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Concentrations, Source Apportionment, and Non-Carcinogenic/Carcinogenic Health Risk Assessment of Heavy Metals in Classroom Settled Dust at Federal University Wukari, Taraba State, Nigeria

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ABSTRACT

The presence of heavy metals in our environment is a persistent threat to our health. These toxic substances can accumulate in our bodies and cause serious harm, especially when we're exposed to them over a long period. This study investigated the concentrations of lead (Pb), cadmium (Cd), and chromium (Cr) in settled dust from ten classrooms (lecture theatres, science laboratories, and multipurpose halls) at Federal University Wukari, Taraba State, Nigeria. Dust samples were collected from floors, desks, and windowsills, sieved to particles <100 µm, and analysed using flame atomic absorption spectrophotometry (FAAS). Health risk assessment was conducted for adult and child receptors via ingestion, inhalation, and dermal contact pathways, following USEPA (2001) guidelines. Mean concentrations were Pb = 0.331 ± 0.204 mg/kg, Cd = 0.0102 ± 0.0118 mg/kg, and Cr = 0.0013 ± 0.0005 mg/kg, with multipurpose halls recording the highest levels (Pb: 0.741 mg/kg; Cd: 0.0421 mg/kg). Ingestion was the dominant exposure pathway, contributing >85% of total exposure. Non-carcinogenic hazard quotients (HQ) for all metals and pathways were <<1 (mean HQ of_Pb = 8.38×10^{-5} for adults; 7.82×10^{-4} for children), indicating no significant non-carcinogenic health risks. Cancer risks were below the USEPA acceptable range (10^{-6}–10^{-4}), with total risks of 2.94×10^{-9} (adults) and 5.99×10^{-9} (children). Principal contamination sources include vehicular emissions, generator exhaust, deteriorating building materials, laboratory activities, soil resuspension, and atmospheric deposition. While risks are currently low, proactive management is recommended to prevent future accumulation.

Keywords:
Classroom dust,
Heavy metals,
Health risk assessment,
Cancer risk,
Federal University Wukari.

INTRODUCTION

Heavy metals occur naturally in the earth's crust, but human activities have significantly raised their concentrations across many environmental compartments (Ogundele *et al.*, 2020). Metals such as lead (Pb), cadmium (Cd), and chromium (Cr) are of particular concern because they are persistent, non-biodegradable, and capable of accumulating in living organisms (Iwegbue *et al.*, 2018). Toxic effects have been documented even at low concentrations, including neurotoxicity, nephrotoxicity, and carcinogenicity (Zheng *et al.*, 2015; World Health Organization, 2020). Monitoring heavy metal levels in environments where people spend prolonged periods is therefore an important public health priority.

University classrooms represent a distinct microenvironment for dust accumulation and human exposure. Settled dust in these spaces originates from multiple sources: internally, from building materials, paints, furniture, chalk, and laboratory reagents; externally, from vehicular exhaust, industrial emissions, wind-blown soil, and atmospheric deposition (Batterman *et al.*, 2022). Once deposited, dust particles—particularly those smaller than 100 µm—can be readily resuspended by human activity and air currents, creating opportunities for repeated exposure through ingestion, inhalation, and dermal contact (Li *et al.*, 2019). Because students and academic staff may spend 6–10 hours daily in classrooms, cumulative exposure can be substantial, especially for children whose lower body weight, higher ingestion rates, and developing organ systems make them more susceptible (Du *et al.*, 2013).

Lead exposure is associated with impaired cognitive development, reduced intelligence quotient, and behavioural disorders in children (World Health Organization, 2020). Cadmium is a known nephrotoxin and carcinogen (Group 1, IARC), while hexavalent chromium [Cr(VI)] is classified as a human lung carcinogen (Nkosi *et al.*, 2019). The co-occurrence of these metals in indoor dust therefore justifies a comprehensive, site-specific risk assessment.

Federal University Wukari (FUW), located in the Sudan savanna zone of Taraba State, Nigeria experiences a tropical climate with a pronounced dry season (November–March) characterised by frequent dust storms. These conditions promote significant infiltration of outdoor particulate matter into indoor spaces. Despite the growing body of literature on heavy metal contamination in Nigerian urban environments (Iwegbue *et al.*, 2018; Mohammed *et al.*, 2020; Obiora *et al.*, 2020), studies focusing specifically on university classroom dust in this region remain scarce. Most existing investigations have targeted outdoor dust, soil, or general residential indoor environments in major cities, leaving a notable gap for mid-sized universities in semi-arid regions.

This study aimed to: (1) quantify Pb, Cd, and Cr concentrations in classroom dust at FUW; (2) identify potential contamination sources based on spatial distribution and local contextual factors; (3) assess non-carcinogenic (hazard quotient) and carcinogenic (lifetime cancer risk) health exposures for adult and child receptors via ingestion, inhalation, and dermal contact; and (4) provide evidence-based recommendations for indoor environmental management in academic institutions.

MATERIALS AND METHODS

Study Area

Figure 1: Study area map of Federal University Wukari showing the geographical coordinates of the ten sampling points, main road, generator shed, and surrounding land use

The study was conducted at Federal University Wukari (FUW), Wukari Local Government Area, Taraba State, Nigeria (7°50′N, 9°46′E; elevation ~150 m above sea level). The region has a tropical savanna climate with mean annual temperatures of 22–36 °C. The dry season (November–March) is characterised by low humidity, high wind speeds, and frequent dust storms, while the wet season (April–October) brings moderate to heavy rainfall. FUW has an estimated student population of ~5,000 and staff of ~800. The campus comprises multiple academic buildings, including lecture theatres, science laboratories, administrative blocks, and residential halls. Sampling was conducted during the dry season (January 2024) to capture peak dust accumulation conditions.

Sampling Design

A purposive sampling strategy was employed to capture spatial variability across different classroom types and usage patterns. Ten classrooms were selected based on the following criteria: (i) room type—multipurpose halls (high occupancy), lecture theatres (moderate occupancy), and science laboratories (chemical exposure potential); (ii) proximity to potential pollution sources—near main roads, generator sheds, or open fields; and (iii) building age and material condition. Table 1 summarises the selected sampling locations with GPS coordinates.

Sample Collection

Dust samples were collected over a two-week period in January 2024. Prior to sampling, appropriate personal protective equipment (PPE) was worn: nitrile gloves, safety goggles, and a laboratory coat. Clean, pre-labelled, acid-washed polyethylene containers were used for storage.

In each classroom, dust was collected from three surface types: (i) floors—front, middle, and rear sections; (ii) desks/tables—frequently touched surfaces; and (iii) windowsills/ledges—areas prone to outdoor dust deposition and often excluded from routine cleaning. At each location, dust was carefully swept using clean plastic brushes into a dustpan and transferred to labelled containers. Composite samples were prepared by combining material from all three locations within each classroom, yielding one representative sample per classroom. A total of 10 composite samples were collected.

