2.5} and PM_{2.5-10} in iron and steel scrap smelting factory environment using PMF, PCFA and UNMIX receptor models. *Environ Monit Assess*. 2016;188(10):574. <https://doi.org/10.1007/s10661-016-5585-8>.
 37. Yuan, S., Zhang, S., Sun, Y., & Guo, M. (2020). Analysis of Pollution Sources of Heavy Metal in Farmland Soils Based on Positive Matrix Factorization Model. Paper presented at the IOP Conference Series: Earth and Environmental Science.
 38. Tian YZ, Shi GL, Han SQ, Zhang YF, Feng YC, Liu GR, et al. Vertical characteristics of levels and potential sources of water-soluble ions in PM₁₀ in a Chinese megacity. *Sci Total Environ*. 2013;447:1–9. <https://doi.org/10.1016/j.scitotenv.2012.12.071>.
 39. Men C, Liu R, Xu F, Wang Q, Guo L, Shen Z. Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China. *Sci Total Environ*. 2018;612:138–47. <https://doi.org/10.1016/j.scitotenv.2017.08.123>.
 40. Dirisu C, Biose E, Aighewi I. Heavy metal contamination of Ewhare dumpsite environment in Nigeria's Niger Delta. *SCIREA J Environ*. 2019;3(2):30–45.
 41. Kamani H, Ashrafi SD, Isazadeh S, Jaafari J, Hoseini M, Mostafapour FK, et al. Heavy metal contamination in street dusts with various land uses in Zahedan, Iran. *Bull Environ Contam Toxicol*. 2015;94(3):382–6.
 42. Yakovlev EY, Zykova E, Zikov S, Malkov A, Bazhenov A. Heavy metals and radionuclides distribution and environmental risk assessment in soils of the Severodvinsk industrial district, NW Russia. *Environ Earth Sci*. 2020;79:1–16.
 43. Mediolla L, Domingues M, Sandoval MG. Environmental assessment of and active tailings pile in the State of Mexico (Central Mexico). *Res J Environ Sci*. 2008;2(3):197–208.
 44. Neto JAB, Gingele FX, Leipe T, Brehme I. Spatial distribution of heavy metals in surficial sediments from Guanabara Bay: Rio de Janeiro, Brazil. *Environ Geol*. 2006;49(7):1051–63. <https://doi.org/10.1007/s00254-005-0149-1>.
 45. Adimalla N, Qian H, Wang H. Assessment of heavy metal (HM) contamination in agricultural soil lands in northern Telangana, India: an approach of spatial distribution and multivariate statistical analysis. *Environ Monit Assess*. 2019;191(4):246. <https://doi.org/10.1007/s10661-019-7408-1>.
 46. Lv J, Liu Y, Zhang Z, Dai J, Dai B, Zhu Y. Identifying the origins and spatial distributions of heavy metals in soils of Ju country (Eastern China) using multivariate and geostatistical approach. *J Soils Sediments*. 2014;15(1):163–78. <https://doi.org/10.1007/s11368-014-0937-x>.
 47. Bradl, H. (2005). Heavy Metals in the Environment. Interface [Heavy Metals in the Environment. Interface]. *Science and Technology. Elsevier Ltd–London*, 6, 269.
 48. Bam EK, Akumah AM, Bansah S. Geochemical and chemometric analysis of soils from a data scarce river catchment in West Africa. *Environ Res Commun*. 2020;2(3):035001.
 49. Barbieri M. The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. *J Geol Geophys*. 2016;5(1):1–4.
 50. Blaser P, Zimmermann S, Luster J, Shotyk W. Critical examination of trace element enrichments and depletions in soils: As, Cr, Cu, Ni, Pb, and Zn in Swiss forest soils. *Sci Total Environ*. 2000;249(1–3):257–80. [https://doi.org/10.1016/S0048-9697\(99\)00522-7](https://doi.org/10.1016/S0048-9697(99)00522-7).
 51. Sutherland RA, Tolosa CA, Tack FMG, Verloo MG. Characterization of Selected Element Concentrations and Enrichment Ratios in Background and Anthropogenically Impacted Roadside Areas. *Arch Environ Contam Toxicol*. 2000;38(4):428–38. <https://doi.org/10.1007/s002440010057>.
