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Research article

Health risk assessments of heavy metals in dust samples collected from classrooms in Ilorin, Nigeria and its impact on public health

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ABSTRACT

Over the past three decades, heavy metals (HMs) in indoor dust have been a significant focus due to their environmental and health risks. This study assessed HM contamination (Co, Pb, Cd, Cr, Ni, and As) in classroom and lecture theatre dust in Ilorin, Nigeria, across dry and rainy seasons. Dust samples from primary, secondary, and university settings were analyzed using atomic absorption spectrometry and ICP-OES. HM concentrations followed the order As > Pb > Co > Cr > Ni > Cd, all below background values. Indices like geoaccumulation (Igeo), contamination factor (CF), and pollution load index (PLI) indicated minimal contamination. The proportion of human health risks attributed to dermal contact, represented by HQderm and CRderm, accounted for 67.76 % and 30.30 % of the total hazard index (HI) and cancer risk (CR) during the dry season, and 86.76 % and 72.65 % during the rainy season, respectively. Health risks via ingestion, inhalation, and dermal exposure showed children were more vulnerable than adults, with dermal pathways contributing significantly to overall risk. Principal component and geo-spatial analyses highlighted natural and anthropogenic HM sources. The findings provide critical data for policymakers to develop effective strategies for minimizing HM exposure in indoor environments.

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Abbreviations

AAS	Atomic absorption spectrometry
ADD	Average daily dose
As	Arsenic
Cd	Cadmium
Co	Cobalt
CF	Contamination factor
CR	Cancer risk
Cr	Chromium
FA	Factor analysis
HI	Hazard index
HM	Heavy metal
HQ	Hazard quotient
IARC	International Agency for Research on Cancer
ICP-OES	Inductively coupled plasma – optical emission spectrometer
Igeo	Geoaccumulation index
LCR	Lifetime cancer risk
LOD	Limit of detection
LOQ	Limit of quantification
Ni	Nickel
Pb	Lead
PCA	Principal component analysis
PLI	Pollution load index
RfC	Reference concentration
RfD	Reference dose
SD	Standard deviation
SF	Slope factor
SGV	Soil guideline value
TLCR	Total lifetime cancer risk
TPS	Tanke primary school
ULT	Unilorin lecture theatre
UPS	Unilorin primary school
USEPA	United States Environmental Protection Agency
USLT	University science lecture theatre

1. Introduction

Heavy metal (HM) contamination of environmental media, such as dust, soil, and particulate matter (PM), is one of the principal consequences of industrialization and urbanization, which have raised pollution levels in urban areas. Due to intense anthropogenic activity and rapid urbanization, megacities have become resource- and chemical-intensive. This has resulted in several environmental issues, including particle pollution and potentially hazardous substances [1–3]. Air pollution caused by particulate matter in the atmosphere is one of the biggest problems facing the globe today, especially in developing nations like Nigeria, where adequate pollution control is lacking. This has resulted in drastic increase in exposure to different pollutants, including heavy metals [4]. Therefore, it is imperative to understand the ways in which the physical and social aspects of the urban environment impact human health in the modern day. HMs such as cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn) are microscopic elements that naturally occur in the environment and result from the weathering of geological substrates [5–7]. Given the world's fast urbanization, it is imperative to understand how heavy metal concentrations in soil affect human health.

Dust, considered a reliable indicator of environmental pollution due to its composition, has become a significant concern in recent years. This poses various environmental health issues, including increased contamination of air, water, and soil in affected areas [8–10]. Epidemiological and experimental studies have highlighted the harmful effects of heavy metals (HM) on respiratory diseases and allergy sensitization [11,12]. Several of these heavy metals are frequently linked to allergy-related disorders in humans [11]. Indoor dust forms when airborne contaminants in the air adhere to indoor particles. Consequently, exposure to indoor pollutants can impact the health and productivity of residents [13]. Dust deposited in buildings primarily originates from both natural sources and human activities, reflecting the organic and inorganic pollution levels in urban areas. Outdoor sources of pollution, including vehicular traffic, atmospheric deposition, industrial emissions, fossil fuel and coal combustion, construction activities, and road dust, contribute to over 80 % of the particles found indoors [14]. Indoor air pollutants originate from various sources, including resident activities and household materials like furniture, carpets, and fans, among others [15]. Human respiration is harmed by small particles because they have low deposition velocities and stay in the atmosphere for longer [16,17]. Indoor environments typically exhibit higher pollutant concentrations and longer exposure durations compared to outdoor settings, where natural processes such as sunlight and microbial activity facilitate pollutant degradation. In indoor spaces, the lack of these factors extends the persistence of chemicals [18]. Consequently, indoor dust is a significant source of human exposure to HMs. The presence of HMs in indoor dust is influenced by factors such as building age, ventilation, smoking habits, daily fuel use for cooking, residents' living practices, and the number of occupants [19].

The intricate and frequently misinterpreted relationships exist between environmental degradation and its impact on health. Children are particularly vulnerable to the severe buildup of HMs in soil due to their heightened vulnerability [12,20]. In addition to

Table 1
Coordinates of the sampling points.

S/N	Location	Coordinate	Activity
1	GDS	8°48′38.86″N 4°59′35.45″E	Studying
2	TPS	8°48′66.58″N 4°60′32.55″E	Studying
3	UPS	8°46′82.18″N 4°64′71.54″E	Studying
4	ULT	8°48′19.68″N 4°67′33.85″E	Studying
5	USLT	8°48′18.59″N 4°67′49.55″E	Studying

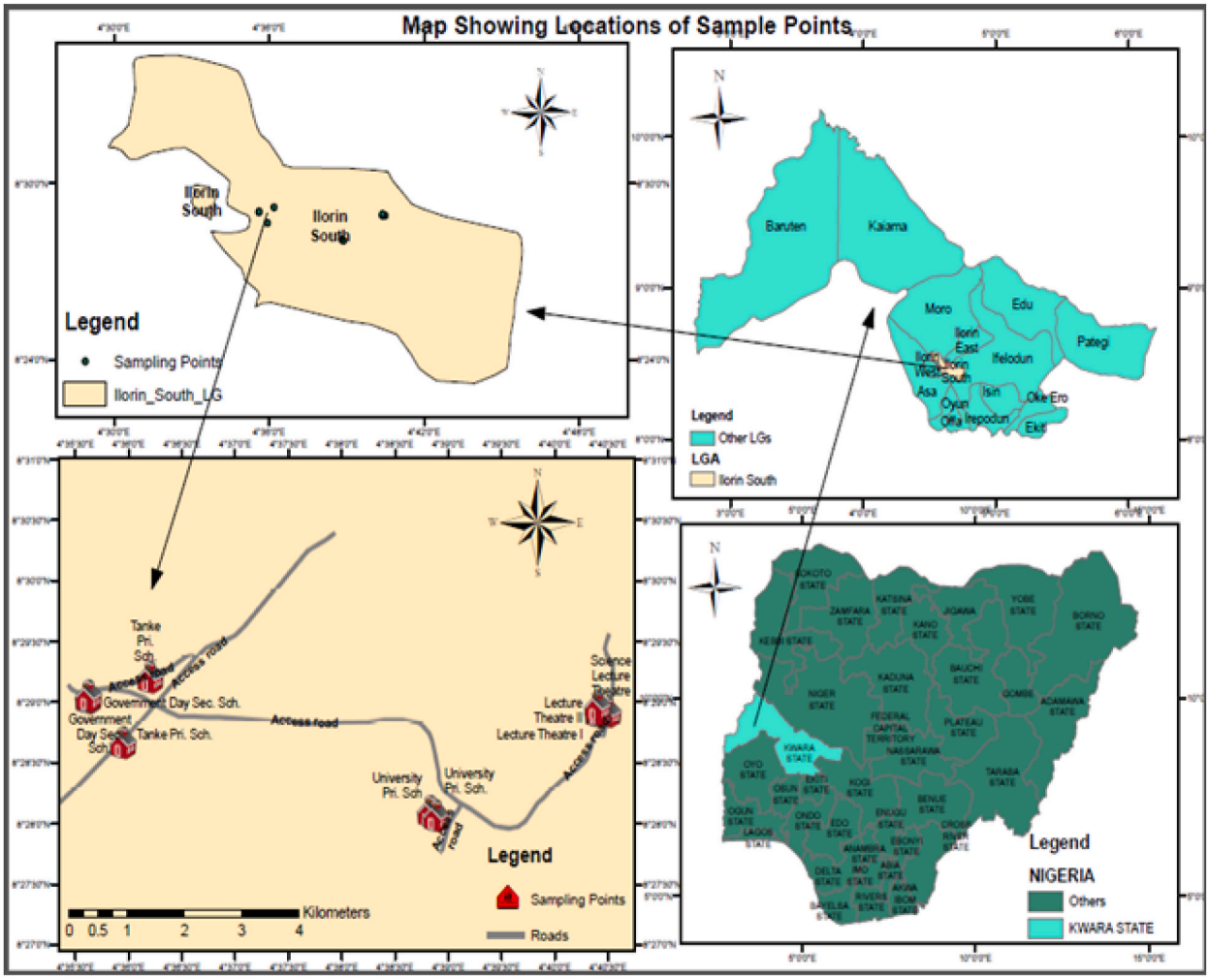


Fig. 1. Map of study area and sampling points.

this, school-aged children can also be exposed to exceptionally high levels of skin contact with dust when using sports equipment, as well as dust ingestion or inhalation by accident [21]. HMs have long been recognized as serious environmental hazards due to their toxicity, persistence, and resistance to degradation [22–24]. HMs present in dust can accumulate in the human body through skin contact, ingestion, or inhalation, with ingestion being the most common route. Babies and toddlers are more vulnerable than adults because they spend a large portion of their time in classrooms, where they may be exposed to indoor dust, play with toys, or eat food that has been touched by infected hands [25]. These metals can seriously deplete some essential nutrients in people, leading to deficiencies in the immune system, psycho-social dysfunction, malnutrition from unbalanced diets, and an increase in the incidence of upper gastrointestinal cancer [26–28]. The basis for evaluating the danger of HMs in humans is the mechanistic premise that these compounds may either be carcinogenic or non-carcinogenic. It has been found that the conventional approach to assessing the health effects of HMs in dust samples does not adequately identify significant pollutants or provide comprehensive hazard levels [8]. Instead, the assessed levels are directly compared with standard guideline limits. Health risk assessment is an essential technique for evaluating the possible health effects of environments caused by different pollutants.

Numerous studies have demonstrated that indoor dust serves as a repository for heavy metals, which can accumulate through natural or anthropogenic processes [29–31]. Studies have also demonstrated the concentrations of metals in classroom dust and their associated health risks to children [1,26,32]. Investigations have also focused on assessing exposure to indoor contaminants and examining indoor air quality [33,34]. Raising public awareness about the severity of indoor air pollution is crucial. There is a lack of data on the analysis of heavy metals in classroom dust within the study area, despite the importance of such information for assessing indoor environmental quality. Furthermore, no existing studies have compared the heavy metal content in classroom dust between Nigeria's two primary seasons, the rainy and dry seasons.