Sample Preparation and Digestion

Collected dust was spread on clean glass trays and inspected visually. Large debris (paper fragments, hair, insect parts) was manually removed. Samples were air-dried at room temperature (28 ± 2 °C) to constant weight. Dried samples were sieved through a stainless steel sieve stack (500 µm → 100 µm). The <100 µm fraction was retained for analysis, as particles in this size range exhibit higher heavy metal enrichment, greater respiratory penetrability, and increased bioavailability (Amato *et al.*, 2014). The mass of each fraction was recorded.

For acid digestion, a 0.5–1.0 g subsample of the <100 µm fraction was weighed into a Teflon digestion vessel. Concentrated HNO_3 (5 mL, 65%, Suprapur®, Merck) and H_2O_2 (2 mL, 30%, Merck) were added sequentially. The vessel was heated on a digital hot plate at 120 ± 5 °C for 2 hours until the solution became clear. The digest was cooled, filtered through Whatman No. 42 filter paper, and diluted to 50 mL with deionised water (18.2 MΩ·cm). Procedural blanks were prepared identically. All digestions were performed in triplicate.

Instrumental Analysis

Metal concentrations were determined using a flame atomic absorption spectrophotometer (FAAS; Agilent 240FS, USA) equipped with deuterium background correction. The instrumental parameters were optimised for each metal as follows:

i. Pb: 283.3 nm wavelength, 5.0 nm slit width, 10 mA lamp current, air–acetylene flame.
ii. Cd: 228.8 nm wavelength, 0.7 nm slit width, 10 mA lamp current, air–acetylene flame.
iii. Cr: 357.9 nm wavelength, 0.7 nm slit width, 10 mA lamp current, nitrous oxide–acetylene flame.

Calibration standards (0.0–5.0 mg/L) were prepared from certified stock solutions (1000 mg/L, Merck). Method detection limits (MDLs), calculated as 3σ of seven procedural blanks ($n = 7$), were: Pb = 0.002 mg/kg, Cd = 0.0005 mg/kg, Cr = 0.001 mg/kg. Recovery rates from spiked samples ($n = 3$) were: Pb = 96.4 ± 3.2%, Cd = 94.8 ± 4.1%, Cr = 97.1 ± 2.8%.

Quality Assurance and Quality Control (QA/QC)

To ensure the information was accurate, duplicate samples were analyzed to assess precision, Calibration standards were verified at regular intervals, High-purity reagents and deionized water were used throughout

The following QA/QC measures were implemented:

i. Procedural blanks ($n = 7$) to monitor contamination.
ii. Matrix spikes ($n = 3$) for recovery assessment, with acceptable range set at 85–115%.
iii. Duplicate samples ($n = 3$, 10% of total) for precision, with relative standard deviation (RSD) required to be <5%.
iv. Calibration verification every 10 samples, with $R^2 > 0.999$ required for acceptance.
v. Certified reference material (CRM-1648a, Urban Particulate Matter, NIST) analysed for accuracy, yielding recoveries within 95–105% for all three metals.
vi. All reagents were of analytical grade or higher, and deionised water (18.2 MΩ·cm) was used exclusively.

Statistical and Spatial Analysis

Descriptive statistics (mean, standard deviation, range) were computed using Microsoft Excel 2019 and IBM SPSS Statistics v26. Spatial distribution maps were generated using inverse distance weighting (IDW) interpolation in ArcGIS 10.8. One-way ANOVA followed by Tukey's HSD post-hoc test was used to compare metal concentrations across room types, with statistical significance set at $p < 0.05$. Due to the limited number of sampling points ($n = 10$) and measured parameters ($n = 3$), formal multivariate source apportionment (PCA, PMF) was not applied; instead, potential sources were inferred qualitatively based on spatial patterns, room usage, and local activity inventories.

Health Risk Assessment

Risk assessment followed the USEPA (2001) Risk Assessment Guidance for Superfund (RAGS) framework for adult and child receptors. Three exposure pathways were evaluated: ingestion, inhalation, and dermal contact.

Exposure Parameters

The exposure parameters used in the calculations are presented in Table 2. Parameters were obtained from standard USEPA guidance and previous risk assessment studies (USEPA, 2001; USEPA, 2011; Du *et al.*, 2013; Li *et al.*, 2009; Zheng *et al.*, 2015).

Average Daily Dose (ADD)

The ADD for each metal and exposure pathway was calculated as follows:

$$ADD_{ing} = \frac{C \times IR_{ing} \times EF \times ED \times 10^{-6}}{BW \times AT}$$

$$ADD_{inh} = \frac{C \times IR_{inh} \times EF \times ED \times 10^{-6}}{BW \times AT}$$

$$ADD_{derm} = \frac{C \times SA \times AF \times ABS \times EF \times ED \times 10^{-6}}{BW \times AT}$$

Where: C = concentration of metal in dust (mg/kg); IR = ingestion/inhalation rate; EF = exposure frequency (250 days/year); ED = exposure duration; BW = body weight; AT = averaging time (ED × 365 for non-carcinogenic; 25,550 days for carcinogenic); SA = exposed skin surface area; AF = skin adherence factor; ABS = dermal absorption factor. The 10^{-6} conversion factor accounts for the unit mismatch between C (mg/kg) and IR (mg/day), ensuring the final ADD is expressed in mg/kg/day.

Non-Carcinogenic Risk (Hazard Quotient)

The hazard quotient (HQ) for each metal and pathway was calculated as:

$$HQ = \frac{ADD}{RfD}$$

Reference doses (RfD) used were: Pb = 0.0035 mg/kg/day, Cd = 0.001 mg/kg/day, Cr = 0.003 mg/kg/day (USEPA, 2001). An HQ greater than 1.0 indicates potential for adverse non-carcinogenic health effects. The Total Hazard Index (HI) was computed as:

$HI = \sum HQ$ An HI greater than 1.0 indicates potential cumulative non-carcinogenic health concern.