 52. Muller G. Index of geoaccumulation in sediments of the Rhine River. *Geojournal*. 1969;2:108–18.
 53. Ali MU, Liu G, Yousaf B, Ullah H, Irshad S, Ahmed R, et al. Evaluation of floor-wise pollution status and deposition behavior of potentially toxic elements and nanoparticles in air conditioner dust during urbanistic development. *J Hazard Mater*. 2019;365:186–95.
 54. Rostami S, Kamani H, Shahsavani S, Hoseini M. Environmental monitoring and ecological risk assessment of heavy metals in farmland soils. *Human and Ecological Risk Assessment: an International Journal*. 2021;27(2):392–404.
 55. Ugwu KE, Ofomatah AC. Concentration and risk assessment of toxic metals in indoor dust in selected schools in Southeast, Nigeria. *SN Applied Sciences*. 2021;3(1):1–13.
 56. 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. *Environ Pollut*. 2019;251:839–49. <https://doi.org/10.1016/j.envpol.2019.05.058>.
 57. Al-Haidarey M, Hassan F, Al-Kubaisey A, Douabul A. The geoaccumulation index of some heavy metals in Al-Hawizeh Marsh, Iraq. *J Chem*. 2010;7(S1):S157–62.
 58. Liu M, Xu Y, Nawab J, Rahman Z, Khan S, Idress M, et al. Contamination features, geo-accumulation, enrichments and human health risks of toxic heavy metal (loids) from fish consumption collected along Swat river, Pakistan. *Environ Technol Innov*. 2020;17:100554.
 59. Ullah I, Ditta A, Imtiaz M, Mehmood S, Rizwan M, Rizwan MS, et al. Assessment of health and ecological risks of heavy metal contamination: a case study of agricultural soils in Thall, Dir-Kohistan. *Environ Monit Assess*. 2020;192(12):786. <https://doi.org/10.1007/s10661-020-08722-3>.
 60. Hakanson L. An ecological risk index for aquatic pollution control: a sedimentological approach. *Water Res*. 1980;14(8):975–1001. [https://doi.org/10.1016/0043-1354\(80\)90143-8](https://doi.org/10.1016/0043-1354(80)90143-8).
 61. Kowalska J, Mazurek R, Gasiorek M, Setlak M, Zaleski T, Waroszewski J. Soil pollution indices conditioned by medieval metallurgical activity - A case study from Krakow (Poland). *Environ Pollut*. 2016;218:1023–36. <https://doi.org/10.1016/j.envpol.2016.08.053>.
 62. Mazurek R, Kowalska J, Gasiorek M, Zadrozny P, Jozefowska A, Zaleski T, et al. Assessment of heavy metals contamination in surface layers of Roztocze National Park forest soils (SE Poland) by indices of pollution. *Chemosphere*. 2017;168:839–50. <https://doi.org/10.1016/j.chemosphere.2016.10.126>.
 63. Zheng-Qi X, Shi-Jun N, Xian-Guo T, Cheng-Jiang Z. Calculation of Heavy Metals' Toxicity Coefficient in the Evaluation of Potential Ecological Risk Index [J]. *Environ Sci Technol*. 2008;2(8):31.
 64. Rastmanesh F, Moore F, Keshavarzi B. Speciation and phytoavailability of heavy metals in contaminated soils in Sarcheshmeh area, Kerman Province, Iran. *Bull Environ Contam Toxicol*. 2010;85(5):515–9. <https://doi.org/10.1007/s00128-010-0149-z>.
 65. Rastmanesh F, Safaie S, Zarasvandi AR, Edraki M. Heavy metal enrichment and ecological risk assessment of surface sediments in Khorramabad River, West Iran. *Environ Monit Assess*. 2018;190(5):273. <https://doi.org/10.1007/s10661-018-6650-2>.