Therefore, this study aims to assess the levels of selected HMs in dust samples collected from various classrooms and lecture halls in Ilorin, Kwara State, Nigeria. Its specific objectives include: (i) evaluate the pollution levels of As, Cd, Cr, Ni, Pb, and Co in indoor dust, (ii) analyze contamination factors (CF), geoaccumulation index (Igeo), and pollution index (PI) to determine the extent of pollution, (iii) examine seasonal variations in toxic metal concentrations between the rainy and dry seasons in classrooms, (iv) evaluate human health risks linked to heavy metals using USEPA models for different age groups (adults and children), and (v) employ factor analysis and correlation analysis to identify factors influencing heavy metal presence in indoor dust.

2. Materials and methods

2.1. The study area

The study area includes the University of Ilorin Permanent Site, Unilorin Primary School, Tanke Community Primary School, and Government Day Secondary School in Tanke Community, which are all located in the Ilorin south local government area. Ilorin South is located between latitudes 8°19′ and 8°32′ north of the equator and longitude $4^{0}40$' east of the Greenwich Meridian. It occupies a land mass of about 174 km^2 and a population of 208,691 during a parallel census conducted by the National Population Commission in 2006. The study area is a settlement that is mostly occupied by students, which makes it very crucial to monitor the HM in dust samples and evaluate their impacts on public health.Table 1 and Fig. 1 show the study area map alongside the global positioning system (GPS) coordinates for the sample.

2.2. Sampling

Dust samples for this study were collected across two seasons (dry and rainy) from four educational institutions in Ilorin South Local Government, Ilorin, Kwara State, using nine (9) sampling points. The institutions included Government Day Secondary School, Tanke Community Primary School, University Primary School (Unilorin), and the University of Ilorin's permanent site. Sampling was conducted in two classrooms per location, with duplicate samples collected from each class to ensure accuracy and reliability. In total, 36 samples were analyzed for heavy metal contamination, evenly distributed between the rainy and dry seasons (18 samples per season). The selection of schools was based on factors such as student population, representation of different age groups, willingness of schools to grant access, and adherence to relevant regulations set by the school authorities.

To collect dust in the classroom, a short sweeping brush, a long broom, and a plastic packer were used to gently dust windows and bookshelves, causing dust to spread around the room. Samples were collected from easily accessible, visible areas in the classrooms where students could come in touch with dust. The sweeping method with a dustpan and brush is widely regarded as an effective approach for collecting bulk samples from both porous and nonporous surfaces, such as classroom surfaces, due to its simplicity, practicality, and ability to capture larger particles [25]. Each sample was placed in a labeled polythene bag and transported to the laboratory for further analysis.

2.3. Sample preparation and analysis

After being air dried for 24 h at room temperature using a different labeled bag, the dust sample was sieved through a 0.25 mm plastic test sieve (ASTM-E11, USA) for analysis. The concentration of the HM (As, Pb, Cd, Cr, Ni, and Co) in each sample was analyzed using approximately 1 g of each sieved dust sample. A 0.25 mm grain size dust sample was chosen because it can easily re-suspend in the air, hang around for a long time, enter the respiratory system, and have an impact on human health. Additionally, the health risks associated with fine particles are substantially higher than those associated with coarser particles. This is because the finer grain fraction has a relatively larger surface area, leading to higher metal concentrations within this fraction [35].

The dust samples (about 1 g each) were weighed and placed in a clean, clearly labeled digestion flask with 3 ml of concentrated HNO_3 and 9 ml of concentrated HCl added. The flask was then heated on a hotplate inside a fume cupboard to start the digestive process. It was determined that digestion was complete when the mixture stopped releasing black fumes, indicating the release of nitrogenous compounds [36]. The digested mixture was allowed to cool before being filtered into a 50-mL volumetric flask, which was then filled to the required volume with distilled water and transferred to a plastic reagent bottle for instrumental analysis (AAS or ICP-OES, depending on the metals), which was used to determine the quantitative concentrations of elements of interest in a given sample [8]. The digested samples were stored at 4 °C in a refrigerator prior to instrumental analysis.

The process produces HM concentrations of up to parts per million in the digested material. A well-calibrated atomic absorption spectrophotometer (AAS) was used to evaluate the amounts of, Co, Pb, Cd, Cr, and Ni in the digested samples after digestion, while an inductively coupled plasma-optical emission spectrophotometer (ICP-OES) was utilized to determine the As content. ICP-OES was utilized to analyze As since it has a lower detection limit than AAS. ICP-OES was used for the analysis of the As because of its toxic effect

and to obtain the actual result, and AAS was used for other metals in order to minimize the cost of analysis.

2.4. Chemical and reagents

The chemicals and reagents used throughout the analysis were analytical grade, with a certificate of analysis and material safety data sheet. The chemicals were purchased from Omega Global Procurement Ltd. in Ilorin, Kwara State, Nigeria. The chemicals required are hydrochloric acid, nitric acid, and distilled water.

2.5. Quality assurance

The following quality control tests were performed on the analytical procedures: duplicate sample digestions and examinations for each sampling point's samples; adjustments for metal concentrations in blanks for reagents, glassware, and other materials; and establishment of the limit of detection (LOD) and limit of quantification (LOQ) for each element. These determinations were made following a standard procedure to ascertain the instrument's operational performance. The calibration curves, produced after the standard solutions of each target metal were examined in the instrument and used to establish the LOD and LOQ. Additionally, the instrument was calibrated prior to use. Plastic and glassware were soaked in 2 % HNO_3 for 24 h before analysis, then cleaned with detergent and thoroughly rinsed with tap and distilled water.

2.6. Statistical analysis

The data from the study were examined statistically using SPSS version 25 to create the cluster analysis graph and PCA. The analysis of HM concentrations at various locations resulted in the estimation of seasonal means and standard deviation (SD). A two-way ANOVA was performed to calculate the correlation of variance, which shows the distribution pattern of the HMs and other parameters in the samples. Factor analysis (FA) was used to identify the potential origins of each HM under examination. Factor analysis was carried out using the principal component extraction approach, which decreased the data set's dimensionality and explained the variability among the observed correlated variables. All findings were analyzed using box and whisker plots, error bar plots, cluster bar plots, factor analysis, and cluster analysis. A Microsoft Excel spreadsheet was used to do descriptive statistics on the data, as well as all contamination assessment tools (CF, PLI, and Igeo), health risk assessment parameters (carcinogenic and non-carcinogenic), and pie charts.

2.7. Non-carcinogenic risk assessment

Non-carcinogenic risk assessment is used to determine an element's lifetime non-carcinogenic health risk. It is calculated by multiplying the average daily dose (ADD) from each exposure pathway by a known reference dose (RfD) or reference concentration (RfC), using Equations (1)–(3). RfD is an oral reference dosage for multiple human exposure routes, whereas RfC is a reference concentration or estimate of continuous inhalation exposure.

$$ADD_{oral} = \frac{C \times Ing_{rate} \times CF \times EF \times ED}{BW \times AT} \tag{1}$$

$$ADD_{inhale} = \frac{C \times Inh_{rate} \times EF \times ED}{PEF \times BW \times AT} \tag{2}$$

$$ADD_{dermal} = \frac{C \times SA \times CF \times SL \times EF \times ABS \times ED}{BW \times AT} \tag{3}$$

2.7.1. The hazard quotient (HQ)

HQ estimates a specific element's lifetime non-carcinogenic health risk. It is calculated by multiplying the ADD for each exposure pathway by a predefined RfD or reference concentration, using Equation (4).

$$hazard\ quotient\ (HQ) = \frac{ADD}{RfD/RfC} \tag{4}$$

2.7.2. Hazard index (HI)

The hazard index (HI) measures the non-carcinogenic danger posed by various routes and components. The total non-carcinogenic risk for humans is calculated by combining the HQs from all three exposure modes (ingestion, dermal contact, and inhalation), using Equation (5). A HI value more than one indicates a significant noncarcinogenic risk to human health, whereas HI values less than one indicate no such risk.

$$hazard\ index\ (HI) = HQ_{oral} + HQ_{dermal} + HQ_{inhale} \tag{5}$$

2.8. Carcinogenic risk assessment

The carcinogenic risk estimate predicts the possibility that a person would develop cancer as a result of their lifetime exposure to carcinogens. As shown in Equation (6), the ADD and cancer slope factor (SF) are compounded to calculate the lifetime cancer risk (LCR), which is used to predict the carcinogenic risk to humans.

$$\textit{lifetime cancer risk } LCR = ADD \times SF \tag{6}$$

The LCR measured for ingestion, cutaneous contact, and inhalation are combined to calculate the total lifetime cancer risk (TLCR), as shown in Equation (7). The USEPA's range is the permitted TLCR for carcinogenic risk. TLCR levels that are above the permitted range indicate that there are potential carcinogenic risks, which are likely to occur.

$$\textit{total lifetime cancer risk } TLCR = LCR_{oral} + LCR_{inhale} + LCR_{dermal} \tag{7}$$

2.9. Dust pollution assessment

The geo-accumulation index, also known as the single factor pollution index (PI), the contamination factor, and the pollution load index were all used to determine the level of metal contamination in classroom dust [37].

2.9.1. Contamination factor (CF)

The CF of each metal under examination was determined using Equation (8) and soil quality criteria for environmental and human health protection. The baseline values were taken from the earth's crust [38].

$$CF_n = \frac{C_{sample}}{C_{background}} \tag{8}$$

where CF_n = contamination factor of each metal,
C_{sample} = determined metal concentrations,
$C_{background}$ = metal background concentration
The CF is classified into four groups:
CF $<$ 1: low contamination
1 $\leq$ CF $<$ 3: moderate contamination
3 $\leq$ CF $<$ 6: considerable contamination
CF $>$ 6: very high contamination.

2.9.2. The pollution load index (PLI)

The pollution level in the classrooms was calculated using the pollution load index (PLI) developed by Tomlinson et al. in 1980. It has no units and represents the total or reciprocal pollution effects of all HMs in a single overall contamination index [38]. The PLI was computed as the mean CF values of metal using Equation (9).

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{\frac{1}{n}} \tag{9}$$

PLI is for the pollution load index, n stands for the number of metals that were examined, and is the metals' contamination factor. PLI readings of 1 or higher indicate pollution, while values lower than 1 point to metal concentrations that are close to background levels. This offers a relative way to evaluate the calibre of the site.

PLI $<$1 indicates perfection, i.e., no pollution or good site quality.
PLI = 1 is considered a reference line when levels of pollutants are present and
PLI $>$1 is considered a worsening of site quality.

2.9.3. Index of geo-accumulation (Igeo)

When comparing the importance of modern metal imports to pre-industrial concentrations, the Index of Geo-accumulation (Igeo) values can be useful. Muller 30 originally devised this approach, which has been used to determine the level of metal contamination in environmental matrices such as dust, silt, and soil. Equation (10) calculates the geoaccumulation index.

$$Igeo = log_2 \frac{C_n}{1.5 \times B_n} \tag{10}$$

where C_n denotes the amount of a specific metal in the sample, and B_n denotes the metal's background concentration. To account for any differences in background values produced by lithological variances in the samples, a constant of 1.5 is applied.

