Published by
NIGERIAN SOCIETY OF PHYSICAL SCIENCES
Available online @ https://journal.nsps.org.ng/index.php/jnsps

J. Nig. Soc. Phys. Sci. 8 (2026) 2559

Journal of the Nigerian Society of Physical Sciences

Concentrations of heavy metal content in indoor dust and potential exposure in preschool children

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Abstract

Indoor dust serves as a medium for the deposition of heavy metals, and young children's rapid physical growth and hand-to-mouth behavior expose them to the impacts of heavy metals. This project aimed to measure the concentrations of heavy metals in classroom dust from the selected preschools in southwestern Nigeria. Dust samples were taken via a dust collector and analyzed quantitatively and qualitatively via the Atomic Absorption Spectroscopy (AAS) scheme. The descriptive and inferential statistical method was employed for the data analysis, and standard calibration, recovery analysis, and blank determination were carried out for the quality control measures. It was found that, in the dry season, the total metal concentrations in dust were 1.82 $\mu g\ g^{-1}$ Cu to 80.00 $\mu g\ g^{-1}$ Zn, whereas, in the wet season, the heavy metal concentrations were 0.83 $\mu g\ g^{-1}$ Co to 38.43 $\mu g\ g^{-1}$ Zn. Hence, the selected preschool dust was significantly enriched with high levels of Cd and As contamination but unpolluted for Co, Cu, Mn, and Pb across all examined metals. The results indicate elevated concentrations of lead (Pb) and cadmium (Cd) in high-traffic indoor spaces, with levels exceeding recommended safety thresholds. Lead (Pb) exposure is linked to neurodevelopmental disorders and reduced cognitive function, Cadmium (Cd) can cause kidney damage and impair bone development, while arsenic (As) is associated with immunotoxicity and an increased risk of cancer. To mitigate these risks, this study recommends practical measures, including frequent wet cleaning of floors and surfaces to reduce dust accumulation and limiting the use of materials known to contain heavy metals, such as lead-based paints and older plumbing fixtures.

DOI:10.46481/jnsps.2026.2559

Keywords: Heavy metal, Indoor dust, Preschool environment, Metal concentration

Article History :
Received: 04 December 2024
Received in revised form: 07 April 2025
Accepted for publication: 10 July 2025
Available online: 19 December 2025

Communicated by: C. A. Onate

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1. Introduction

Heavy metal contamination in indoor environments has emerged as a significant public health concern due to its potential long-term effects on human health. Indoor dust, a complex mixture of particulate matter, serves as a major pathway for exposure to toxic metals such as lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), chromium (Cr), and nickel (Ni). These contaminants originate from various sources, including deteriorating building materials, industrial emissions, household products, and outdoor air pollution infiltrating indoor spaces. Young children, particularly preschoolers, are at heightened risk due to their frequent hand-to-mouth behaviors, higher respiratory rates, and underdeveloped detoxification systems, which make them more susceptible to the adverse effects of heavy metals [1, 2]. School classrooms and playgrounds are spaces intended to let children play, keep them happy, and grow their learning

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Email address: `jacob.akinpelu@bowen.edu.ng` (J. A. Akinpelu) capabilities. In addition, the exposure of children to environmental risks may cause potential health challenges like cancer, neurological dysfunction, an endocrine disorder, and potentiate infertility owing to testicular function disorder [3, 4].

However, children are most susceptible to ecological toxicants, and their contact with potential health risk factors such as heavy metals is generally ignored. Consequently, children have a greater heavy metals assimilation rate into the digestive system and more significant hemoglobin poisoning by these metals than adults. Heavy metal contamination in indoor environments has emerged as a significant public health concern due to its potential long-term effects on human health. Indoor dust, a complex mixture of particulate matter, serves as a major pathway for exposure to toxic metals [5]. Aweda *et al.* [6] reported that several indoor pollutants are assimilated via substances that initially float in the air and subsequently deposit as dust. Pathways of unconscious exposure to noxious metals are through ingestion, inhalation, and dermal exposure, as reported by Olatunde *et al.* [7]. Meanwhile, Poggio *et al.* [8] emphasized that soil ingestion has a more significant consequence in children due to tendencies to ingest large quantities. It was revealed that the low resilience of children to toxic heavy metals is mainly ingestion through oral routes, basically from hand-to-mouth disposition. These heavy metals tend to interfere with the normal functioning of the body's organ systems or sometimes potentiate other diseases [9].