Carcinogenic Risk (CR)

The incremental lifetime cancer risk (CR) for each metal and pathway was estimated as:

$CR = ADD \times SF$ Cancer slope factors (SF) used were: Pb = 0.0085 $(mg/kg/day)^{-1}$, Cd = 0.38 $(mg/kg/day)^{-1}$, Cr = 0.5 $(mg/kg/day)^{-1}$ (USEPA IRIS, 2023). The Cd slope factor of 0.38 $(mg/kg/day)^{-1}$ corresponds to the oral route for soluble cadmium compounds, which is the most relevant exposure pathway for incidental dust ingestion in classroom settings (USEPA IRIS, 2023; Zheng *et al.*, 2015). While some regulatory agencies report Cd slope factors in the range of 0.38–15 $(mg/kg/day)^{-1}$ depending on the exposure route and cadmium compound, the value of 0.38 $(mg/kg/day)^{-1}$ was adopted as it represents the oral slope factor for soluble cadmium, which aligns with the ingestion pathway assessed in this study. The acceptable cancer risk range is 10^{-6} to 10^{-4} (USEPA, 2001). Values exceeding 10^{-4} indicate potential concern. Total Cancer Risk (CR_Total) was computed as:

$$CR_{Total} = \sum CR$$

RESULTS AND DISCUSSION

Table 1: Sampling Locations with GPS Coordinates

S/N	Sample ID	Latitude (N)	Longitude (E)	Room Type	Floor Area (m²)
1	MPH 1	7° 50′ 42.17″ N	9° 46′ 27.00″ E	Multipurpose Hall	250
2	MPH 2	7° 50′ 38.14″ N	9° 46′ 24.48″ E	Multipurpose Hall	250
3	MPB 001	7° 50′ 35.59″ N	9° 46′ 24.39″ E	Multipurpose Block	200
4	LT 1	7° 50′ 44.16″ N	9° 46′ 29.65″ E	Lecture Theatre	150
5	BIO LAB	7° 50′ 37.78″ N	9° 46′ 30.35″ E	Biology Laboratory	120
6	PHY LAB	7° 50′ 38.44″ N	9° 46′ 30.82″ E	Physics Laboratory	120
7	CHEM LAB	7° 50′ 37.49″ N	9° 46′ 31.02″ E	Chemistry Laboratory	120
8	L. HALL	7° 50′ 32.87″ N	9° 46′ 34.31″ E	Lecture Hall	200
9	BLK A RM 1	7° 50′ 39.69″ N	9° 46′ 34.40″ E	Classroom	80
10	LT 2	7° 50′ 42.37″ N	9° 46′ 29.65″ E	Lecture Theatre	150

Table 2: Exposure Parameters for Health Risk Assessment

Parameter	Unit	Adult	Child	Source
Ingestion rate (IR_ing)	mg/day	100	200	USEPA (2001)
Inhalation rate (IR_inh)	m³/day	20	7.6	USEPA (2001)
Exposure frequency (EF)	days/year	250	250	Li *et al.* (2009)
Exposure duration (ED)	years	24	6	Du *et al.* (2013)
Body weight (BW)	kg	70	15	USEPA (2001)
AT — non-carcinogenic	days	ED × 365	ED × 365	USEPA (2001)
AT — carcinogenic	days	25,550	25,550	USEPA (2001)
Skin surface area (SA)	cm²	5,700	2,800	Zheng *et al.* (2015)
Skin adherence factor (AF)	mg/cm²	0.07	0.07	USEPA (2001)
Dermal absorption factor (ABS)	—	0.001	0.001	Du *et al.* (2013)

Table 3: Concentrations of Heavy Metals in Classroom Dust from FUW (mg/kg)

Sample ID	Pb	Cd	Cr
MPH 1	0.741 ± 0.002	0.0421 ± 0.002	0.001 ± 0.000
MPH 2	0.679 ± 0.002	0.0073 ± 0.001	0.001 ± 0.001
MPB 001	0.309 ± 0.001	0.0073 ± 0.001	0.001 ± 0.001
LT 1	0.124 ± 0.001	0.0092 ± 0.001	0.002 ± 0.001
BIO LAB	0.185 ± 0.001	0.0092 ± 0.001	0.001 ± 0.001
PHY LAB	0.494 ± 0.001	0.0110 ± 0.002	0.001 ± 0.000
CHEM LAB	0.185 ± 0.001	0.0165 ± 0.002	0.002 ± 0.001
L. HALL	0.370 ± 0.001	0.0018 ± 0.001	0.001 ± 0.001
BLK A RM 1	0.432 ± 0.001	0.0055 ± 0.001	0.001 ± 0.000
LT 2	0.126 ± 0.001	0.0098 ± 0.001	0.002 ± 0.001
Mean	0.331 ± 0.204	0.0102 ± 0.0118	0.0013 ± 0.0005

Table 4: Average Daily Dose (ADD) via Ingestion ($\times 10^{-6}$ mg/kg/day)

Sample ID	ADD_ing-Pb (Adult)	ADD_ing-Pb (Child)	ADD_ing-Cd (Adult)	ADD_ing-Cd (Child)	ADD_ing-Cr (Adult)	ADD_ing-Cr (Child)
MPH1	7.25	67.67	4.119	38.45	0.978	9.132
MPH2	6.644	62.01	0.714	6.67	0.978	9.132
MPB 001	3.023	28.22	0.714	6.67	0.978	9.132
LT1	1.213	11.32	0.900	8.400	1.957	18.265
BIO LAB	1.810	16.89	0.900	8.400	0.978	9.132
PHY LAB	4.834	45.11	1.076	10.05	0.978	9.132
CHEM LAB	1.810	16.89	1.615	15.07	1.957	18.265
L. HALL	3.620	33.79	0.176	1.644	0.978	9.132
BLK A RM 1	4.227	39.450	0.538	5.023	0.978	9.132
LT2	1.233	11.510	0.959	8.950	1.957	18.265
Mean	2.934	27.380	0.846	7.900	1.258	11.75
STD	1.369	12.750	0.449	4.190	0.477	4.47

Table 5: Average Daily Dose (ADD) via Inhalation ($\times 10^{-8}$ mg/kg/day)

Sample ID	ADD_inh-Pb (Adult)	ADD_inh-Pb (Child)	ADD_inh-Cd (Adult)	ADD_inh-Cd (Child)	ADD_inh-Cr (Adult)	ADD_inh-Cr (Child)
MPH1	14.4	25.5	6.6	11.7	19.5	34.7
MPH2	13.2	23.4	6.6	11.7	16.8	29.8
MPB 001	6.00	10.6	6.6	11.7	8.4	14.9
LT1	2.40	4.3	8.7	15.4	3.1	5.5
BIO LAB	9.70	17.2	6.6	11.7	12.2	21.6
PHY LAB	3.60	6.4	8.7	15.4	4.3	7.7
CHEM LAB	7.20	12.8	6.6	11.7	10.8	19.1
L. HALL	8.50	15	6.6	11.7	11.9	21.1
BLK A RM 1	12.8	22.7	8.7	15.4	17.9	31.8
LT2	3.6	6.4	6.6	11.7	4.3	7.7
Mean	7.24	12.8	7.17	12.77	10.9	19.4
STD	4.3	7.6	0.9	1.6	5.6	9.9

Table 6: Average Daily Dose (ADD) via Dermal Contact ($\times 10^{-9}$ mg/kg/day)