Table 2
Descriptive statistics of the total concentration of HM in the indoor dust during dry season and rainy season (mg/L).

Location		Dry season						Rainy season					
		Co	Pb	Cd	Cr	Ni	As	Co	Pb	Cd	Cr	Ni	As
GDS	Min	0.00110	0.02100	ND	ND	ND	ND	0.00010	ND	ND	0.00018	ND	ND
	Max	0.00600	0.03800	0.00050	0.00310	0.00051	0.00340	0.00076	0.03200	0.00022	0.00220	0.00500	0.09810
	Mean	0.00360	0.02975	0.00023	0.00084	0.00023	0.00085	0.00042	0.02050	0.00006	0.00071	0.00150	0.06170
	SD	0.0025	0.0074	0.0002	0.0015	0.0003	0.0017	0.0003	0.0146	0.0001	0.0010	0.0024	0.0449
TPS	Min	ND	0.01700	ND	0.00021	ND	ND	ND	0.00100	ND	0.00021	ND	0.00570
	Max	0.00150	0.02500	0.00000	0.00027	0.00012	0.00000	0.00130	0.01000	0.00016	0.00024	0.00400	0.09650
	Mean	0.00040	0.01975	0.00000	0.00024	0.00003	0.00000	0.00065	0.00475	0.00004	0.00022	0.00125	0.04840
	SD	0.0007	0.0036	0.0000	0.0000	0.0001	0.0000	0.0005	0.0041	0.0001	0.0000	0.0019	0.0493
UPS	Min	ND	0.00010	ND	ND	ND	0.00630	0.00000	0.00100	ND	ND	ND	ND
	Max	0.00270	0.00200	0.00010	0.00260	0.00000	0.03130	0.00110	0.00650	0.00003	0.00260	0.00300	0.06560
	Mean	0.00118	0.00098	0.00003	0.00123	0.00000	0.01458	0.00050	0.00318	0.00001	0.00168	0.00128	0.02920
	SD	0.0012	0.0010	0.0001	0.0013	0.0000	0.0116	0.0006	0.0024	0.0000	0.0012	0.0015	0.0342
ULT	Min	0.0023	ND	ND	ND	ND	0.0091	0.0001	0.0006	ND	ND	ND	ND
	Max	0.0030	0.0001	0.0002	0.0035	0.0004	0.0414	0.0032	0.0060	0.0001	0.0022	0.0010	0.0878
	Mean	0.0027	0.0000	0.0000	0.0019	0.0001	0.0210	0.0009	0.0024	0.0000	0.0010	0.0003	0.0420
	SD	0.0003	0.0001	0.0001	0.0018	0.0002	0.0151	0.0015	0.0025	0.0001	0.0010	0.0005	0.0486
USLT	Min	0.0050	ND	ND	ND	ND	0.0181	0.0017	ND	ND	ND	ND	ND
	Max	0.0056	0.0023	0.0000	0.0000	0.0008	0.0562	0.0020	0.0015	0.0000	0.0000	0.0000	0.0633
	Mean	0.0053	0.0012	0.0000	0.0000	0.0004	0.0372	0.0019	0.0008	0.0000	0.0000	0.0000	0.0317
	SD	0.0004	0.0016	0.0000	0.0000	0.0006	0.0269	0.0002	0.0011	0.0000	0.0000	0.0000	0.0448
Canada SGV			140	10	0.4	50	12		140	10	0.4	50	12
Norway SGV			90	12.2	75	90	12		90	12.2	75	90	12
Earth crust		18	16	0.13	83	58	1.7	18	16	0.13	83	58	1.7
Continental shale		19	20	0.3	45	68	13	19	20	0.3	45	68	13

ND = Not detected.

Table 3
Comparison between the concentrations of HMs in indoor dust of the study area and concentration of HMs in indoor dust of previous works.

Location	Co	Pb	Cd	Cr	Ni	As	Reference
Jeddah, Saudi Arabia (μg/g)	0.8–16.0	35.0–225.0	0.7–4.3	21.0–63.0	4.0–68.0	1.8–13.0	[32]
Rawang, Malaysia (μg/g)	2.92E-03 - 9.16E-02	1.77E-04 - 1.55E-02	1.87E-03 - 2.96E-02	3.19E-03 -1.83E-01	9.61E-02 - 2.88E + 00	4.33E-03 - 5.44E-02	[26]
Asaluyeh, South of Iran (mg/kg)	0.99–23.2	1.24–13.4	0.15–4.80	0.81–86.5	11.4–20.9	0.65–9.96	[39]
Khorramabad, Iran (mg/kg)	–	10.28–101.65	8.02–17.72	3.49–22.55	25.00–89.47	–	[40]
Ado-Ekiti, Nigeria (mg/kg)	–	0.03–9.40	–	0.20–1.75	–	–	[41]
North china (mg/kg)	–	40–49.973	0.23–621.10	29.50–758.00	–	9.40–1695.10	[42]
Southern Nigeria (mg/kg)	3.50–232.00	26.50–1530.00	0.003–8.00	7.8–346	10.5–490.00	–	[43]
Southern Nigeria (mg/kg)	0.50–146	4.50–540	ND-91.5	0.10–1,100	0.50–1,150	–	[35]
Lagos, Nigeria (mg/kg)	–	14.9–114	0–1.3	39.8–606	10.5–40.3	1.4–4.8	[1]
Ilesha, Nigeria (mg/kg)	3.50–32.80	6.06–28.61	0.02–0.20	29.00–212.00	4.10–73.80	0.20–4.50	[44]
Ilorin, Nigeria (mg/kg)	3.35	5.55	0.12	1.92	1.35	0.08	[21]
Ilorin, Nigeria (mg/kg)	0.001747	0.009473	0.0000396	0.000777	0.00051	0.03182	**This study**

Table 4
Contamination level of different HMs in dust depending on CF, PLI, and Igeo values.

Location	HM	Dry season				Rainy season			
		Conc. (mg/L)	CFn	PLI	Igeo	Conc. (mg/L)	CFn	PLI	Igeo
GDS	Co	0.00360	2.00E-04	1.23E-03	−12.87	0.00042	2.33E-05	1.80E-03	−15.97
	Pb	0.02975	1.86E-03		−9.66	0.02050	1.28E-03		−10.19
	Cd	0.00023	1.77E-03		−9.73	0.00006	4.62E-04		−11.67
	Cr	0.00084	1.01E-05		−17.18	0.00071	8.55E-06		−17.42
	Ni	0.00023	3.97E-06		−18.53	0.00150	2.59E-05		−15.82
	As	0.00085	5.00E-04		−11.55	0.06170	3.63E-02		−5.37
TPS	Co	0.000400	2.22E-05	0.00E+00	−16.04	0.00065	3.61E-05	1.09E-03	−15.34
	Pb	0.019750	1.23E-03		−10.25	0.00475	2.97E-04		−12.30
	Cd	0.000000	0.00E+00		0.00	0.00004	3.08E-04		−12.25
	Cr	0.000238	2.87E-06		−19.00	0.00022	2.65E-06		−19.11
	Ni	0.000030	5.17E-07		−21.47	0.00125	2.16E-05		−16.09
	As	0.00000	0.00E+00		0.00	0.04840	2.85E-02		−5.72
UPS	Co	0.001175	6.53E-05	0.00E+00	−14.49	0.00050	2.78E-05	1.00E-03	−15.72
	Pb	0.000983	6.14E-05		−14.58	0.00318	1.99E-04		−12.88
	Cd	0.000025	1.92E-04		−12.93	0.00001	7.69E-05		−14.25
	Cr	0.001228	1.48E-05		−16.63	0.00168	2.02E-05		−16.17
	Ni	0.000000	0.00E+00		0.00	0.00128	2.21E-05		−16.05
	As	0.01458	8.58E-03		−7.45	0.02920	1.72E-02		−6.45
ULT	Co	0.0027	1.50E-04	0.00E+00	−13.29	0.0009	5.00E-05	0.00E+00	−14.87
	Pb	0.0000	0.00E+00		−18.28	0.0024	1.50E-04		−13.29
	Cd	0.0000	0.00E+00		0.00	0.0000	0.00E+00		0.00
	Cr	0.0019	2.29E-05		−16.00	0.0010	1.20E-05		−16.93
	Ni	0.0001	1.72E-06		−19.73	0.0003	5.17E-06		−18.15
	As	0.0210	1.24E-02		−6.92	0.0420	2.47E-02		−5.92
USLT	Co	0.0053	2.94E-04	0.00E+00	−12.31	0.0019	1.06E-04	0.00E+00	−13.80
	Pb	0.0012	7.50E-05		−14.29	0.0008	5.00E-05		−14.87
	Cd	0.0000	0.00E+00		0.00	0.0000	0.00E+00		0.00
	Cr	0.0000	0.00E+00		0.00	0.0000	0.00E+00		0.00
	Ni	0.0004	6.90E-06		−17.73	0.0000	0.00E+00		0.00
	As	0.0372	2.19E-02		−6.10	0.0317	1.86E-02		−6.33

3. Results and discussions

3.1. Descriptive statistics

Table 2 displays the typical metal concentrations in indoor dust from classrooms and lecture halls in Ilorin, Kwara State. There were significant differences in the metal concentrations in the dust from various sites within an institution and between institutions ($p <$

Table 5
ADD of HMs in samples collected at study area during dry season.