 66. Soltani N, Keshavarzi B, Moore F, Tavakol T, Lahijanzadeh AR, Jaafarzadeh N, Kermani M. Ecological and human health hazards of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in road dust of Isfahan metropolis, Iran. *Sci Total Environ*. 2015;505:712–23. <https://doi.org/10.1016/j.scitotenv.2014.09.097>.

67. USEPA. (2001). Risk assessment guidance for superfund (RAGS), vol III—Part A, process for conducting probabilistic risk assessment. Office of emergency and remedial response, Washington, DC.
68. USEPA. (1993). Reference dose (RfD): description and use in health risk assessments. Background document 1A: Integrated Risk Information System (IRIS) Washington (DC).
69. Du Y, Gao B, Zhou H, Ju X, Hao H, Yin S. Health Risk Assessment of Heavy Metals in Road Dusts in Urban Parks of Beijing, China. *Procedia Environ Sci*. 2013;18:299–309. <https://doi.org/10.1016/j.proenv.2013.04.039>.
70. IARC. (2011). International Agency for Research on Cancer Agent Classified by the IARC Monograph.
71. USEPA. (2011). Exposure factors handbook: 2011 edition: USEPA Office of Research and Development Washington.
72. Naimabadi, A., Gholami, A., & Ramezani, A. M. (2020). Determination of heavy metals and health risk assessment in indoor dust from different functional areas in Neyshabur, Iran *Indoor and Built Environ*, 1420326X20963378.
73. Kurt-Karakus PB. Determination of heavy metals in indoor dust from Istanbul, Turkey: estimation of the health risk. *Environ Int*. 2012b;50:47–55. <https://doi.org/10.1016/j.envint.2012.09.011>.
74. Rasmussen P, Subramanian K, Jessiman B. A multi-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. *Sci Total Environ*. 2001;267(1–3):125–40.
75. Chattopadhyay G, Lin KC, Feitz AJ. Household dust metal levels in the Sydney metropolitan area. *Environ Res*. 2003;93(3):301–7. [https://doi.org/10.1016/S0013-9351\(03\)00058-6](https://doi.org/10.1016/S0013-9351(03)00058-6).
76. Lisiewicz M, Heimbürger R, Golimowski J. Granulometry and the content of toxic and potentially toxic elements in vacuum-cleaner collected, indoor dusts of the city of Warsaw. *Sci Total Environ*. 2000;263(1–3):69–78. [https://doi.org/10.1016/S0048-9697\(00\)00667-7](https://doi.org/10.1016/S0048-9697(00)00667-7).
77. Tong ST, Lam KC. Home sweet home? A case study of household dust contamination in Hong Kong. *Sci Total Environ*. 2000;256(2–3):115–23. [https://doi.org/10.1016/S0048-9697\(00\)00471-X](https://doi.org/10.1016/S0048-9697(00)00471-X).
78. Tong ST, Lam KC. Are nursery schools and kindergartens safe for our kids? The Hong Kong study. *Sci Total Environ*. 1998;216(3):217–25.
79. Latif MT, Othman MR, Kim CL, Murayadi SA, Sahaimi KNA. Composition of household dust in semi-urban areas in Malaysia. *Indoor and Built Environ*. 2009;18(2):155–61.
80. Kim N, Fergusson J. Concentrations and sources of cadmium, copper, lead and zinc in house dust in Christchurch, New Zealand. *Sci Total Environ*. 1993;138(1–3):1–21. [https://doi.org/10.1016/0048-9697\(93\)90400-Z](https://doi.org/10.1016/0048-9697(93)90400-Z).
81. Neisi A, Goudarzi G, Akbar Babaei A, Vosoughi M, Hashemzadeh H, Naimabadi A, et al. Study of heavy metal levels in indoor dust and their health risk assessment in children of Ahvaz city, Iran. *Toxin Rev*. 2016;35(1–2):16–23.
82. Turner A, Ip KH. Bioaccessibility of metals in dust from the indoor environment: application of a physiologically based extraction test. *Environ Sci Technol*. 2007;41(22):7851–6. <https://doi.org/10.1021/es071194m>.
83. Darus FM, Nasir RA, Sumari SM, Ismail ZS, Omar NA. Heavy metals composition of indoor dust in nursery schools building. *Procedia Soc Behav Sci*. 2012;38:169–75.