The concentration of chemical pollutants, such as semi-organic volatile compounds, is frequently larger in indoor than outdoor air [10]. Several indoor pollutants are engrossed via particulate matter, which is suspended in the air and later becomes dust. Heavy metals exist naturally with moderately large atomic weight and a low density five times the water density [11]. Trace elements such as Zn, Pb, Hg, Cu, Cr, Co, Cd, and As are known to be tenacious environmental contaminants. The occurrence of the elements in a location could lead to contamination from diverse sources in an urban area. It has been acknowledged that atmospheric and vehicular pollution significantly contributes to trace element contamination [12]. Substantial metals like copper (Cu), zinc (Zn), and cobalt (Co) are needed for typical body development and elements of normal body physiology, while the high concentrations of different elements such as lead (Pb), manganese (Mn), chromium (Cr) and cadmium (Cd) are considered profoundly dangerous to human life [13].

A measure of Cr is required for typical body capacity, while its high level in the body may be poisonous to organs like the liver and kidney tissues and may be genotoxic, leading to cancerous growth [14]. Large concentrations of Cu and Mn may lead to mental dysfunction like Alzheimer's and manganese; these primarily affect the intellectual functions of children at a later age of 10 years [15]. Pb is a dangerous and cancer-causing metal and other health challenges like migraine, crabbiness, stomach upset, nervous, kidney, circulatory, and respiratory dysfunction [16]. As reported, the children are prone to Pb poison, and exposure to large amounts of Pb may cause severe functional challenges like behavioral unsettling influences, memory disintegration, and decreased capacity to comprehend, as well as anemia after long-term exposure. Soils and dust have become very good diagnostic tools for environmental conditions influencing human health [17]. Non-degradable metals can be bio-transformed into compounds having less mobility or toxicity than their original form [18, 19].

Young children, specifically toddlers, can quickly consume soil or indoor dust unconsciously because they are always indoors and regularly play on the floors, engaging in mouthing hands, playing with toys and other items, or ingesting contaminated food through their hands [20]. Heavy metals have been reported to have hazardous effects on biochemical processes in the body due to continuous bioaccumulation. Children are exceedingly vulnerable to environmental hazards because systems (tissues and organs) are underdeveloped. Thus, the children are more vulnerable to organ malfunction or disorder [21, 22]. The poisoning that results from heavy metals may also cause mental retardation because heavy metal poisoning interferes period with brain growth and differentiations that take place in actively growing children [23–26]. Researchers generally report that heavy metals in preschool children come from dust and soil; children are exposed to these metals by ingesting dirty indoor dust [27–29].

Several research activities have been geared towards studying environmental heavy metals, but with no depth report on the level of preschool classroom pollutants and the remediation of the environment. Therefore, the study aims to investigate indoor heavy metal dust and the possible health implications in some selected preschool classrooms. This study's novelty lies in its focus on preschool environments in Nigeria, integrating risk assessment models specific to young children's behaviors, such as frequent hand-to-mouth activity, which amplifies exposure risks. To mitigate these risks, practical measures are recommended, including frequent wet cleaning of floors and surfaces and the replacement of materials known to contain heavy metals, such as lead-based paints and older plumbing fixtures. For the case study, Oyo and Osun States in Nigeria, with a total population of 8.5 million, are considered. Thus, heavy metal content, seasonal differences of potentially toxic heavy metals, and pollution indices were all determined. Investigation is carried out on the seasonal variations of exposure to metal using dust samples from preschool classrooms. Playgrounds and classrooms are equipped with products made from chemically unbound toxic plasticizers that are gradually released into the environment. The trace elements are regularly in the soil at diverse concentrations; geological factors and possible pollution from various sources largely control their levels in the soil. Therefore, this study examines heavy metals levels, such as (Zn, Pb, Hg, Cu, Cr, Co, Cd, and As) and the health risks related to children's exposure levels. Children have a high heavy metals ingestion rate into the digestion system and higher trace elements hemoglobin sensitivity than adults.