Location	HM	Children			Adults		
		ADDing	ADDinh	ADDderm	ADDing	ADDinh	ADDderm
GDS	Co	2.37E-08	6.61E-13	6.63E-08	2.54E-09	3.73E-13	1.01E-08
	Pb	1.96E-07	5.47E-12	5.48E-07	2.10E-08	3.08E-12	8.36E-08
	Cd	1.51E-09	4.23E-14	4.23E-12	1.62E-10	2.38E-14	6.47E-13
	Cr	5.52E-09	1.54E-13	1.55E-08	5.92E-10	8.70E-14	2.36E-09
	Ni	1.51E-09	4.23E-14	4.23E-09	1.62E-10	2.38E-14	6.47E-10
	As	5.59E-09	1.56E-13	4.69E-10	5.99E-10	8.81E-14	7.17E-11
TPS	Co	2.63E-09	7.35E-14	7.36E-09	2.82E-10	4.14E-14	1.12E-09
	Pb	1.30E-07	3.63E-12	3.64E-07	1.39E-08	2.05E-12	5.55E-08
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	1.56E-09	4.37E-14	4.38E-09	1.68E-10	2.47E-14	6.69E-10
	Ni	1.97E-10	5.51E-15	5.52E-10	2.11E-11	3.11E-15	8.43E-11
	As	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
UPS	Co	7.73E-09	2.16E-13	2.16E-08	8.28E-10	1.22E-13	3.30E-09
	Pb	6.46E-09	1.81E-13	1.81E-08	6.93E-10	1.02E-13	2.76E-09
	Cd	1.64E-10	4.59E-15	4.60E-13	1.76E-11	2.59E-15	7.03E-14
	Cr	8.07E-09	2.26E-13	2.26E-08	8.65E-10	1.27E-13	3.45E-09
	Ni	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	As	9.59E-08	2.68E-12	8.05E-09	1.03E-08	1.51E-12	1.23E-09
ULT	Co	1.78E-08	4.96E-13	4.97E-08	1.90E-09	2.80E-13	7.59E-09
	Pb	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	1.25E-08	3.49E-13	3.50E-08	1.34E-09	1.97E-13	5.34E-09
	Ni	6.58E-10	1.84E-14	1.84E-09	7.05E-11	1.04E-14	2.81E-10
	As	1.38E-07	3.86E-12	1.16E-08	1.48E-08	2.18E-12	1.77E-09
USLT	Co	3.48E-08	9.74E-13	9.76E-08	3.73E-09	5.49E-13	1.49E-08
	Pb	7.89E-09	2.20E-13	2.21E-08	8.45E-10	1.24E-13	3.37E-09
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ni	2.63E-09	7.35E-14	7.36E-09	2.82E-10	4.14E-14	1.12E-09
	As	2.45E-07	6.83E-12	2.05E-08	2.62E-08	3.85E-12	3.14E-09

0.05). The variances could be attributed to different building types, site activities, cleaning practices, type and characteristics, indoor environment features, local geology, and prevalent human activities in the area. The average concentrations of the investigated metals were higher in the dust from sample locations away from the university campus (GPS and TPS) than in the campus itself (UPS, ULT, and USLT), which may be due to inputs from anthropogenic activities and heavy traffic density.

The metal concentrations in classroom and lecture hall dust throughout the dry and rainy seasons were as follows: As > Pb > Co > Cr > Ni > Cd. Metals in dust have no defined limits at the local, national, or international levels. However, because soil accounts for 30–40 % of dust loading [35], the regulatory control limits for metals in the soil were used as a benchmark for determining the significance of metal concentrations in the dust samples.

The descriptive statistic was shown alongside soil guideline values (for soil in residential areas) for two countries to illustrate the variety of worldwide values and to provide context for the range of total heavy metal concentrations seen in Table 2. According to Famuyiwa and Entwistle [1], the external environment frequently influences the indoor environment. The descriptive statistics for all HMs at all locations throughout both dry and rainy seasons show that none of the heavy metal readings surpassed the Norwegian and Canadian soil guideline values (SGV) or typical soil background levels (earth crust and continental shale). HMs in indoor dust from selected research are presented (Table 3), adding context to the results. Although these studies focus on classroom dust, there are differences in sample preparation and analysis, further limiting direct comparisons. However, HM concentrations in the current investigation are consistent with the mean/geomean findings reported in previous studies (Table 2).

Compared to the SGVs, most heavy metals evaluated in this study did not indicate elevated amounts; in fact, several of them were lower than those found in other Nigerian cities. For example, reported measurements of Co, Pb, Cd, Cr, Ni, and As in Ilorin [21], Ilesha [44], and Lagos [1] were all greater than those observed in the present study. Several of the schools investigated herein were located far from active commercial areas; therefore, indoor dust samples ascribed to indoor sources should contain lower levels of heavy metal. The concentration of heavy metals in interior dust will vary depending on local activity. Heavy metals can enter houses through a variety of routes, including particle backscattering from people and animals, airborne dust particles (for example, through open windows), and a wide range of indoor sources such as building materials, furniture, and consumer products. Higher levels of heavy metals in indoor dust were found in studies from China [42], Saudi Arabia [32], Malaysia [26], and Pakistan [45,46], which are probably related to their long histories of urbanization and industrialization.

3.2. Contamination assessment

Geo-accumulated Index (I_{geo}) has been broadly applied in the assessment of HM contamination levels in school indoor dust samples.

Table 6
ADD of HMs in samples obtained from the study area during the rainy season.

Location	HM	Children			Adults		
		ADDing	ADDinh	ADDderm	ADDing	ADDinh	ADDderm
GDS	Co	2.76E-09	7.72E-14	7.73E-09	2.96E-10	1.65E-14	1.18E-09
	Pb	1.35E-07	3.77E-12	3.77E-07	1.44E-08	8.07E-13	5.76E-08
	Cd	3.95E-10	1.10E-14	1.10E-09	4.23E-11	2.36E-15	1.69E-13
	Cr	4.67E-09	1.30E-13	1.31E-08	5.00E-10	2.80E-14	2.00E-09
	Ni	9.86E-09	2.76E-13	2.76E-08	1.06E-09	5.91E-14	4.22E-09
	As	4.06E-07	1.13E-11	1.14E-06	4.35E-08	2.43E-12	5.20E-09
TPS	Co	4.27E-09	1.19E-13	1.20E-08	4.58E-10	2.56E-14	1.83E-09
	Pb	3.12E-08	8.73E-13	8.75E-08	3.35E-09	1.87E-13	1.34E-08
	Cd	2.63E-10	7.35E-15	7.36E-10	2.82E-11	1.57E-15	1.12E-13
	Cr	1.45E-09	4.04E-14	4.05E-09	1.55E-10	8.66E-15	6.18E-10
	Ni	8.22E-09	2.30E-13	2.30E-08	8.81E-10	4.92E-14	3.51E-09
	As	3.18E-07	8.89E-12	8.91E-07	3.41E-08	1.91E-12	4.08E-09
UPS	Co	3.29E-09	9.19E-14	9.21E-09	3.52E-10	1.97E-14	1.41E-09
	Pb	2.09E-08	5.84E-13	5.85E-08	2.24E-09	1.25E-13	8.94E-09
	Cd	6.58E-11	1.84E-15	1.84E-10	7.05E-12	3.94E-16	2.81E-14
	Cr	1.10E-08	3.09E-13	3.09E-08	1.18E-09	6.61E-14	4.72E-09
	Ni	8.42E-09	2.35E-13	2.36E-08	9.02E-10	5.04E-14	3.60E-09
	As	1.92E-07	5.36E-12	5.38E-07	2.06E-08	1.15E-12	2.46E-09
ULT	Co	5.92E-09	1.65E-13	1.66E-08	6.34E-10	3.54E-14	2.53E-09
	Pb	1.58E-08	4.41E-13	4.42E-08	1.69E-09	9.45E-14	6.75E-09
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	6.58E-09	1.84E-13	1.84E-08	7.05E-10	3.94E-14	2.81E-09
	Ni	1.97E-09	5.51E-14	5.52E-09	2.11E-10	1.18E-14	8.43E-10
	As	2.76E-07	7.72E-12	7.73E-07	2.96E-08	1.65E-12	3.54E-09
USLT	Co	1.25E-08	3.49E-13	3.50E-08	1.34E-09	7.48E-14	5.34E-09
	Pb	5.26E-09	1.47E-13	1.47E-08	5.64E-10	3.15E-14	2.25E-09
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ni	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	As	2.08E-07	5.82E-12	5.84E-07	2.23E-08	1.25E-12	2.67E-09

The different I_{geo} values for different dust samples collected from schools in two different seasons are shown in Table 4. Following the contamination level classification by Muller, the I_{geo} values for all the HMs analyzed in school dust samples are all negative, which implies that Pb, As, Cd, Cr, Ni, and Co fall in the class of practically unpolluted (I_{geo} <1). The descriptive statistic was presented alongside soil guideline values (for soil in residential areas) for two nations that illustrate the range of international values in order to give some context to the range of total heavy metal concentrations observed. (Ugwu & Ofomatah, 2021b). The values of I_{geo} for all the analyzed heavy metals are negative at all schools. These negative values imply that the environment is unpolluted with metals.

The pollution intensity or contamination status was measured using Forstner and Wittmann's recommendations [25]. This was based on the calculated CF values shown in Table 4. At all schools, the average concentration indicated contamination factor is in the sequence of USLT > ULT > UPS > GDS > TPS and GDS > TPS > ULT > USLT > UPS for the dry and wet seasons, respectively. According to (Rahman et al., 2021), CF < 1 indicates low contamination. Table 4 summarizes the contamination factor results, indicating that the heavy metals evaluated contributed low contamination to the sample sites.

The pollution load index, based on Tomllinson's approach, reveals that the PLI was less than unity in all of the tested schools, as shown in Table 4. The PLI values ranged from 0.00E+00 to 1.23E-03. This shows that the dust was not contaminated by heavy metals. It also suggests no pollution or high site quality. The descending order of site quality was GDS > TPS > UPS, whereas ULT and USLT recorded 0.00, indicating that they were not recognized.

3.3. Health risk assessment

Tables 5–8 provide the results of the current study's human health risk assessment (carcinogenic and non-carcinogenic risks) for both the dry and rainy seasons. Exposures to HMs in indoor dusts tested fell under tolerable limits for both carcinogenic and non-carcinogenic hazards for both age groups (children and adults).

3.3.1. Estimation of the calculated average daily dose

The estimation of the average daily dose (ADD) of HM in each dust sample is presented in Tables 5 and 6 for dry and rainy seasons, respectively. The ADD of HM was determined on exposure via ingestion, inhalation, and dermal contact denoted by ADD_{oral},ADD_{Inhale},ADD_{dermal}, respectively. As can be seen in Table 5, the trends observed from the study were in the order $ADD_{dermal} > ADD_{Oral} > ADD_{inhale}$ for both adults and children during the dry season. This indicates that dermal contact is the primary exposure pathway, while inhalation is the least significant.

However, the trend observed in the average daily exposure during the rainy season as presented in Table 6 is in the order

Table 7
Health risk assessment of HMs in indoor dusts of the study area during dry season.