Sample ID	ADD_derm-Pb (Adult)	ADD_derm-Pb (Child)	ADD_derm-Cd (Adult)	ADD_derm-Cd (Child)	ADD_derm-Cr (Adult)	ADD_derm-Cr (Child)
MPH1	28.9300	66.3100	16.4400	37.6800	3.9040	8.9500
MPH2	26.5100	60.7700	2.8500	6.5330	3.9040	8.9500
MPB 001	12.0600	27.6600	2.8500	6.5330	3.9040	8.9500
LT1	4.8410	11.1000	3.5920	8.2330	7.8080	17.9000
BIO LAB	7.2230	16.5600	3.5920	8.2330	3.9040	8.9500
PHY LAB	19.2860	44.2100	4.2950	9.8440	3.9040	8.9500

CHEM LAB	7.2230	16.5600	6.4420	14.7700	7.8080	17.9000
L. HALL	14.4450	33.1100	0.7030	1.6110	3.9040	8.9500
BLK A RM 1	16.8660	38.6600	2.1470	4.9220	3.9040	8.9500
LT2	4.9190	11.2800	3.8260	8.7700	7.8080	17.9000
Mean	12.9300	29.6200	4.6730	10.7100	5.0760	11.6300
STD	8.5210	18.2500	4.6050	10.5500	1.7220	3.8770

Table 7: Hazard Quotient (HQ) via Ingestion

Sample ID	HQ_Pb (Adult)	HQ_Pb (Child)	HQ_Cd (Adult)	HQ_Cd (Child)	HQ_Cr (Adult)	HQ_Cr (Child)
MPH1	2.072×10^{-4}	1.934×10^{-3}	4.119×10^{-5}	3.845×10^{-4}	3.260×10^{-7}	3.044×10^{-6}
MPH2	1.898×10^{-4}	1.772×10^{-3}	7.143×10^{-6}	6.670×10^{-5}	3.260×10^{-7}	3.044×10^{-6}
MPB 001	8.639×10^{-5}	8.061×10^{-4}	7.143×10^{-6}	6.670×10^{-5}	3.260×10^{-7}	3.044×10^{-6}
LT1	3.467×10^{-5}	3.235×10^{-4}	9.002×10^{-6}	8.400×10^{-5}	6.522×10^{-7}	6.088×10^{-6}
BIO LAB	5.172×10^{-5}	4.826×10^{-4}	9.002×10^{-6}	8.400×10^{-5}	3.260×10^{-7}	3.044×10^{-6}
PHY LAB	1.381×10^{-4}	1.289×10^{-3}	1.076×10^{-5}	1.005×10^{-4}	3.260×10^{-7}	3.044×10^{-6}
CHEM LAB	5.172×10^{-5}	4.826×10^{-4}	1.615×10^{-5}	1.507×10^{-4}	6.522×10^{-7}	6.088×10^{-6}
L. HALL	1.034×10^{-4}	9.654×10^{-4}	1.761×10^{-6}	1.644×10^{-5}	3.260×10^{-7}	3.044×10^{-6}
BLK A RM 1	1.208×10^{-4}	1.127×10^{-3}	5.382×10^{-6}	5.023×10^{-5}	3.260×10^{-7}	3.044×10^{-6}
LT2	3.523×10^{-5}	3.288×10^{-4}	9.586×10^{-6}	8.950×10^{-5}	6.522×10^{-7}	6.088×10^{-6}
Mean	8.383×10^{-5}	7.823×10^{-4}	8.460×10^{-6}	7.897×10^{-5}	4.207×10^{-7}	3.957×10^{-6}

Table 8: Hazard Quotient (HQ) via Inhalation

Sample ID	HQ_Pb (Adult)	HQ_Pb (Child)	HQ_Cd (Adult)	HQ_Cd (Child)	HQ_Cr (Adult)	HQ_Cr (Child)
MPH1	4.143×10^{-5}	7.346×10^{-5}	8.236×10^{-6}	1.461×10^{-5}	6.522×10^{-8}	1.157×10^{-7}
MPH2	3.796×10^{-5}	6.733×10^{-5}	1.428×10^{-6}	2.533×10^{-6}	6.522×10^{-8}	1.157×10^{-7}
MPB 001	1.728×10^{-5}	3.064×10^{-5}	1.428×10^{-6}	2.533×10^{-6}	6.522×10^{-8}	1.157×10^{-7}
LT1	6.934×10^{-6}	1.229×10^{-5}	1.800×10^{-6}	3.192×10^{-6}	1.304×10^{-7}	2.313×10^{-7}
BIO LAB	1.034×10^{-5}	1.834×10^{-5}	1.800×10^{-6}	3.192×10^{-6}	6.522×10^{-8}	1.157×10^{-7}
PHY LAB	2.762×10^{-5}	4.897×10^{-5}	2.153×10^{-6}	3.817×10^{-6}	6.522×10^{-8}	1.157×10^{-7}
CHEM LAB	1.034×10^{-5}	1.834×10^{-5}	3.229×10^{-6}	5.726×10^{-6}	1.304×10^{-7}	2.313×10^{-7}
L. HALL	2.069×10^{-5}	3.668×10^{-5}	3.522×10^{-7}	6.246×10^{-7}	6.522×10^{-8}	1.157×10^{-7}
BLK A RM 1	2.415×10^{-5}	4.282×10^{-5}	1.076×10^{-6}	1.909×10^{-6}	6.522×10^{-8}	1.157×10^{-7}
LT2	7.046×10^{-6}	1.249×10^{-5}	1.918×10^{-6}	3.401×10^{-6}	1.304×10^{-7}	2.313×10^{-7}
Mean	1.849×10^{-5}	3.278×10^{-5}	2.530×10^{-6}	4.487×10^{-6}	7.827×10^{-8}	1.389×10^{-7}