2. Materials and methods

2.1. Study area

Two study areas of high population in southwestern (Ibadan and Osogbo) Nigeria are considered. The two cities are located

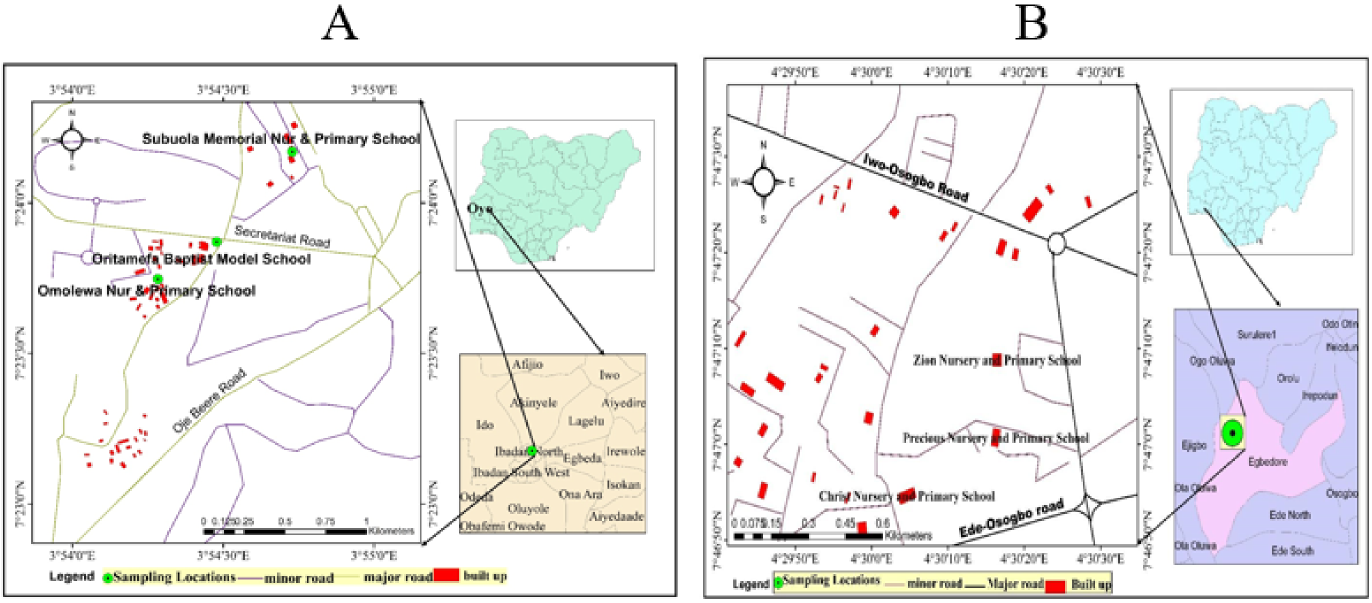

Figure 1: Sample site maps for Ibadan and Osogbo.

Table 1: Showing the locations of the sampled sites.

S/N	Location(s)	Sampling sites
1	Ibadan	Omolewa Memorial Nursery and Primary School Oritamefa Baptist Model School Subuola Memorial Nursery and Primary School
2	Osogbo	Zion Nursery and Primary School Precious Nursery and Primary School Christ Nursery and Primary School

in Oyo and Osun States, respectively, in Nigeria. Six sampling sites, including major schools in Ibadan and Oshogbo, located within the densely populated area, were chosen for this study, as shown in Table 1. These cities were selected due to their high population densities, rapid urbanization, and diverse socio-economic settings, which contribute to variations in indoor environmental pollution. Ibadan, one of Nigeria's largest cities, has a mix of old and modern infrastructure, heavy traffic emissions, and industrial activities, all of which may influence indoor dust composition. Osogbo, as a growing administrative and commercial hub, presents a different urban dynamic with potential sources of heavy metal contamination, including small-scale industries, vehicular emissions, and household materials. By selecting these two locations, the study captures a broad range of indoor dust pollution scenarios, making the findings more generalizable to other Nigerian urban environments.

A stratified sampling approach was employed to ensure adequate representation across different building types, including preschools, residential houses, and commercial premises within both cities. The sample size was determined based on population distribution, environmental diversity, and previous studies on indoor heavy metal pollution. A statistically significant number of dust samples were collected from multiple locations within each city to account for spatial variations in heavy metal concentrations. This approach enhances the reliability of risk assessments and provides a robust basis for developing targeted mitigation strategies. The Ibadan study area is with the coordinate of [7°23′47″N 3°55′0″E] as shown in Figure 1(A) has an estimated population of 3,649,0003 in 2022. It covers an area of 3,080 km^2 (1,190 sq mi) with a population density of 985.13/km^2 (2,551.5/sq mi) and about 230 m (750 ft) above sea level. It experiences a tropical savannah climate. The Osogbo study area is with the coordinate of [7°45′20″N 4°33′08″E] Figure 1(B) metropolis had a population of 395,500 in 2016. It covers an area of 47 km^2 (18 sq mi) with a population density of 985.13/km^2 (2,551.5/sq mi) and about 320 m (1,050 ft) above sea level. It experiences a tropical savannah climate. Figure 1 shows the study area's sampling point.