Location	HM	HQing	HQinh	HQderm	HIchildren	HQing	HQinh	HQderm	HIadult	TLCRchildren	TLCRadult
GDS	Co	7.89E-07	2.32E-08	1.10E-05	1.19E-05	8.45E-08	1.31E-08	1.69E-06	1.78E-06	6.48E-12	3.66E-12
	Pb	5.59E-05	1.55E-09	1.05E-03	1.11E-03	5.99E-06	8.76E-10	1.61E-04	1.67E-04	1.17E-07	1.77E-08
	Cd	1.51E-06	4.23E-11	4.23E-07	1.94E-06	1.62E-07	2.38E-11	6.47E-08	2.27E-07	2.66E-13	1.50E-13
	Cr	1.84E-06	5.40E-09	2.58E-04	2.60E-04	1.97E-07	3.04E-09	3.94E-05	3.96E-05	1.05E-08	1.48E-09
	Ni	7.56E-08	2.05E-12	7.84E-07	8.60E-07	8.10E-09	1.16E-12	1.20E-07	1.28E-07	4.09E-09	6.13E-10
	As	1.86E-05	1.04E-08	3.82E-06	2.25E-05	2.00E-06	5.87E-09	5.83E-07	2.58E-06	9.09E-09	1.01E-09
TPS	Co	8.77E-08	2.58E-09	1.23E-06	1.32E-06	9.39E-09	1.45E-09	1.87E-07	1.98E-07	7.20E-13	4.06E-13
	Pb	3.71E-05	1.03E-09	6.99E-04	7.36E-04	3.98E-06	5.81E-10	1.07E-04	1.11E-04	7.75E-08	1.18E-08
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	5.22E-07	1.53E-09	7.30E-05	7.36E-05	5.59E-08	8.62E-10	1.12E-05	1.12E-05	2.97E-09	4.18E-10
	Ni	9.86E-09	2.68E-13	1.02E-07	1.12E-07	1.06E-09	1.51E-13	1.56E-08	1.67E-08	5.33E-10	8.00E-11
	As	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
UPS	Co	2.58E-07	7.57E-09	3.61E-06	3.87E-06	2.76E-08	4.27E-09	5.50E-07	5.82E-07	2.12E-12	1.19E-12
	Pb	1.85E-06	5.13E-11	3.48E-05	3.67E-05	1.98E-07	2.89E-11	5.31E-06	5.51E-06	3.86E-09	5.86E-10
	Cd	1.64E-07	4.59E-12	4.60E-08	2.10E-07	1.76E-08	2.59E-12	7.03E-09	2.46E-08	2.89E-14	1.63E-14
	Cr	2.69E-06	7.89E-09	3.77E-04	3.80E-04	2.88E-07	4.45E-09	5.75E-05	5.78E-05	1.53E-08	2.16E-09
	Ni	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	As	3.20E-04	1.79E-07	6.55E-05	3.85E-04	3.42E-05	1.01E-07	1.00E-05	4.43E-05	1.56E-07	1.73E-08
ULT	Co	5.92E-07	1.74E-08	8.28E-06	8.89E-06	6.34E-08	9.82E-09	1.26E-06	1.34E-06	4.86E-12	2.74E-12
	Pb	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	4.16E-06	1.22E-08	5.83E-04	5.87E-04	4.46E-07	6.88E-09	8.90E-05	8.95E-05	2.37E-08	3.34E-09
	Ni	3.29E-08	8.92E-13	3.41E-07	3.74E-07	3.52E-09	5.03E-13	5.21E-08	5.56E-08	1.78E-09	2.67E-10
	As	4.60E-04	2.57E-07	9.43E-05	5.55E-04	4.93E-05	1.45E-07	1.44E-05	6.39E-05	2.25E-07	2.48E-08
USLT	**Co**	1.16E-06	3.42E-08	1.63E-05	1.75E-05	1.24E-07	1.93E-08	2.48E-06	2.63E-06	9.54E-12	5.38E-12
	Pb	2.25E-06	6.26E-11	4.25E-05	4.47E-05	2.42E-07	3.53E-11	6.49E-06	6.73E-06	4.71E-09	7.16E-10
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ni	1.32E-07	3.57E-12	1.36E-06	1.50E-06	1.41E-08	2.01E-12	2.08E-07	2.22E-07	7.11E-09	1.07E-09
	As	8.15E-04	4.56E-07	1.67E-04	9.83E-04	8.74E-05	2.57E-07	2.55E-05	1.13E-04	3.98E-07	4.40E-08

Table 8
Health risk assessment of HMs in indoor dusts of the study area during rainy season.

Location	HM	HQing	HQinh	HQderm	HIchildren	HQing	HQinh	HQder	HIadult	TLCRchildren	TLCRadult
GDS	Co	9.21E-08	2.71E-09	1.29E-06	1.38E-06	9.86E-09	5.80E-10	1.97E-07	2.07E-07	7.56E-13	1.62E-13
	Pb	3.85E-05	1.07E-09	7.26E-04	7.64E-04	4.13E-06	2.29E-10	1.11E-04	1.15E-04	8.04E-08	1.22E-08
	Cd	3.95E-07	1.10E-11	1.10E-04	1.11E-04	4.23E-08	2.36E-12	1.69E-08	5.91E-08	6.94E-14	1.49E-14
	Cr	1.56E-06	4.56E-09	2.18E-04	2.19E-04	1.67E-07	9.77E-10	3.33E-05	3.34E-05	8.87E-09	1.25E-09
	Ni	4.93E-07	1.34E-11	5.11E-06	5.61E-06	5.28E-08	2.87E-12	7.81E-07	8.34E-07	2.66E-08	4.00E-09
	As	1.35E-03	7.56E-07	9.24E-03	1.06E-02	1.45E-04	1.62E-07	4.23E-05	1.87E-04	2.31E-06	7.30E-08
TPS	Co	1.42E-07	4.19E-09	1.99E-06	2.14E-06	1.53E-08	8.98E-10	3.05E-07	3.21E-07	1.17E-12	2.51E-13
	Pb	8.92E-06	2.48E-10	1.68E-04	1.77E-04	9.56E-07	5.31E-11	2.57E-05	2.66E-05	1.86E-08	2.83E-09
	Cd	2.63E-07	7.35E-12	7.36E-05	7.39E-05	2.82E-08	1.57E-12	1.12E-08	3.94E-08	4.63E-14	9.92E-15
	Cr	4.82E-07	1.41E-09	6.75E-05	6.80E-05	5.17E-08	3.03E-10	1.03E-05	1.04E-05	2.75E-09	3.87E-10
	Ni	4.11E-07	1.11E-11	4.26E-06	4.67E-06	4.40E-08	2.39E-12	6.51E-07	6.95E-07	2.22E-08	3.33E-09
	As	1.06E-03	5.93E-07	7.24E-03	8.31E-03	1.14E-04	1.27E-07	3.32E-05	1.47E-04	1.81E-06	5.73E-08
UPS	Co	1.10E-07	3.22E-09	1.53E-06	1.65E-06	1.17E-08	6.91E-10	2.34E-07	2.47E-07	9.00E-13	1.93E-13
	Pb	5.97E-06	1.66E-10	1.13E-04	1.19E-04	6.40E-07	3.56E-11	1.72E-05	1.78E-05	1.25E-08	1.90E-09
	Cd	6.58E-08	1.84E-12	1.84E-05	1.85E-05	7.05E-09	3.94E-13	2.81E-09	9.86E-09	1.16E-14	2.48E-15
	Cr	3.68E-06	1.08E-08	5.16E-04	5.19E-04	3.95E-07	2.31E-09	7.87E-05	7.91E-05	2.10E-08	2.95E-09
	Ni	4.21E-07	1.14E-11	4.36E-06	4.78E-06	4.51E-08	2.45E-12	6.66E-07	7.11E-07	2.27E-08	3.41E-09
	As	6.40E-04	3.58E-07	4.37E-03	5.01E-03	6.86E-05	7.66E-08	2.00E-05	8.87E-05	1.09E-06	3.46E-08
ULT	Co	1.97E-07	5.80E-09	2.76E-06	2.96E-06	2.11E-08	1.24E-09	4.22E-07	4.44E-07	1.62E-12	3.47E-13
	Pb	4.51E-06	1.25E-10	8.50E-05	8.95E-05	4.83E-07	2.68E-11	1.30E-05	1.35E-05	9.41E-09	1.43E-09
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	2.19E-06	6.42E-09	3.07E-04	3.09E-04	2.35E-07	1.38E-09	4.68E-05	4.71E-05	1.25E-08	1.76E-09
	Ni	9.86E-08	2.68E-12	1.02E-06	1.12E-06	1.06E-08	5.73E-13	1.56E-07	1.67E-07	5.33E-09	8.00E-10
	As	9.21E-04	5.14E-07	6.29E-03	7.21E-03	9.86E-05	1.10E-07	2.88E-05	1.28E-04	1.57E-06	4.97E-08
USLT	Co	4.16E-07	1.22E-08	5.83E-06	6.26E-06	4.46E-08	2.62E-09	8.90E-07	9.37E-07	3.42E-12	7.33E-13
	Pb	1.50E-06	4.18E-11	2.83E-05	2.98E-05	1.61E-07	8.95E-12	4.32E-06	4.49E-06	3.14E-09	4.77E-10
	Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ni	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	As	6.95E-04	3.88E-07	4.74E-03	5.44E-03	7.44E-05	8.32E-08	2.17E-05	9.63E-05	1.19E-06	3.75E-08

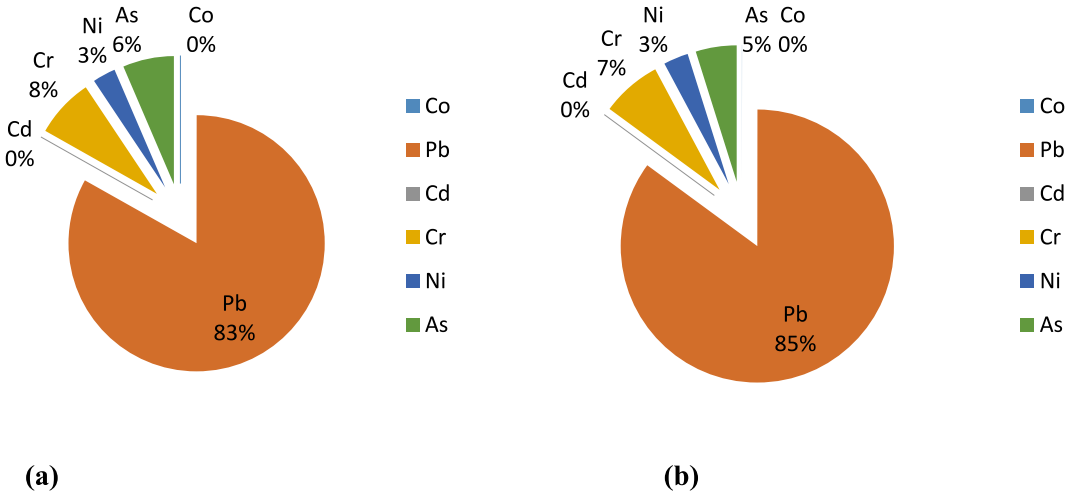


Fig. 2. Pie chart showing contributions of HM to carcinogenic risks to children (a) and adult (b) during dry season.