84. Lu X, Zhang X, Li LY, Chen H. Assessment of metals pollution and health risk in dust from nursery schools in Xi'an, China. *Environ Res*. 2014;128:27–34.
85. Praveena SM, Abdul Mutalib NS, Aris AZ. Determination of heavy metals in indoor dust from primary school (Sri Serdang, Malaysia): estimation of the health risks. *Environ Forensic*. 2015;16(3):257–63.
86. Adekola F, Dosumu O. Metal determination in household dusts from Ilorin City, Nigeria. *NISEB Journal*. 2001;1(3):1595–6938.
87. Adaramodu A, Osuntogun A, Ehi-Eromosele C. Heavy metal concentration of surface dust present in e-waste components: the Westminster Electronic Market, Lagos case study. Heavy Metal Concentration of Surface Dust Present in E-Waste Components: The Westminster Electronic Market, Lagos Case Study. 2012;2(2):9–13.
88. Iwegbue CM, Nwose N, Egbueze FE, Odali EW, Tesi GO, Nwajei GE, Martincigh BS. Risk assessment of human exposure to potentially toxic metals in indoor dust from some small and medium scale enterprise workplace environments in southern Nigeria. *Indoor and Built Environment*. 2020;29(8):1137–54.
89. Bamidele, O., Boisa, N., & Obunwo, C. (2020). Determination and Risk Assessment of Heavy Metals Concentrations collected from Indoor houses at Lagos State of Nigeria.
90. Zhao Y, Chen C, Zhao B. Emission characteristics of PM_{2.5}-bound chemicals from residential Chinese cooking. *Build Environ*. 2019b;149:623–9.
91. Chao CY, Wong KK. Residential indoor PM₁₀ and PM_{2.5} in Hong Kong and the elemental composition. *Atmos Environ*. 2002;36(2):265–77.
92. Kuligowski J, Halperin KM. Stainless steel cookware as a significant source of nickel, chromium, and iron. *Arch Environ Contam Toxicol*. 1992;23(2):211–5.
93. Taner S, Pekey B, Pekey H. Fine particulate matter in the indoor air of barbecue restaurants: elemental compositions, sources and health risks. *Sci Total Environ*. 2013;454–455:79–87. <https://doi.org/10.1016/j.scitotenv.2013.03.018>.
94. Bernhard D, Rossmann A, Wick G. Metals in cigarette smoke. *IUBMB Life*. 2005;57(12):805–9. <https://doi.org/10.1080/15216540500459667>.
95. Caruso RV, O'Connor RJ, Stephens WE, Cummings KM, Fong GT. Toxic metal concentrations in cigarettes obtained from US smokers in 2009: results from the International Tobacco Control (ITC) United States survey cohort. *Int J Environ Res Public Health*. 2014;11(1):202–17.
96. Sebiawu GE, Mensah NJ, Ayiah-Mensah F. Analysis of heavy metals content of tobacco and cigarettes sold in Wa Municipality of Upper West Region, Ghana. *Chem Process Eng Res*. 2014;25:24–33.
97. Elsayed Y, Dalibalta S, Gomes I, Fernandes N, Alqtaishat F. Chemical composition and potential health risks of raw Arabian incense (Bakhour). *J Saudi Chem Soc*. 2016;20(4):465–73.
98. Thorpe A, Harrison RM. Sources and properties of non-exhaust particulate matter from road traffic: a review. *Sci Total Environ*. 2008;400(1–3):270–82. <https://doi.org/10.1016/j.scitotenv.2008.06.007>.
99. Kluge B, Wessolek G. Heavy metal pattern and solute concentration in soils along the oldest highway of the world—the AVUS Autobahn. *Environ Monit Assess*. 2012;184(11):6469–81. <https://doi.org/10.1007/s10661-011-2433-8>.
100. Wong P, Wang J. The accumulation of polycyclic aromatic hydrocarbons in lubricating oil over time—a comparison of supercritical fluid and liquid–liquid extraction methods. *Environ Pollut*. 2001;112(3):407–15. [https://doi.org/10.1016/S0269-7491\(00\)00142-1](https://doi.org/10.1016/S0269-7491(00)00142-1).