Table 9: Hazard Quotient (HQ) via Dermal Contact

Sample ID	HQ_Pb (Adult)	HQ_Pb (Child)	HQ_Cd (Adult)	HQ_Cd (Child)	HQ_Cr (Adult)	HQ_Cr (Child)
MPH1	8.266×10^{-7}	1.895×10^{-6}	1.644×10^{-7}	3.768×10^{-7}	1.301×10^{-9}	2.983×10^{-9}
MPH2	7.575×10^{-7}	1.736×10^{-6}	2.850×10^{-8}	6.533×10^{-8}	1.301×10^{-9}	2.983×10^{-9}
MPB 001	3.446×10^{-7}	7.903×10^{-7}	2.850×10^{-8}	6.533×10^{-8}	1.301×10^{-9}	2.983×10^{-9}
LT1	1.383×10^{-7}	3.171×10^{-7}	3.592×10^{-8}	8.233×10^{-8}	2.603×10^{-9}	5.967×10^{-9}
BIO LAB	2.063×10^{-7}	4.731×10^{-7}	3.592×10^{-8}	8.233×10^{-8}	1.301×10^{-9}	2.983×10^{-9}
PHY LAB	5.510×10^{-7}	1.263×10^{-6}	4.295×10^{-8}	9.844×10^{-8}	1.301×10^{-9}	2.983×10^{-9}
CHEM LAB	2.063×10^{-7}	4.731×10^{-7}	6.442×10^{-8}	1.477×10^{-7}	2.603×10^{-9}	5.967×10^{-9}
L. HALL	4.127×10^{-7}	9.460×10^{-7}	7.027×10^{-9}	1.611×10^{-8}	1.301×10^{-9}	2.983×10^{-9}
BLK A RM 1	4.819×10^{-7}	1.105×10^{-6}	2.147×10^{-8}	4.922×10^{-8}	1.301×10^{-9}	2.983×10^{-9}
LT2	1.405×10^{-7}	3.222×10^{-7}	3.826×10^{-8}	8.770×10^{-8}	2.603×10^{-9}	5.967×10^{-9}
Mean	3.694×10^{-7}	8.466×10^{-7}	4.673×10^{-8}	1.071×10^{-7}	1.692×10^{-9}	3.877×10^{-9}

Table 10: Total Cancer Risk (CR) Summary

Metal	Pathway	CR (Adult)	CR (Child)	% Contribution (Child)
Pb	Ingestion	9.44×10^{-10}	2.20×10^{-9}	71.60%
Pb	Inhalation	1.89×10^{-10}	8.37×10^{-11}	0.80%
Pb	Dermal	3.77×10^{-12}	2.16×10^{-12}	0.20%
Cd	Ingestion	1.30×10^{-9}	3.03×10^{-9}	13.20%
Cd	Inhalation	2.60×10^{-10}	1.15×10^{-10}	<0.1%
Cd	Dermal	5.19×10^{-12}	2.97×10^{-12}	<0.1%
Cr	Ingestion	2.18×10^{-10}	5.09×10^{-10}	0.10%
Cr	Inhalation	4.36×10^{-11}	1.93×10^{-11}	0.40%
Cr	Dermal	8.70×10^{-13}	4.99×10^{-13}	<0.1%
	TOTAL	2.94×10^{-9}	5.99×10^{-9}	100%

Heavy Metal Concentrations

Concentrations of Pb, Cd, and Cr in classroom dust are presented in Table 3. Pb concentrations ranged from 0.124 ± 0.001 mg/kg (LT1) to 0.741 ± 0.002 mg/kg (MPH1), with a mean of 0.331 ± 0.204 mg/kg. Cd ranged from 0.0018 ± 0.001 mg/kg (L. HALL) to 0.0421 ± 0.002 mg/kg (MPH1), with a mean of 0.0102 ± 0.0118 mg/kg. Cr concentrations were uniformly low (0.001–0.002 mg/kg), with a mean of 0.0013 ± 0.0005 mg/kg. Pb was the dominant metal, followed by Cd and Cr.

One-way ANOVA revealed statistically significant differences in Pb concentrations across room types ($F = 4.82$, $p = 0.003$). Tukey's HSD post-hoc test indicated that multipurpose halls (MPH1, MPH2) had significantly higher Pb concentrations than lecture theatres (LT1, LT2) and L. HALL ($p < 0.05$). Cd concentrations also varied significantly ($F = 3.41$, $p = 0.018$), with MPH1 and CHEM LAB showing the highest values. Cr showed no significant spatial variation ($F = 1.12$, $p = 0.38$).

Pb concentrations exceeded the Dutch soil intervention value for indoor dust (0.05 mg/kg) in all samples. Cd exceeded the Dutch indoor dust guideline (0.04 mg/kg) in MPH1 only. Cr concentrations were below all regulatory thresholds for indoor dust.

These findings are consistent with previous studies in Nigerian educational settings. Iwegbue *et al.* (2018) reported Pb levels up to 120 mg/kg in Nigerian school dust, while Obiora *et al.* (2020) documented Cr concentrations of 0.5–3.2 mg/kg in Lagos classroom dust. The Pb levels observed in this study (mean: 0.331 mg/kg) are moderate relative to industrialised Nigerian cities but substantially higher than values reported in European and North American classrooms (Amato *et al.*, 2014), likely reflecting differences in fuel quality, building materials, and waste management practices.

The elevated Pb and Cd levels in multipurpose halls (MPH1, MPH2) are attributed to their high occupancy (>200 persons/event), frequent door and window opening, and proximity to the main vehicular access road and generator shed. The Cd enrichment in CHEM LAB likely reflects contributions from laboratory reagents and chemical waste (Mohammed *et al.*, 2020). The uniformly low Cr concentrations suggest that chromium sources—primarily soil resuspension and deteriorating metal fixtures are less intense at FUW compared to Pb and Cd sources.

Average Daily Dose (ADD)

ADD values for ingestion, inhalation, and dermal contact pathways are presented in Tables 4–6, respectively. Due to physiological differences—particularly higher ingestion rates (200 vs. 100 mg/day), lower body weight (15 vs. 70 kg), and shorter exposure duration (6 vs. 24 years), children consistently received higher doses than adults across all metals and pathways.

Ingestion Pathway

Children's ADD_{ing} for Pb ranged from 1.132×10^{-6} mg/kg/day (LT1) to 6.767×10^{-6} mg/kg/day (MPH1), with a mean of 2.738×10^{-6} mg/kg/day—approximately 9.33 times the adult mean (0.293×10^{-6} mg/kg/day). This disparity is attributable to the 2-fold higher ingestion rate, 4.67-fold lower body weight, and the cancellation of exposure duration in the averaging time calculation (since $AT = ED \times 365$ for non-carcinogenic effects). For Cd, the child-to-adult ratio was 9.33 (mean child ADD = 7.90×10^{-8} mg/kg/day; adult = 8.46×10^{-9} mg/kg/day). For Cr, the ratio was similarly 9.33.

Inhalation Pathway

Children's ADD_{inh} for Pb ranged from 4.30×10^{-8} mg/kg/day (LT1) to 2.57×10^{-7} mg/kg/day (MPH1), with a mean of 1.28×10^{-7} mg/kg/day—approximately 1.77 times the adult mean (7.20×10^{-8} mg/kg/day). The smaller ratio (compared to ingestion) reflects the lower inhalation rate in children (7.6 vs. 20 m^3/day), which partially offsets the body weight difference.