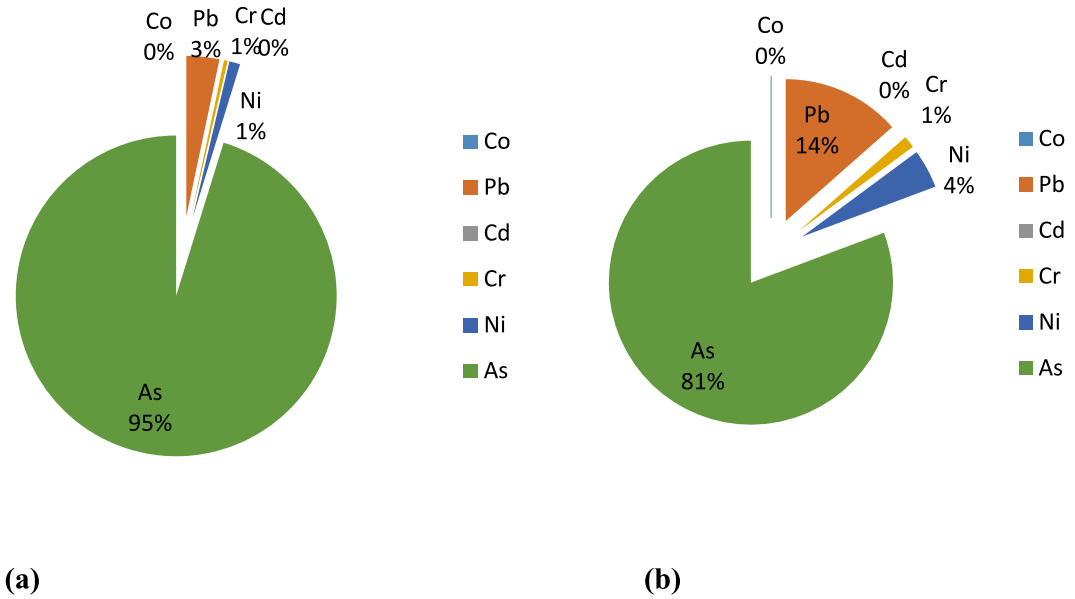


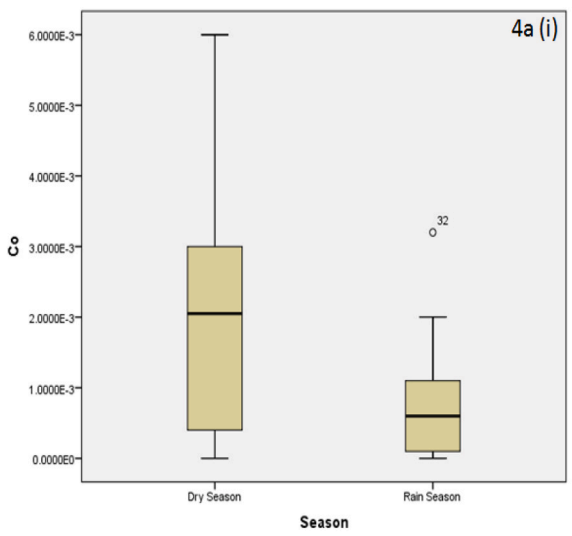
Fig. 3. Pie chart showing contributions of HMs to carcinogenic risks to children (a) and adult (b) during rainy season.

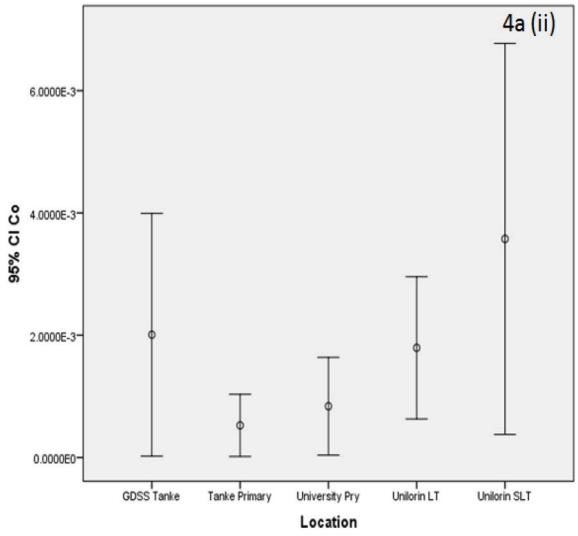
$ADD_{dermal} > ADD_{Oral} > ADD_{inhale}$ for adults. This implies that dermal is the major pathway of exposure while inhalation is the least significant. For children, the order is $ADD_{ingest} > ADD_{dermal} > ADD_{inhale}$, implying that ingestion is the major pathway of exposure while the least pathway is inhalation. For both age groups, dermal contact emerged as the primary exposure pathway, followed by ingestion and inhalation. However, during the rainy season, adults exhibited a different pattern, with ingestion being the most significant route, followed by dermal contact and inhalation.

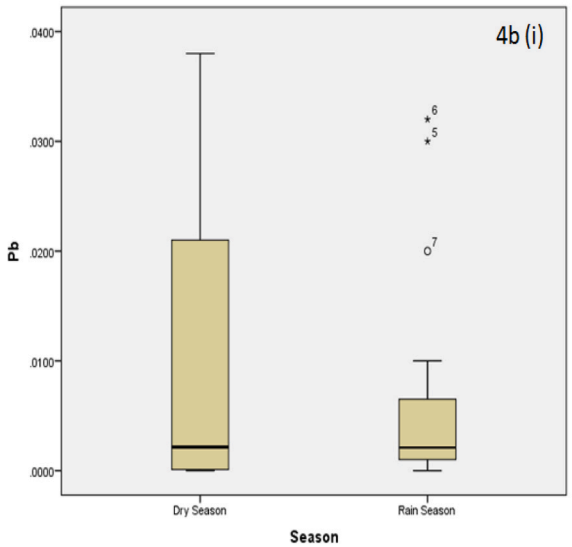
In the HM analyzed, arsenic was the highest contributor to non-carcinogenic risks for both children and adults during the rainy season, followed by Pb, Ni, Cr, Co, and Cd in that order. During the dry season, Pb was the predominant contributor, followed by As, Co, Cr, Ni, and Cd. This pattern contrasts with the findings of Famuyiwa and Entwistle [1], which reported a trend of Cr > Ni > Pb > Al > As > Zn > Mn > Cu.

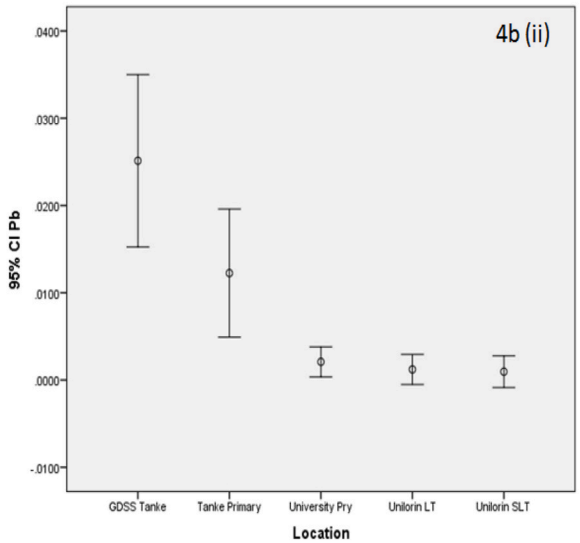
3.3.2. *Non-carcinogenic risk of heavy metals in classroom dust*

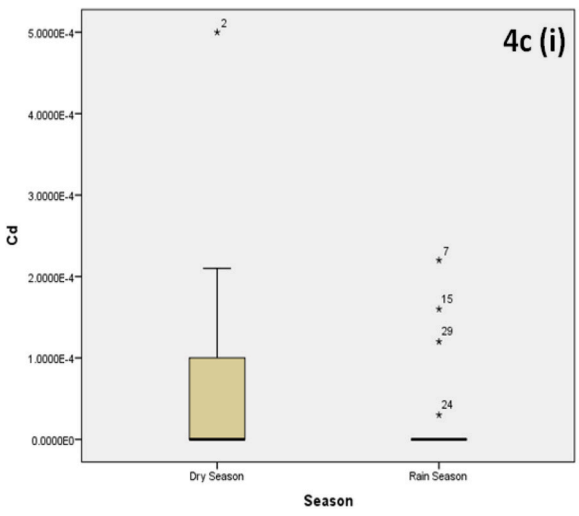
The non-carcinogenic risk of the examined HMs was estimated using the hazard quotients (HQ) and hazard indices (HI) of HM intake from the samples, which are the three exposure pathways considered in this study. HQ and HI were calculated as shown in Tables 7 and 8 for the dry and wet seasons, respectively. The computed HQ varied from 0.00×1000 to 1.33×10^{-3} and 0.00×1000 to 9.24×10^{-3} for the dry and rainy seasons, respectively. During the dry season, the HI obtained from the study sites followed the pattern


4a (i)
Co
6.0000E-3
5.0000E-3
4.0000E-3
3.0000E-3
2.0000E-3
1.0000E-3
0.0000E0
32
Dry Season
Rain Season
Season


4a (ii)
95% CI Co
6.0000E-3
4.0000E-3
2.0000E-3
0.0000E0
GDSS Tanke
Tanke Primary
University Pry
Unilorin LT
Unilorin SLT
Location


4b (i)
Pb
.0400
.0300
.0200
.0100
.0000
6
5
7
Dry Season
Rain Season
Season


4b (ii)
95% CI Pb
.0400
.0300
.0200
.0100
.0000
-.0100
GDSS Tanke
Tanke Primary
University Pry
Unilorin LT
Unilorin SLT
Location


4c (i)
Cd
5.0000E-4
4.0000E-4
3.0000E-4
2.0000E-4
1.0000E-4
0.0000E0
2
7
15
29
24
Dry Season
Rain Season
Season

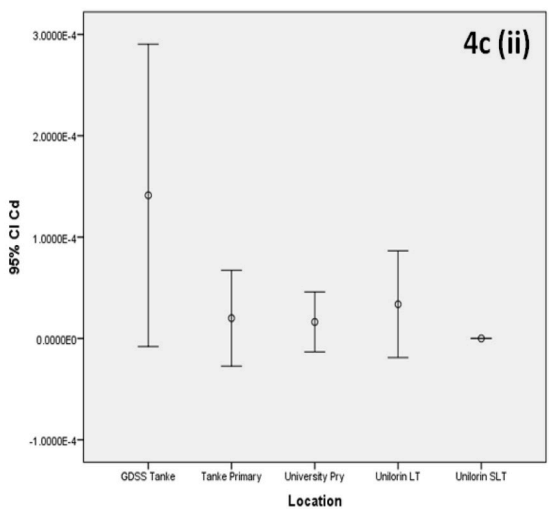

4c (ii)
95% CI Cd
3.0000E-4
2.0000E-4
1.0000E-4
0.0000E0
-1.0000E-4
GDSS Tanke
Tanke Primary
University Pry
Unilorin LT
Unilorin SLT
Location

Fig. 4. a (i), 4b (i), and 4c (i) represent the box and whisker plots for the annual spread of Co, Pb, and Cd concentrations, respectively, in classroom dust samples collected from the study areas. Fig. 4a (ii), 4b (ii), and 4c (ii) represent the error bar plot for the annual spread of Co, Pb, and Cd concentrations, respectively, in classroom dust samples collected from the studied area, Ilorin. Fig. 4d (i), 4e (i), and 4f (i) represent the box and whisker plots for the annual spread of Cr, Ni, and As concentrations, respectively, in classroom dust samples collected from the study areas. Fig. 4d (i), 4e (i), and 4f (i) represent the error bar plots for the annual spread of Cr, Ni, and As concentrations, respectively, in classroom dust samples collected from the studied area, Ilorin.