The fieldwork for this research was executed between December 2022 and July 2023 (this spans the period of dry and wet seasons). The broom and the packer were carefully cleaned with ethanol before sweeping the floor; thus, the floor dust samples were taken into sample bottles. Particles like food crumbles and papers entrenched in the sampled dust were separated after mild shaky to separate the dust attached to the particles. The sampled dust was air-dried and filtered using a 2 mm stainless-steel sieve and then kept in flexible bottles until analysis. Air-drying of the samples took place in the laboratory for about 4-5 days (laboratory dust was prevented). Unwanted particles like dirt and grits were separated from dehydrated dust to homogenize the samples with mortar and pestle. Also, 1g of sampled soil was weighed, and 20 mL of perchloric acid was introduced before it was subjected to boiling and filtration [20].

Table 2: Background values of metals in shale/rock Olatunde *et al*. [7].

Metals	As	Cd	Co	Cu	Mn	Pb	Zn
Contents	7.0	0.3	19	45	850	20	95

Table 3: Geo-accumulation index classes, Sun *et al*. [33].

I-geo	I-geo class	Pollution intensity
<0	0	Practically uncontaminated
0-1	1	Uncontaminated to normal contaminated
1-2	2	Normal contaminated
2-3	3	Normal to highly contaminated
3-4	4	Highly contaminated
4-5	5	Highly to very high contaminated
5-6	6	Very extremely contaminated

2.2. *Digestion of sample and analysis of heavy metal*

The heavy metal contents in solutions were obtained by applying GFAAS. A graphical linear calibration (concentration against absorbance) per heavy metal was analyzed through a standard commercial solution (multi-element 1,000 ppm GFAAS adjustment at regular 3, PG 990). The limit of the instrument detection for each sample mass (g) was obtained as Pb, 1.0 μg g^{-1} for Cu, 0.05 μg g^{-1} for As and Zn, 0.01 μg g^{-1} for Cd, 0.09 μg g^{-1} for Mn (see Refs. [19, 26]) and 0.5 μg g^{-1} for Co. The heavy metals quantity in the soil and indoor dust was evaluated in μg g^{-1} units (heavy metal mass (μg)/sample mass (g)).

2.3. *Pollution evaluation indices*

The classroom heavy metals pollution assessment in preschool children proffers an understanding of the dust contamination stages for the chosen preschool classrooms within the Ibadan and Oshogbo Metropolis. The dust heavy metals contamination levels were evaluated with geo-accumulation index (I-geo), contamination load index (CLI) and contamination factor (CF), as explained below.

2.3.1. *Contamination index*

The contamination index of metals in the dust samples was calculated using the relationship as shown in equation (1):

$$CI(Contamination\ Index) = \frac{Dust\ metal\ contents}{Metal\ background\ level}. \quad (1)$$

As shown in Table 2, average shale metal values were taken as the background content [28, 30]; the data obtained from calculating the contamination index were grouped into four grades varying from uncontaminated to extremely contaminated. They are in this manner: CF < 1 = small pollution; 1 ≤ CF < 3= rational pollution; 3 ≤ CF ≤ 6 = substantial pollution; CF > 6 = large pollution.

2.3.2. *Contamination load index*

Each preschool location was estimated for the metal contamination extent by engaging the contamination load index (PLI) technique as shown in equation (2), established by Gong *et al*. [32].

$$PLI = n\sqrt{CF_1 \times CF_2 \times CF_3 \times \ \ldots CF_n}. \quad (2)$$

Here, n is the analyzed metal number (seven considered), and the contamination factor is denoted as CF, which is evaluated as explained in equation (2). The CLI gives a simple site quality assessment proportional means, where a value of CLI < 1 connotes perfection; CLI = 1 presents pollutants baseline levels, and CLI > 1 indicates site quality deterioration.

2.3.3. *Geo-accumulation evaluation index*

The geo-accumulation evaluation index (I-geo) values were obtained for various metals, as explained by Muller [28] as shown in equation (3):

$$I - geo = \log_2 \left[C_n / 1.5 B_n\right], \quad (3)$$

where C_n measures sample heavy metal content, B_n denotes the element level geochemical background, 1.5, and n gives the correction matrix background factor resulting from gynogenic inputs. Sun *et al*. [33] prescribed seven grades or classes, as shown in the geo-accumulation index as given in Table 3.