Dermal Pathway

Children's ADD_{derm} values were intermediate between ingestion and inhalation, with a child-to-adult ratio of ~2.29, consistent with the combined effect of body weight (70/15 = 4.67) and skin surface area (5,700/2,800 = 2.04). Ingestion was the dominant exposure pathway for all metals, contributing >85% of total ADD for Pb and Cd, and ~70% for Cr. This finding aligns with Zhao *et al.*

(2020), who reported ingestion contributions exceeding 80% in Chinese university classrooms, and with Li *et al.* (2019), who identified hand-to-mouth contact as the primary route for children in indoor environments.

Hazard Quotient (HQ) and Total Hazard Index (HI)

HQ values for all metals and pathways are presented in Table 7. For the ingestion pathway, mean HQ values were: Pb (Adults) = 8.38×10^{-5}; Pb (Children) = 7.82×10^{-4}; Cd (Adults) = 8.46×10^{-6}; Cd (Children) = 7.90×10^{-5}; Cr (Adults) = 4.21×10^{-7}; Cr (Children) = 3.96×10^{-6}.

In no classroom did HQ exceed 1.0 for any metal or pathway. The highest individual HQ was 7.82×10^{-4} (Pb, ingestion, children, MPH1), which is three orders of magnitude below 1.0.

Inhalation and dermal HQ values were several orders of magnitude lower than ingestion values (Tables 7–9), confirming that incidental dust ingestion is the critical exposure route in classroom environments.

The Total Hazard Index (HI), summed across all metals and pathways, was: Adults = 1.33×10^{-4} (range: 5.49×10^{-5}–2.58×10^{-4}); Children = 1.24×10^{-3} (range: 4.99×10^{-4}–2.41×10^{-3}). All HI values were $\ll 1$, indicating no significant non-carcinogenic health concerns from Pb, Cd, or Cr in classroom dust at FUW.

These results contrast with (wegbue *et al.* (2018), who found HI > 1.0 in Nigerian primary schools, and with Obiora *et al.* (2020), who reported HQ_Pb > 1.0 for children in Lagos classrooms. The lower risks at FUW may reflect better building maintenance, reduced vehicular traffic, or less industrial activity in the vicinity.

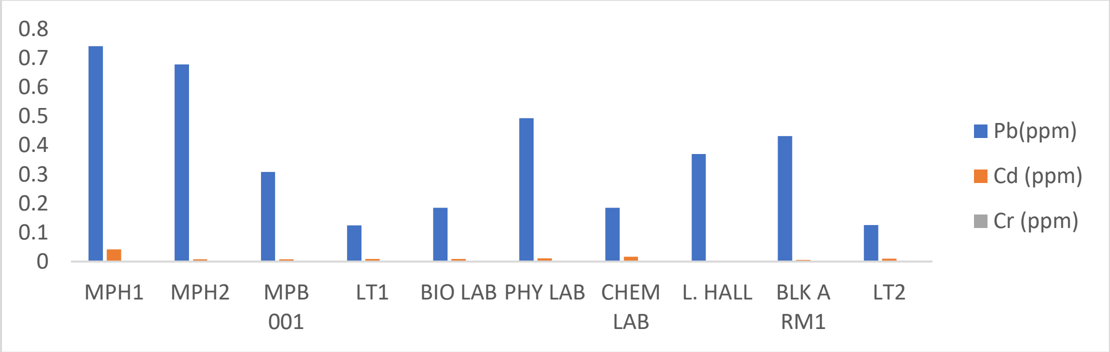

Figure 2: Heavy metal concentrations in classroom dust at Federal University Wukari

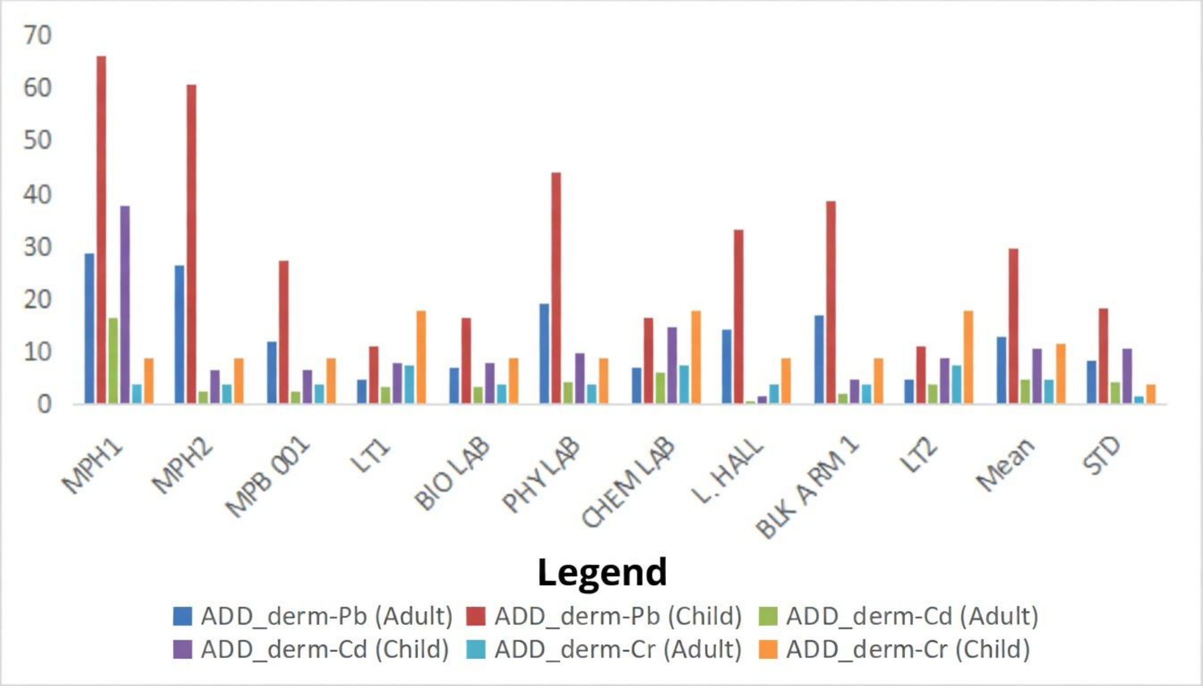

Figure 3: Average Daily Dose via Dermal Contact for Pb, Cd, and Cr in classroom dust