As > Pb > Cr > Co > Ni > Cd for children and Pb > As > Cr > Co > Ni > Cd for adults. The trend in the HI obtained from the study sites was in the order As > Pb > Cr > Cd > Ni > Co for children and As > Pb > Cr > Ni > Co > Cd during rainy season. The findings were inconsistent with the earlier publication, which stated that Cr > Pb > Cd > Cu > Zn [47]. However, the magnitudes of the HQ were less than 1×10^{-4}. As a result, there is no need to remediate the research locations. The health risk assessment for non-carcinogenic exposure through dust ingestion, inhalation, and dermal contact indicated HI values of 1.74E-04 for children and 2.40E-05 for adults in the dry season, while in the rainy season, the HI values were 1.30E-03 for children and 3.33E-05 for adults. In general, the HQ and HI recorded are less than one, implying no probable non-carcinogenic effect at the sites and hence no health risk to the students and instructors [47].

3.3.3. Carcinogenic risk of heavy metals in classroom dust

Fig. 2 and Table 7 indicate the HMs cancer risks in Ilorin interior dust for schools during the dry season, while Fig. 3 and Table 8 show the same hazards during the rainy season. The tables show the cancer risks for five HMs (Pb, As, Cr, Cd, and Ni). Of the five HMs tested for cancer risk, Pb had the highest value (Fig. 2a and b) during the dry season, while As had the highest value (Fig. 3a and b) during the rainy season.

Cancer risk via dermal pathway (CR_{dermal}) accounted for 74.24 % and 21.38 % of total cancer risk (CR) in children and adults, respectively during rainy season. $CR_{oral}, CR_{dermal}, CR_{inhale}$ in children were observed to be 9.34, 4.67 and 98.86 times that of Adults in this studied. Cancer risk via dermal pathway (CR_{dermal}) accounted for 29.43 % and 37.56 % of total cancer risk (CR) in children and adults, respectively during dry season. $CR_{oral}, CR_{dermal}, CR_{inhale}$ in children were observed to be 9.34, 1.77 and 6.54 times that of Adults in this studied. The box plots of indoor CRs in Ilorin are demonstrated in figures below. Using the international standard endorsed by USEPA and International Agency for Research on Cancer (IARC) [21], the indoor lifetime cancer risks of the five HMs studied in classroom 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.

Furthermore, the human health hazard contribution through dermal contact HQ_{dermal} and CR_{dermal} to overall HI and CR during dry season in this study were 67.76 % and 30.30 %, respectively, the human health hazard contribution through dermal contact HQ_{dermal} and CR_{dermal} to overall HI and CR during rainy season in this study were 86.76 % and 72.65 %, signifying generally that dermal route contributed more to non-cancer risk than cancer risk in this study, which contradicts the previous study for residential indoor dust [21], where ingestion route contributed more to cancer risk than non-cancer risk. The risk assessment results showed that children are more exposed to indoor HM health concerns (cancer and non-cancer risks) from Ilorin classroom dust than adults (Fig. 3a and b). Similar findings on children's vulnerability to HM exposure hazards in indoor dust have been reported in numerous cities [1,21,44]. Children are frequently active in numerous indoor and outdoor games, which are primarily hand-to-mouth activities, increasing their rate of respiration per unit of body weight.

3.4. Statistical analysis of HMs

3.4.1. Analysis for cobalt in different locations

Cobalt concentrations varied between 0.0005 ± 0.0006 and 0.0036 ± 0.0020 mg/kg across all locations. USLT had the highest concentration of 0.0053 ± 0.0004 mg/kg during the dry season, while location 1 (GDS) had the lowest concentration of 0.0004 ± 0.0003 mg/kg during the rainy season. This is due to the higher population density in USLT compared to GDS, as well as the possibility of increased heavy metal concentration in the dry season due to reduced water volume and increased evaporation [48]. Rainy seasons result in higher dilution of heavy metals due to increased water volume and velocity [49], as illustrated in Fig. 4a(i) and 4a(ii). Fig. 4a (i) also revealed the existence of a minor anomaly in the rainy season data. The coefficient of variance (CV) is 67.0 %.

3.4.2. Analysis for plead in different locations

Pb was found in the elemental state in trace amounts, with mean concentrations ranging from 0.0010 ± 0.0011 to 0.0251 ± 0.0118 mg/kg across all locations. During the dry season, GDS measured the maximum concentration of 0.0298 ± 0.0074 mg/kg, while site 4 (ULT) had the lowest value of 0.00003 ± 0.00005 mg/kg. Because of the sampling site, GDS is close to major roads, whereas ULT is fairly far from the main road on campus. Rainy seasons have higher concentrations of heavy metals due to decreased water volume and flow, as well as increased evaporation from bodies of water [48], as illustrated in Fig. 4b(i) and 4b(ii). Fig. 4b(i) also demonstrates the occurrence of severe, chronic, and mild outliers in the rainy season dataset. The coefficient of variation is 80.8 %, which is extremely high.

3.4.3. Analysis for cadmium in different locations

Cadmium is a metalloid found in trace amounts in the elemental state, with average concentrations ranging from 0.0000 ± 0.0000

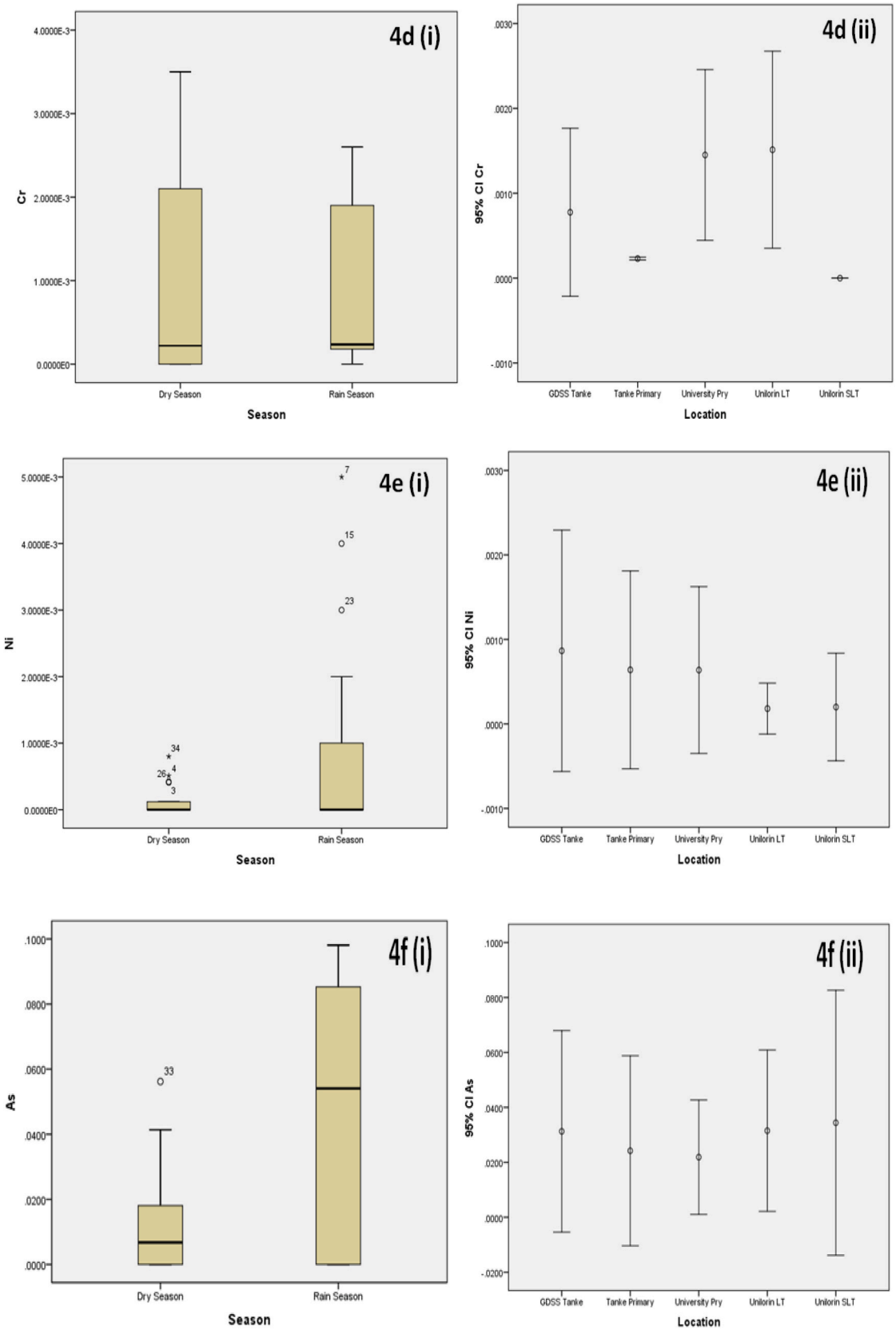


Fig. 4. (*continued*).

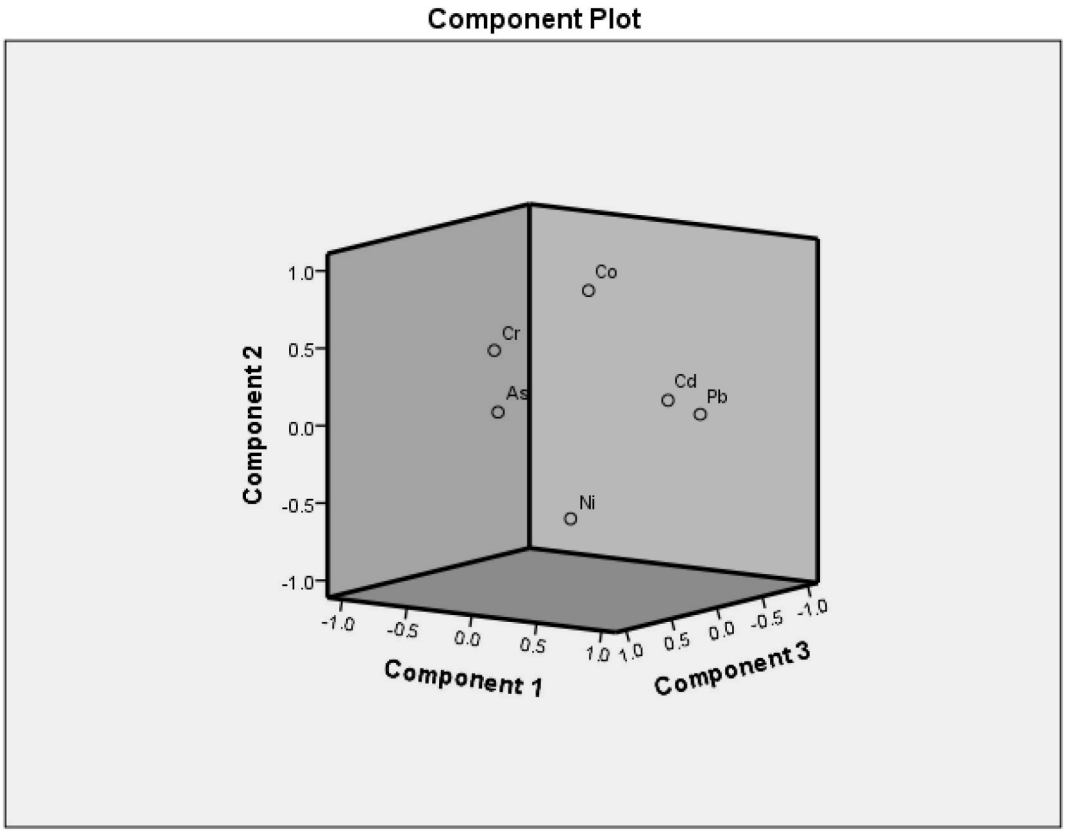


Fig. 5. PCA showing annual seasonal distributions of HMs across studied areas.