2.4. *Quality control*

High-grade laboratory cleanser was used to wash all glassware and plastic products; they were rinsed with deionized liquid, and nitric acid of 10% was introduced immediately and kept for the night. Double-deionized water obtained from the purification water simplicity system prepared all solutions and dilutions. All chemicals used were analytical-grade chemicals. The analysis was executed in triplicate, and the mean values were determined. All stages of the analysis were subjected to quality control to prevent interference and decrease error risk. Gloves were used while carrying out the experiment stages powerlessly to avoid contamination. Polyethene bottles and glassware that were employed for the analysis of the heavy metals were cleaned by soaking them in nitric acid, then they were with deionized liquid. Furthermore, pre-calibration of all instruments used in this analysis was done before use.

2.5. *Instrumentation calibration and measurement*

The digested dust sample was analyzed for their metal contents by applying atomic flame absorption spectrophotometry, 990 PG model (PG analytical instrument), available at Bowen University, Iwo, Nigeria. An autosampler fitted with an absorption atomic spectrophotometer was utilized for the heavy metals analysis. The atomic flame absorption spectrophotometry was fortified with cathode hollow metal lamps (cathode photon and cathode varian lamps) that were applied to determine the absorbance. The atomic flame absorption spectrophotometry was operated as per the manufacturer's instructions. All the contents are expressed in μg/g.

Table 4: Mean heavy metals content in indoor dust sample for dry and wet seasons (μg/g).

Study site	As	Cd	Co	Cu	Mn	Pb	Zn
Dry Season							
1	2.48	41.47	19.80	2.20	41.46	2.77	1.78
2	25.42	38.98	3.80	4.17	38.98	21.68	59.00
3	30.48	21.83	37.02	18.92	21.83	20.78	80.00
4	73.22	29.55	3.53	18.68	29.40	4.88	27.08
5	39.15	54.40	3.63	1.82	54.40	20.38	38.63
6	2.51	3.03	2.80	1.57	30.25	37.38	19.55
Overall mean±SD	28.88±4.08	31.54±4.66	11.76±1.80	7.89±1.30	36.10±4.50	17.98±3.30	37.67±5.74
Wet Season							
1	1.73	5.00	0.83	4.58	21.92	3.38	7.08
2	2.83	18.65	0.87	21.85	20.40	5.18	20.63
3	2.92	2.37	2.92	2.83	21.10	6.52	38.43
4	1.60	19.88	17.30	2.48	20.35	3.80	2.98
5	1.50	4.65	2.21	3.63	1.32	5.88	5.00
6	5.28	3.62	2.22	3.83	19.28	3.32	30.33
Overall mean± SD	2.64±0.83	9.03±1.70	4.39±0.93	6.53±1.08	17.40±3.23	4.68±0.96	17.41±2.50
FAO/WHO,2011	7	3	19	20-100	850	300	300

Table 5: ANOVA of the classroom dust samples for both dry and wet seasons.

Source of variation	DF	SS	MS	F-ratio	F critical
Dry Season					
Treatment	6	11720.98	1185.24	8.99	2.37
Error	35	4609.56	131.70		
Total	41				
Wet Season					
Treatment	6	14693.96	872.47	3.23	2.37
Error	35	9459.12	270.26		
Total	41				

Table 6: Correlation analysis of heavy metals in the dust samples.

Metal	As	Cd	Co	Cu	Mn	Pb	Zn
As	1						
Cd	0.49	1					
Co	0.46	0.10	1				
Cu	0.53	0.12	0.28	1			
Mn	-0.03	0.15	0.56	0.16	1		
Pb	0.38	0.32	0.36	0.29	0.19	1	
Zn	0.40	0.20	0.01	0.40	0.03	0.36	1

2.6. *Risk evaluation*

The analysis total measure of trace metals was utilized to determine the healthiness hazard of the children due the heavy metal absorption. The trace metals mean contents were utilized to evaluate intake at various paths utilizing the standard exposure USEPA's equations [29]. Children were exposed to the pollutant soils in three various ways that comprise skin exposure (I_{dermal}), inhalation intake ($I_{inhalation}$) and oral intake ($I_{ngestion}$). Cancer/noncancerous risk assessment in this research was calculated depending on this evidence. For intake assessment through each exposure pathway, the subsequent equations were applied.