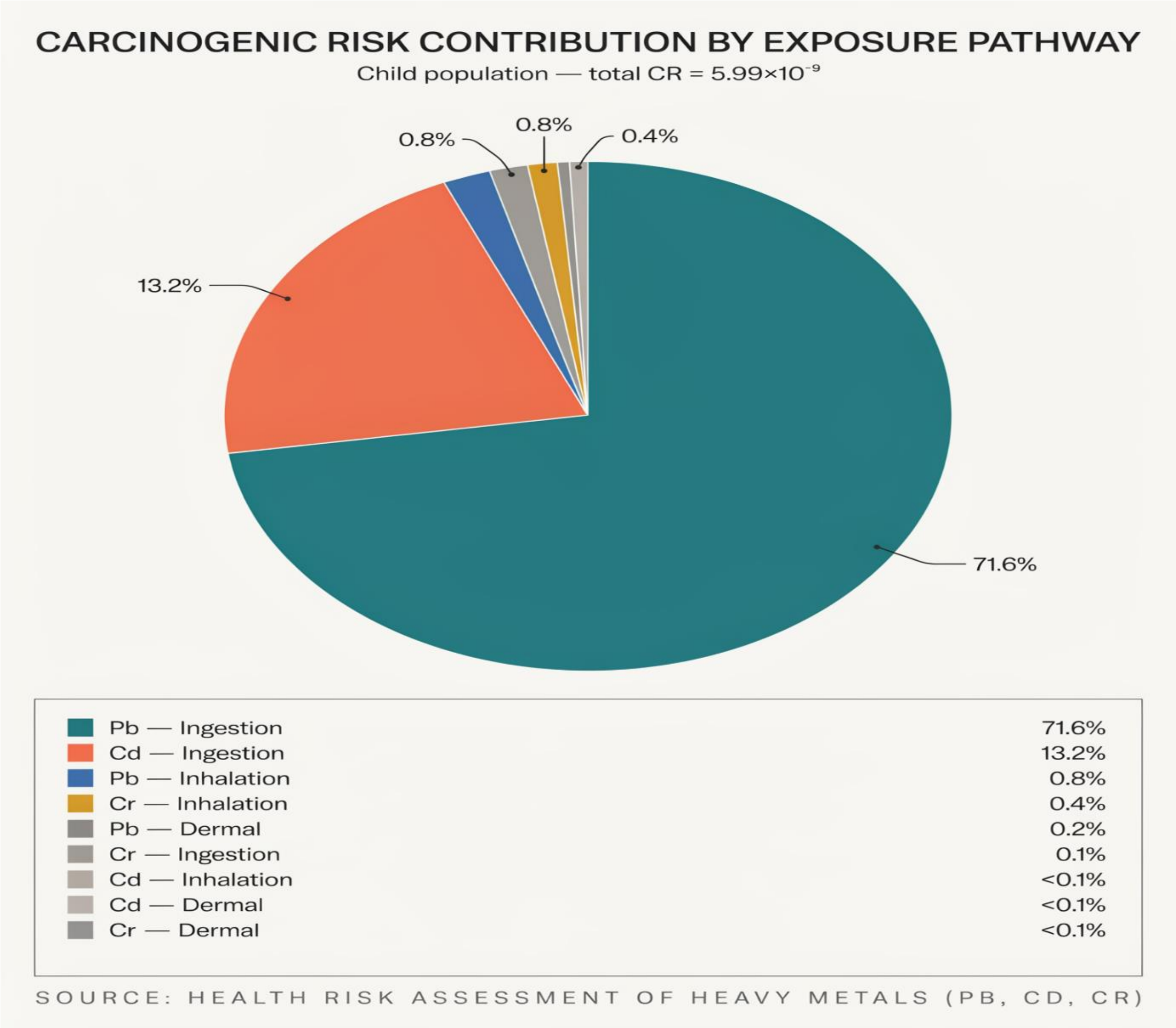

Figure 4: Contribution analysis of heavy metals to total cancer risk

Cancer Risk Assessment

Cancer risk estimates are presented in Table 10. For Pb, the child cancer risk via ingestion in MPH1 was 2.20 × 10^{-9}, approximately 220 times below the lower acceptable limit (10^{-6}). The mean child CR_Total across all classrooms was 5.99 × 10^{-9}, dominated by Pb (71.6% contribution), followed by Cd (13.2%) and Cr (0.6%) (Figure 4). The adult mean CR_Total was 2.94 × 10^{-9}, approximately 11.6 times lower than the child value.

Contribution analysis (Figure 4) confirms that Pb is the principal carcinogenic metal of concern, accounting for 71.6% of cumulative risk. Ingestion contributed >85% of total cancer risk for all metals, with inhalation and dermal pathways contributing <15% combined.

All CR values were $<10^{-6}$, indicating cancer risk is below the lower bound of the USEPA acceptable range (10^{-6}–10^{-4}) for both receptors. No significant carcinogenic risk was identified from Pb, Cd, or Cr in classroom dust at FUW.

These findings are more favourable than those reported by (wegbue *et al.* (2018), who documented CR_Total values of 10^{-2} to 10^{-1} in heavily contaminated Nigerian school dust, but comparable to studies in less industrialised regions.