to 0.0001 ± 0.0002 mg/kg across all locations. Location GDS had the highest concentration of 0.0002 ± 0.0002 mg/kg during the dry season, while locations 2 (TPS) and 5 (USLT) had the lowest concentration of 0.0000 ± 0.0000 mg/kg during the dry season, as well as Location 3 (UPS) during the rainy season. This is because the locations with the lowest heavy metal concentrations are further away from the major road than the location with the highest concentration. According to Gungshik et al. [49], the rainy season has a lower concentration of metals due to runoff and rainfall, which can lead to leaching and dilution of soil solutions (Fig. 4c (i) and 4c (ii). Fig. 4c (i) further revealed the existence of extreme outliers in the data. The season and interaction effects do not differ significantly (NS) ($p \geq 0.05$), but the location impact does. The coefficient of variation (CV) is 42.0 %, indicating modest or minimal variance.

3.4.4. Analysis for chromium in different locations

Chromium is a metalloid found in modest amounts in the elemental state, with mean concentrations ranging from 0.0000 ± 0.0000 to 0.0015 ± 0.0012 mg/kg across all locations. During the dry season, ULT had the maximum concentration of 0.0019 ± 0.0018 mg/kg, whereas site 5 (USLT) had the lowest concentration of 0.0000 ± 0.0000 mg/kg (zero concentration) due to population and student activities. Fig. 4d (i) and 4d (ii) show that rainy seasons have higher values than dry seasons. Fig. 4d (i) illustrates that there are no outliers in the dataset. Season, location, and interaction effects show no significant variation or difference (NS) ($p < 0.05$). The CV is 29.9 %.

3.4.5. Analysis for nickel in different locations

Nickel is found in the elemental state in trace amounts, with mean concentrations ranging from 0.0002 ± 0.0004 to 0.0009 ± 0.0017 mg/kg across all locations. Location UPS and USLT had no nickel in the dry and rainy seasons, respectively. GDS had the maximum concentration of 0.0015 ± 0.0024 mg/kg during the wet season due to the sample location's vicinity to main roadways.

HM concentrations rise during dry and rainy seasons due to lower water volume and flow and higher evaporation from water bodies [49,50]. Fig. 4e (i) and 4e (ii) summarize this trend. Fig. 4e (i) further demonstrates the occurrence of outliers in the data. Season, location, and interaction effects show no significant variation or difference (NS) ($p \geq 0.05$). The CV is 25.4 %.

3.4.6. Analysis for arsenic in different locations

The average arsenic concentration at various locations varied from 0.0219 ± 0.0249 to 0.0344 ± 0.0303 mg/kg. At location TPS, there was no arsenic detected during the rainy season. In contrast, GDS had the highest concentration of 0.0617 ± 0.0449 mg/kg in the rainy season, while the lowest concentration, 0.00085 ± 0.0017 mg/kg, was also at GDS during the dry season due to the higher

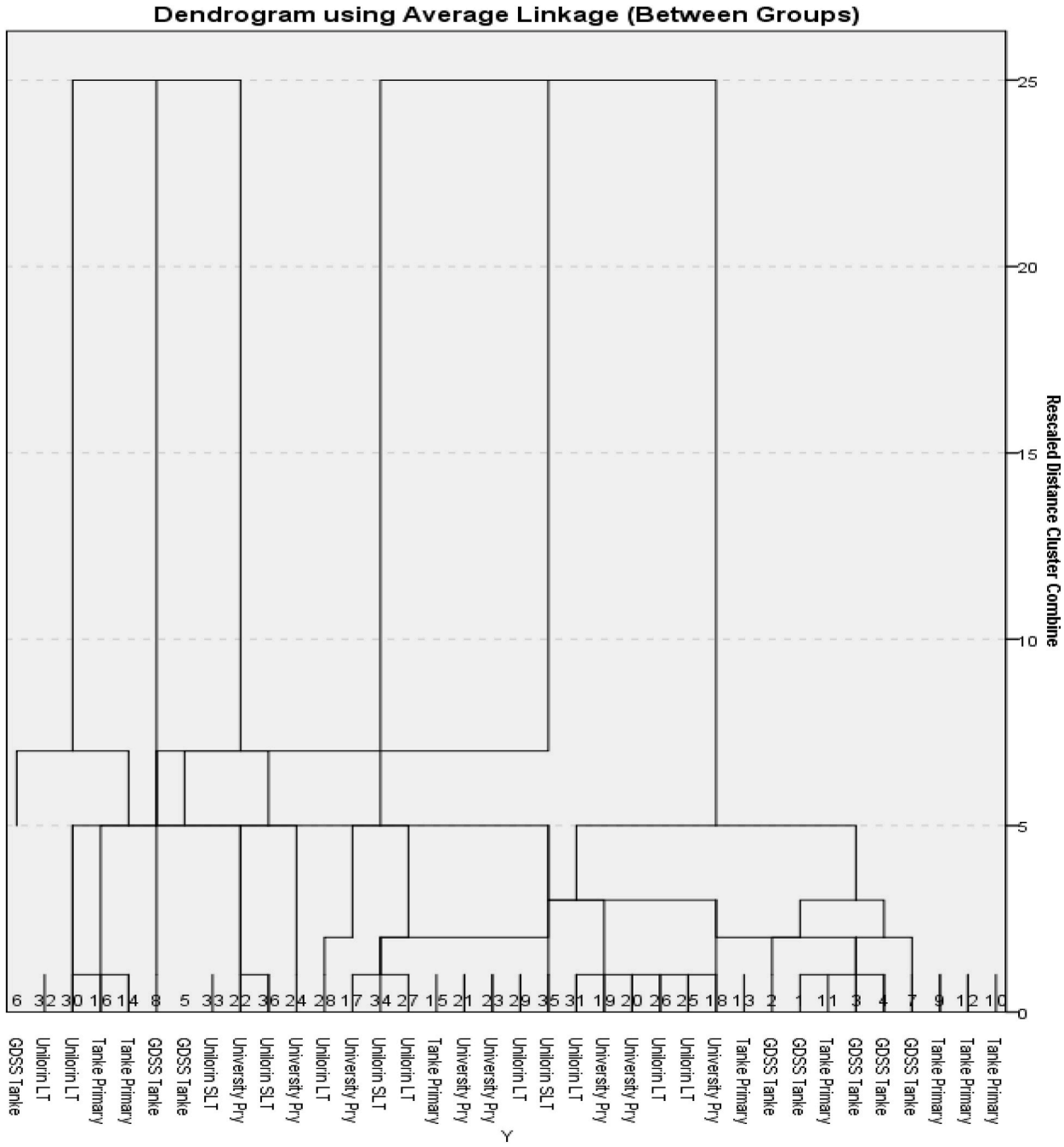


Fig. 6. Cluster analysis graph showing HMs distribution across the studied areas.

dilution of heavy metals from increased water volume and flow. Fig. 4f (i) and 4f (ii) show that the order of increasing seasonal values is dry < rainy. This is due to the runoff effect that removes trace metals from soil and the effect of rainfall, which may facilitate the leaching of metals and the dilution of soil solution during wet season [37,48]. Fig. 4f (i) also revealed the presence of a mild outlier in the data. Location and interaction effects show no significant variation or difference ($p \geq 0.05$), although there is a considerable difference by season. The coefficient of variation is 33.8 %.

3.5. Factor and cluster analysis of concentration of metals

A standard two-dimensional PCA for six HMs (Co, Pb, Cd, Cr, Ni, and As) measured in the studied areas is shown in Fig. 5. The distributions of Co, Cd, and Pb are highly concentrated in Locations 1 and 3, suggesting they originate from human activities. PCA also

illustrates seasonal variations in HM concentrations across all studied areas, as shown in Fig. 5. SPSS version 25 statistical software was used to plot the cluster analysis graph and PCA (Figs. 5 and 6). HMs grouped together on the same axis indicate they have a similar origin in the samples.

4. Conclusion

This study examined the contamination levels, sources, and health risks of selected HMs in classroom dust from schools in low, medium, and high population density areas in Ilorin, Nigeria, over a one-year period. The mean concentrations of the metals were found to follow the decreasing order of As > Pb > Co > Cr > Ni > Cd. The two-way analysis of variance (ANOVA) technique proposed that indoor dust of different classrooms was contributing significantly to the mean HM concentration ($p \leq 0.05$). All HM concentrations were below their respective background values (Earth's crust and continental shale), while the Igeo, CF, and PI results indicated similar findings, showing low or no contamination in the classroom dust of Ilorin schools. Health risk assessment of non-carcinogenic risk via dust ingestion, inhalation, and dermal contact revealed HI values of 1.74E-04 and 2.40E-05 for children and adults, respectively, during the dry season, and HI values of 1.30E-03 and 3.33E-05 for children and adults, respectively, during the rainy season. The CR values for HMs were under the tolerable risk. This study's analysis of the contribution of exposure pathways to human health hazards during the dry and rainy seasons shows that the dermal route increased non-cancer risk more than cancer risk. This study proposes that strong action should be taken by government regulators against anthropogenic sources of HM to curtail contamination footprints and health risks to the local population.

CRediT authorship contribution statement

Hussein K. Okoro: Validation, Supervision, Project administration, Methodology, Conceptualization. **Muyiwa M. Orosun:** Validation, Supervision, Project administration, Methodology, Conceptualization. **Afisat F. Agboola:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation. **Ebuka Chizitere Emenike:** Writing – review & editing, Writing – original draft, Validation, Formal analysis, Data curation, Conceptualization. **Sireesha Nanduri:** Writing – review & editing, Writing – original draft, Validation. **Navin Kedia:** Writing – review & editing, Writing – original draft, Validation. **Muthena Kariem:** Writing – review & editing, Resources, Methodology, Funding acquisition. **Ati Priya:** Writing – review & editing, Writing – original draft, Validation. **Safia Obaidur Rab:** Writing – review & editing, Writing – original draft, Validation.

Compliance with ethical standards

This article does not contain any studies involving human or animal subjects.

Data availability

All data generated or analyzed during this study are included in this article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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