2.7. *Enrichment factor*

To determine the enrichment fact of the heavy metal, the presented mathematical model of equation (4) is applied:

$$EF = \left[\frac{\left(\frac{Q}{QZn} - Sample \right)}{\left(\frac{Q}{QZn} - Background \right)} \right]. \tag{4}$$

(a) Numerator is the heavy metal ratio to the Fe sample concentration

(b) Denominator defines the background natural value for Zn heavy metal ratio

(c) Q denotes crust sample element concentration

(d) QZn describes the referenced Zn element concentration. Concentration value for Zn is 0.87(μg/g).

2.8. *Statistical data analysis*

To examine the preschool dust characteristics, the contents of dust heavy metal levels were subjected to one-way analysis of variance to test the significance of differences in heavy metal accumulation between the various study sites during the dry and wet seasons. The statistical solving is conducted using the Statistical Package for Social Sciences (SPSS). The correlation significance and correlation coefficients for heavy metals were determined and analyzed utilizing the one-way variance analysis test with a 95% confidence level for normally distributed data.

Table 7: Contamination index of metals in the dust samples for both seasons.

Metals	A			B			C			D			E			F		
	MC	BV	CI	MC	BV	CI	MC	BV	CI	MC	BV	CI	MC	BV	CI	MC	BV	CI
Dry Season																		
As	2.48	7	0.35	25.42	7	3.63	30.48	7	4.35	73.22	7	10.46	39.15	7	5.69	2.51	7	0.36
Cd	41.47	0.3	138.23	38.98	0.3	129.93	21.83	0.3	72.77	29.55	0.3	98.50	54.40	0.3	181.33	3.03	0.3	10.10
Co	19.80	19	1.04	3.80	19	0.20	37.02	19	1.95	3.53	19	0.19	3.63	19	0.19	2.80	19	0.15
Cu	4.58	45	0.10	21.85	45	0.49	2.83	45	0.06	2.48	45	0.06	3.63	45	0.08	3.83	45	0.09
Mn	41.46	850	0.05	38.98	850	0.05	21.83	850	0.03	29.40	850	0.03	54.40	850	0.06	30.25	850	0.04
Pb	3.38	20	0.17	5.18	20	0.26	6.52	20	0.33	3.80	20	0.19	5.88	20	0.29	3.32	20	0.17
Zn	7.08	95	0.07	20.63	95	0.22	38.43	95	0.40	2.98	95	0.03	5.00	95	0.05	30.33	95	0.32
Wet Season																		
As	1.73	7	0.25	2.83	7	0.40	2.92	7	0.42	1.60	7	0.23	1.50	7	0.21	5.28	7	0.75
Cd	5.00	0.3	16.67	18.65	0.3	62.17	2.37	0.3	7.90	19.88	0.3	66.27	4.65	0.3	15.50	3.62	0.3	12.07
Co	0.83	19	0.04	0.87	19	0.05	2.92	19	0.15	17.30	19	0.91	2.21	19	0.12	2.22	19	0.12
Cu	2.20	45	0.05	4.17	45	0.09	18.92	45	0.42	8.68	45	0.42	1.82	45	0.04	1.50	45	0.03
Mn	21.92	850	0.03	20.40	850	0.02	21.10	850	0.02	20.35	850	0.02	1.32	850	0.002	19.28	850	0.02
Pb	2.77	20	0.14	21.68	20	1.08	20.98	20	1.05	4.88	20	0.24	20.38	20	1.02	37.38	20	1.87
Zn	1.78	95	0.02	59.00	95	0.62	80.00	95	0.84	27.08	95	0.29	38.63	95	0.41	19.55	95	0.21

Table 8: Pollution load index of heavy metals for both seasons.

Site	As	Cd	Co	Cu	Mn	Pb	Zn	Total
Dry								
A	0.25	138.23	1.04	0.10	0.05	0.17	0.07	139.91
B	0.40	129.93	0.20	0.49	0.05	0.26	0.22	131.55
C	0.42	72.77	1.95	0.06	0.03	0.33	0.40	75.96
D	0.23	98.50	0.19	0.06	0.03	0.19	0.03	99.23
E	0.21	181.33	0.19	0.08	0.06	0.29	0.05	182.21
F	0.75	10.10	0.15	0.09	0.04	0.17	0.32	11.62
Wet								
A	0.35	16.67	0.04	0.05	0.03	0.14	0.02	17.30
B	3.63	62.17	0.05	0.09	0.02	1.08	0.62	67.66
C	4.35	7.90	0.15	0.42	0.02	1.05	0.84	14.73
D	10.45	66.27	0.91	0.42	0.02	0.24	0.29	78.60
E	5.69	15.50	0.12	0.04	0.02	1.02	0.41	22.78
F	0.36	12.07	0.12	0.03	0.02	1.87	0.21	14.68