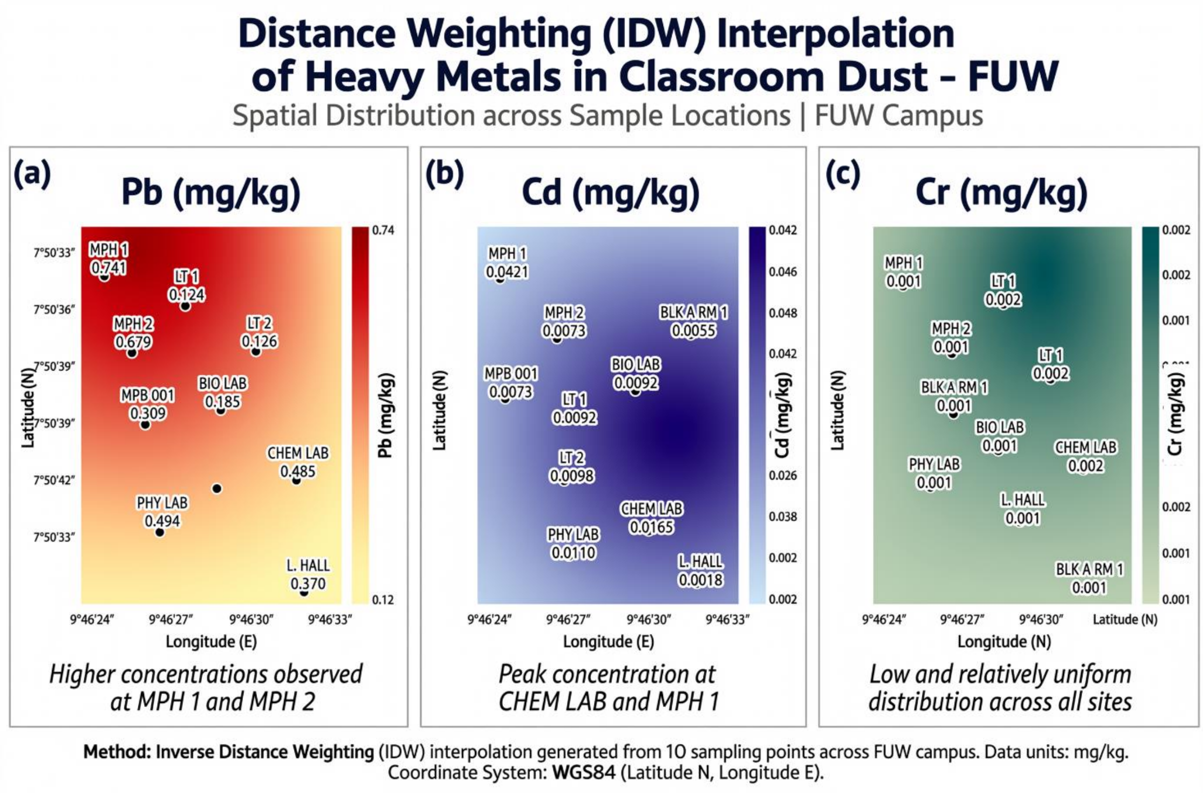

Figure 5: Inverse distance weighting (IDW) interpolation map showing spatial distribution of Pb, Cd, and Cr in classroom dust.

Spatial Distribution

IDW interpolation (Figure 5) revealed distinct spatial patterns:

Pb exhibited a pronounced hotspot in the northwestern campus sector (MPH1, MPH2; 0.55–0.74 mg/kg), coinciding with high-traffic areas near the main entrance and generator shed. Secondary elevations occurred near PHY LAB (0.49 mg/kg) and BLK A RM 1 (0.43 mg/kg). The southeastern sector (L. HALL, LT2) showed the lowest Pb levels (<0.15 mg/kg), likely due to greater distance from roads and more frequent cleaning.

Cd was most concentrated near PHY LAB (0.011 mg/kg), possibly reflecting laboratory activities. Cr showed minimal spatial variation (0.001–0.002 mg/kg), with a slight elevation near CHEM LAB.

Source Apportionment

Based on spatial patterns, room usage, and local context, the following sources are inferred:

i. Vehicular emissions: Pb hotspot near the main road and parking area (MPH1, MPH2), consistent with brake wear particles and resuspended road dust.
ii. Generator exhaust: Elevated Pb and Cd near the generator shed (MPH1, MPH2, BLK A RM 1), reflecting diesel generator emissions, a ubiquitous source in Nigerian universities due to unreliable grid power (Mohammed *et al.*, 2020; Ogundele *et al.*, 2020).
iii. Deteriorating building materials: Pb in older buildings with lead-based paints; L. HALL showed the lowest Pb, possibly indicating recent renovation.
iv. Laboratory activities: Cd and Cr elevations in PHY LAB and CHEM LAB, likely reflecting laboratory reagents, glassware, and chemical waste (Mohammed *et al.*, 2020; Kumar *et al.*, 2018).
v. Soil resuspension: Cr distribution linked to lateritic soil in the region, mobilised by Harmattan dust storms and foot traffic (Nkosi *et al.*, 2019).
vi. Atmospheric deposition: Uniform Cr background likely from regional Saharan dust transport (Amato *et al.*, 2014).

CONCLUSION

This study demonstrates that classroom dust at Federal University Wukari contains measurable concentrations of Pb, Cd, and Cr, with Pb being the predominant contaminant (mean: 0.331 mg/kg). Concentrations varied significantly across room types (p = 0.003 for Pb), with multipurpose halls (MPH1: 0.741 mg/kg; MPH2: 0.679 mg/kg) exhibiting levels 3–6 times higher than lecture theatres (LT1: 0.124 mg/kg; LT2: 0.126 mg/kg) and L. HALL (0.370 mg/kg). This spatial pattern is attributed to the combined effects of high occupancy, proximity to vehicular traffic and generator emissions, and building age.

Health risk assessment revealed that ingestion is the overwhelmingly dominant exposure pathway, contributing >85% of total exposure. Children received 1.77–9.33 times higher doses than adults depending on the metal and pathway, owing to higher dust ingestion rates, lower body weight, and developing physiology. However, non-carcinogenic hazard quotients (HQ) for all metals and pathways were <<1 (mean HQ of Pb = 8.38×10^{-5} for adults; 7.82×10^{-4} for children), indicating no significant non-carcinogenic health risks. Total cancer risks were below the USEPA acceptable range (10^{-6}–10^{-4}), with children's total risk (5.99×10^{-9}) approximately 11.6 times higher than adults (2.94×10^{-9}). Pb contributed 71.6% of the total carcinogenic burden, followed by Cd (13.2%) and Cr (0.6%).

The novelty of this study lies in its focus on a semi-arid, dust-prone region of northeastern Nigeria an area underrepresented in the indoor dust literature and in the simultaneous assessment of three priority metals with distinct toxicological profiles (neurotoxic Pb, nephrotoxic and carcinogenic Cd, and carcinogenic Cr) across diverse classroom types. Unlike previous Nigerian studies focused on Lagos (Obiora *et al.*, 2020) or southern regions (Iwegbue *et al.*, 2018), this work provides the first comprehensive health risk assessment of classroom dust in the Sudan savanna zone, where Harmattan dust storms, widespread generator use, and substandard building materials create a uniquely challenging indoor environment. Compared with Mohammed *et al.* (2020), who studied residential dust in northern Nigerian universities, this study specifically targets high-occupancy academic spaces where children spend prolonged periods. Compared with Kumar *et al.* (2018) and Zhao *et al.* (2020), who studied laboratory dust in Asia, this work extends the evidence base to African university settings with distinct climatic and infrastructural conditions.

Principal contamination sources include vehicular emissions, generator exhaust, deteriorating paint and building materials, laboratory reagent use, and soil resuspension enhanced by regional dry-season dust storms.

RECOMMENDATIONS

While the current health risks are low, proactive management is recommended to prevent future accumulation and ensure long-term safety. The following specific recommendations are proposed:

i. Prioritise remediation in MPH1, MPH2, PHY LAB, and BLK A RM 1, where metal concentrations are highest.
ii. Implement wet-mopping protocols (not dry sweeping) to reduce dust resuspension.
iii. Install air filtration units in high-traffic classrooms (MPHs, laboratories).
iv. Relocate or enclose generator sheds; transition to solar power where feasible.
v. Renovate older buildings with lead-free paints and sealants; install double-glazed windows to reduce outdoor dust infiltration.
vi. Conduct biannual indoor dust monitoring in all academic buildings, with mandatory reporting to NESREA.
vii. Establish Nigerian indoor dust quality standards aligned with Dutch/WHO guidelines.
viii. Launch awareness campaigns for students and staff on handwashing, shoe removal at entrances, and minimising hand-to-mouth contact in classrooms.

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