101. Zhao K, Fu W, Qiu Q, Ye Z, Li Y, Tunney H, et al. Spatial patterns of potentially hazardous metals in paddy soils in a typical electrical waste dismantling area and their pollution characteristics. *Geoderma*. 2019a;337:453–62. <https://doi.org/10.1016/j.geoderma.2018.10.004>.
102. See SW, Balasubramanian R. Chemical characteristics of fine particles emitted from different gas cooking methods. *Atmos Environ*. 2008;42(39):8852–62.

103. Suryawanshi S, Chauhan AS, Verma R, Gupta T. Identification and quantification of indoor air pollutant sources within a residential academic campus. *Sci Total Environ*. 2016;569:46–52.
104. Szczepkowski, A., & Nicewicz, D. (2008). The content of heavy metals in the wood of healthy and dying oak trees (*Quercus robur* L., *Q. petraea* (Matt.) Liebl.). *Acta Sci Pol Silv Colendar Rat Ind Lignar*, 7(4), 55–65.
105. Qin X, Zhang ZF, Li YW, Shen Y, Zhao SH. Sources Analysis of Heavy Metal Aerosol Particles in North Suburb of Nanjing. *Huan Jing Ke Xue*. 2016;37(12):4467–74. <https://doi.org/10.13227/j.hj.kx.201605237>.
106. Han Y-J, Kim H-W, Cho S-H, Kim P-R, Kim W-J. Metallic elements in PM_{2.5} in different functional areas of Korea: Concentrations and source identification. *Atmos Res*. 2015;153:416–28.
107. Wang Y, Jia C, Tao J, Zhang L, Liang X, Ma J, et al. Chemical characterization and source apportionment of PM_{2.5} in a semi-arid and petrochemical-industrialized city Northwest China. *Sci Total Environ*. 2016;573:1031–40. <https://doi.org/10.1016/j.scitotenv.2016.08.179>.
108. Wang J, Li S, Li H, Qian X, Li X, Liu X, et al. Trace metals and magnetic particles in PM_{2.5}: Magnetic identification and its implications. *Sci Rep*. 2017;7(1):1–11.
109. Komarnicki GJ. Lead and cadmium in indoor air and the urban environment. *Environ Pollut*. 2005;136(1):47–61. <https://doi.org/10.1016/j.envpol.2004.12.006>.
110. Spengler JD, Chen Q. Indoor air quality factors in designing a healthy building. *Annu Rev Energy Environ*. 2000;25(1):567–600.
111. Lee SC, Li W-M, Ao C-H. Investigation of indoor air quality at residential homes in Hong Kong—case study. *Atmos Environ*. 2002;36(2):225–37.
112. Ozturk B. A comparison of the performances of dry and wet vacuum cleaners for the control of indoor particulate matters. *J Int Environ Appl Sci*. 2006;1:107–19.
113. Yin, H.-Q., Chen, F.-R., Chen, X.-R., Chen, Y.-N., Jia, S.-J., & Wang, X.-Y. (2010). Assessment of heavy metal pollutions to the soils in Tongling City, Anhui *J Safety Environ*, 10(3).
114. Dashtizadeh M, Kamani H, Ashrafi SD, Panahi AH, Mahvi AH, Balarak D, et al. Human health risk assessment of trace elements in drinking tap water in Zahedan city, Iran. *J Environ Health Sci Eng*. 2019;17(2):1163–9.
115. Jafarzadeh N, Heidari K, Meshkinian A, Kamani H, Mohammadi AA, Conti GO. Non-carcinogenic risk assessment of exposure to heavy metals in underground water resources in Saraven, Iran: Spatial distribution, monte-carlo simulation, sensitive analysis. *Environ Res*. 2022;204:112002.
116. Adeniran, J. A., Yusuf, R. O., & Oke, E. O. (2019b). Deposition and coagulation of aerosols from household spray products. *Songklanakarin Journal of Science & Technology*, 41(1).

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