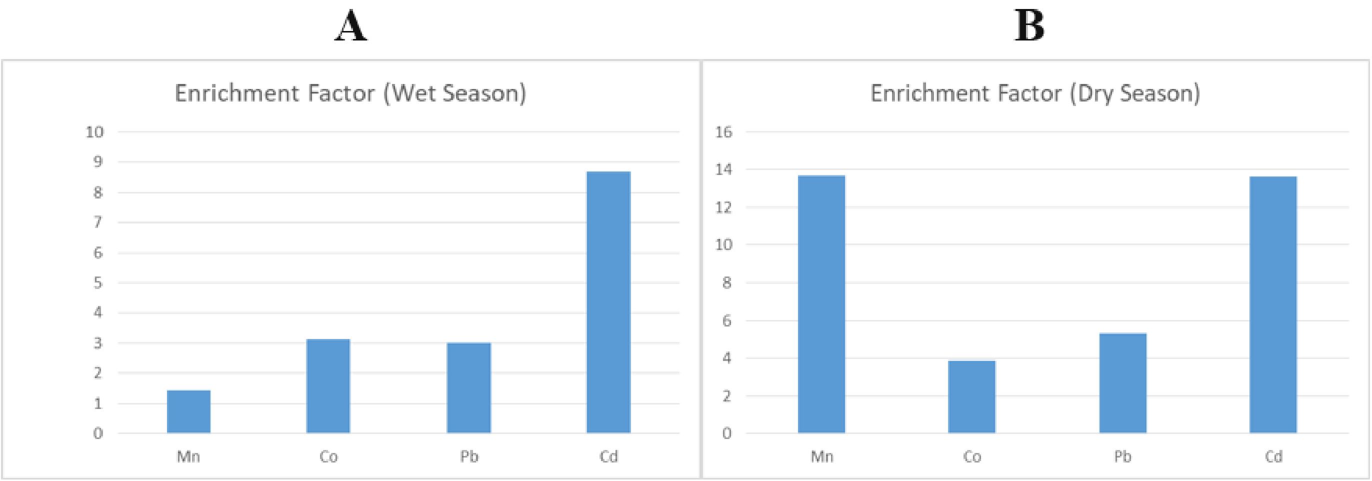

Figure 2: Enrichment factor of (a) wet season (b) dry season.

3. Results and discussion

Heavy metals in indoor dust originate from a variety of anthropogenic and natural sources, which contribute to the accu-

Table 9: Contamination factor utilizing geo-accumulation index (I-geo) for dry and wet seasons.

Element	Mean Content	Bv	Background matric	I-geo
Dry Season				
As	2.64	7	1.5	-1.99
Cd	31.54	0.3	1.5	6.13
Co	11.76	19	1.5	-1.28
Cu	6.53	45	1.5	-3.37
Mn	36.10	850	1.5	-5.14
Pb	4.68	20	1.5	-2.68
Zn	17.41	95	1.5	-3.03
Wet Season				
As	28.88	7	1.5	1.46
Cd	9.03	0.3	1.5	4.38
Co	4.39	19	1.5	-2.70
Cu	7.89	45	1.5	-3.10
Mn	17.40	850	1.5	-6.20
Pb	17.98	20	1.5	-0.74
Zn	37.67	95	1.5	-1.92

mulation of toxic elements within enclosed environments. The primary sources include construction materials, traffic emissions, industrial activities, household items, and outdoor air pollution infiltration. Identifying these sources is critical for developing mitigation strategies to reduce exposure risks, particularly for preschool children. The outcomes of the analysis for the classroom dust samples are presented in Table 4.

Locations portrayed no considerable impact on the variation of heavy metals between grouped means for various sites (Table 5). This signifies that there is some degree of input of these metals between sites.

The heavy metal correlation contents in dust samples were determined by applying Pearson's correlation coefficient, and the outcomes are demonstrated in Table 6. Correlation significance was seen to take place between As and Cu ($r = 0.53$), Co, and Mn ($r = 0.56$) at two-tailed 0.01 levels. This specifies that As and Cu, and Co and Mn might initiate from analogous contamination sources (Table 6). The other metals were, thus, not interrelated. The heavy metals contents display minimal seasonal differences in the sampling sites, and the variation range is relatively minimal. Seasonal variations significantly influence the concentration of heavy metals in indoor dust, primarily due to changes in meteorological conditions, human activities, and environmental pollution levels. Understanding these seasonal fluctuations is crucial for assessing periods of heightened exposure risk, particularly for preschool children. The seasonal variation of heavy metal contamination in indoor dust highlights critical periods of increased health risk, particularly in the dry season. Since preschool children are more vulnerable due to frequent dust ingestion, implementing season-specific exposure reduction strategies is essential for protecting public health. In general, the contents of heavy metals in the dry season are more significant than in the wet season.

Table 7 signified that CI values for the metals varied from 0.05 at sites C and D to 181.33 at site E during the dry season, while it ranged from 0.002 at site E to 66.27 at site D during the wet season. These findings deduced that As, Co, Cu, Mn, Pb, and Zn were in the low contamination group, and these low contamination ranks of the dust samples found during the study area for both seasons. Utilizing the CI classes previously described, all the school dust witnessed a very high contamination rating for Cd in both seasons. The elevated values of Cd in these school dust samples might be owing to the effect of the existence of Cd in particulate matter from wall surfaces, building materials, outdoor dust, and other indoor materials patted by the children can determine their heavy metals exposure.

To effectively compare whether the six school dust samples experienced pollution or not, the contamination load index (CLI) was used. The CLI is meant to provide a general contamination quantity of degree at the sample sites along several sites. Table 8 presents the outcomes of the CLI for the seven metals analyzed at the different schools. Obtained from the findings of the CLI in Table 8, the general contamination degree is of the sequence E > A > B >D >C > and F, indicating strong indications of contamination or degradation of location status. Moderately high values from the study sites denote input from human-related sources ascribed to human activities and/or vehicular emissions. Classroom dust plies through several commercial transports, business centers and townships possessing high populations. They are also patronized by long trucks that carry such items as vehicles, cement materials, logs of wood, iron rods, building materials, school materials, wall surfaces, other indoor materials, and other similar things. Cement material and products are related to heavy metals [32–35] and hence may increase considerable metal pollutants to classroom dust.

3.1. Geo-accumulation index (I-geo) of heavy metals along the classroom dust samples

Geo-accumulation (I-geo) grade signified in Table 9 revealed that all classroom dust samples examined ranged from practically uncontaminated (< 0) to moderately contaminated for both wet and dry seasons. Based on the enrichment factor Figure 2 (a and b), Cadmium revealed varying enrichment from the human-induced activities excluding Zn, Mn, Cu, Co, and As, which indicated I-geo of below zero for all samples, suggesting that all the samples were practically unpolluted by Zn, Mn, Cu, Co and As. This implies that Zn, Mn, Cu, Co, and As contributions in the classroom dust samples were practically linked with the parent material that formed the soil or other natural or small anthropogenic diffuse sources. The substantial contamination of classroom dust illustrated by the I-geo rating as presented in Table 9, is an obvious sign that anthropogenic activities added an amount of metal like Cd into the dust. The elevated value of Cd in both seasons signified that its sources could consist of leaching, run-off, or aerial depositions of particulate matter out of classroom activities. A continuous building up on topsoil of dust composing traces of this metal would, at a point, threaten the environment.

4. Conclusion

The study designated that the occurrence of some of the metals in the study area came about as a result of anthropogenic effects, which may include furniture, electronic, personal care and cleaning commodities, floor and blackboard coverings, pupil's movement from outside to inside a classroom and vehicular emissions, apart from natural sources. The degree of the general contamination at a location revealed:

- Minimal signals of pollution worsening by the seven evaluated metals in all the classrooms.
- The analytical results signified that in both dry and wet seasons, some of the metals were above the natural heavy metals content of surface soil, which is a matter of concern as these metals can pile up to pollute the ecosystem.
- Monitoring schemes should be implemented to control the metal content, which could cause threats with continual accumulation of contaminated dust on topsoil and leaching by rain.
- It is also crucial that remedial techniques of conservation control practice be enacted to effectively manage the prevailing heavy metal pollution of preschool dust due to classroom emissions and other man-made activities. One such remedial measure is growing bio-accumulators.

By implementing evidence-based policies and school-level interventions, authorities can significantly reduce heavy metal exposure risks for preschool children. Collaboration between educators, parents, policymakers, and health officials is essential for ensuring a safer learning environment and long-term public health benefits. Given the persistent nature of heavy metal contamination in indoor dust, particularly in urban areas with high traffic emissions and industrial activities, it is crucial to establish sustained monitoring and remediation strategies. Continuous assessment will help identify trends, evaluate the effectiveness of interventions, and protect vulnerable populations, especially preschool children.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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