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Elemental Profiling, Pollution and Health Risks Assessments of Classroom Dust from Selected Nursery and Kindergarten Schools Ogun State, Nigeria

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Knowing the concentration of elements in children's classroom dust and the associated ecological and health risks is essential in preventing and controlling possible elemental poisoning. Dust samples were collected from 37 nursery and kindergarten classrooms across three local government areas in Abeokuta, Nigeria, and assessed for elemental concentrations using X-ray fluorescence (XRF) spectrophotometry. The hazard and the cancer risk indexes were estimated using the geo-accumulation index (I_{geo}) and health risks posed to children. The highest mean concentrations (mg/kg) of Ca, Fe, K, and Ti ranged between 4034.22–15995.09, 1758.95–2409.62, 5146.66–8996.75, and 730.96–1140.38, respectively. About 33.33% of the monitored metals displayed I_{geo} values within the moderately polluted and extremely polluted categories in Abeokuta South and North. All the monitored locations were strongly polluted with Ca, Fe, K and Ti, including arsenic at Abeokuta South. Metals with high pollution ($C_f > 6$) were Ca, Fe, Co, As, K, Ti and Ge in Abeokuta South. Ca, Fe, Co, As, K, Sc, Ti and Ge in Abeokuta North; and Ca, Fe, As, K, Sc, Ti and Ge at Odeda. Arsenic levels were 128.42 (considerable), 2934.27 (very high) and 179.33 (high) for the ecological risk factors. Dust samples for Abeokuta South and North posed the least and greatest ecological risks, respectively, and the risk potentials of arsenic across all the locations were in the ecologically risky ranges. However, hazard indexes < 1 were recorded across the monitored sites, indicating no immediate non-carcinogenic health risks, while cancer risks for Co, Ni, As, and Cr were < 1.0E–04, respectively, depicting no significant carcinogenic risk. This study concluded that the levels of elements monitored do not pose any health risk to the children but are of concern to the ecosystem. Therefore, policies on locating schools in areas with minimum anthropogenic pollution should be formulated and continuous cleaning of classroom surfaces should be encouraged.

Keywords: dust, metal pollution, health, children, cancer risk.

Introduction

Profiling the levels of elements, especially metals, in the natural environment are of significant concern due to their non-biodegradability and toxic health effects. The principal and natural sources of metals in the environment are rocks and soils through pedogenesis (Fairbrother et al., 2007; Alloway, 2013). The air-driven specks of dust may be deposited on indoor surfaces (Darus et al., 2012) through impaction, sedimentation, and interception (Poggio et al., 2009; Addo et al., 2012). The composition of dust is complex, including organic, inorganic, and microbial entities. The different constituents are released into the environment and transported away from production sources through wind action (Kurt-Karakus, 2012). With recent environmental attention, soils and dust have become essential indicators for diagnosing environmental pollution and human health impacts (Davydova, 2005).

Each year, 6.7 million premature deaths are attributed to the consequences of ambient and home air pollution. Living with chronic obstructive pulmonary disease (COPD), lung cancer, ischemic heart disease, stroke, and other non-communicable diseases is worsened by indoor air pollution. Reduced ventilation exacerbates the global issue of poor indoor air quality. It is important to consider how well a ventilation system can modify the air in each area and get rid of any indoor pollution that is already present (Hormigos-Jimenez et al., 2018). The airflow pattern, which depicts how the air flows inside the indoor area during ventilation, has an impact on how the air is distributed, and pressure gradients (either naturally occurring or artificially created) have an impact as well (Kwon et al., 2011). Various health problems, including cancer, heart disease, cognitive deficiencies, and respiratory illnesses, can be brought on by both short- and long-term exposure to indoor air pollution. A single exposure to a pollutant or repeated exposure may cause some health problems to manifest quickly. Vulnerable populations, including children, teenagers, and the elderly, might suffer harm from poor indoor air quality (Tsakas et al., 2011; Cincinelli and Martellini, 2017).

Humans are exposed to metals from metal-ladened dust or particle by-products from industrial, municipal, commercial and agricultural activities through inhalation (Popoola et al., 2012), ingestion (Morais et al., 2012) by intentional or unintentional consumption of poorly washed raw fruits and vegetables, and dermal by absorption through the skin pores (Han et al., 2017). Whichever exposure route, once metals gain access to the body system, they get distributed to various organs like the kidney, liver, heart, brain, and bones (Morais et al., 2012). The inhalation of toxic elements through the numerous tiny air sacs allows deep transport into the lungs and the bloodstream, initiating, aggravating, and becoming co-factors of diseases of the internal organs (Tong and Lam, 2000; Gbadebo and Bankole, 2007).

Although living organisms require different measures of metals (Kabata-Pendias, 2011), the toxicity and resultant health impacts of metals depend on many factors, such as the age of the exposed person, type of metal, route of exposure, and concentration or dose and exposure duration. Some metals have already been known and classified as mutagens and carcinogens with various negative impacts on internal organs (Olujimi et al., 2015). For instance, Borgman et al. (2005) and Pandey and Madhuri (2014) have reported that Cd, Hg, Pb, Cr and As are highly poisonous, while Hu et al. (2017) reiterate the classification of As, Cd, Cr and Ni as being Class B1 carcinogens. Similarly, Cd accumulation may affect children and adults (Schoeters et al., 2006) and possess a mechanism to induce cancer (Joseph, 2009). Cu and Fe are referred to as essential elements, but the harmful impacts of high doses and long-term exposure have been reported by Lambert et al. (2000) and ATSDR (2004).

People in Nigeria and other West African countries are exposed to metals, especially having contact with dust from November to March each year. It is already reported that dust emanates from the dynamic interaction of wind and atmospherically suspended particles often disturbed by wind and human activities (Dimari et al., 2008). In addition, geographical locations have proved to correlate with heavy metals in dust samples (Nkansah et al., 2015). Anthropogenic activities will affect the soil and dust of schools in the surrounding areas. For instance, the buildup of trace metals in x10-waste recycling facilities can considerably increase the levels in soil and dust, which could severely influence human health, especially in vulnerable groups like children and pregnant women (Yekeen et al., 2016).

People spend most of their time indoors, such as in offices, schools, and homes (Jamaludin et al., 2017). Adebamowo et al. (2006) revealed the substantial levels of Pb in house paints manufactured and sold in Nigeria. Children are most vulnerable because they readily absorb metals due to the development of their body systems (Aguilera et al., 2010), low resilience to poisons and hand-to-mouth habits (Acosta et al., 2009), geophagia and dust inhalation (Popoola et al., 2012). The study of dust and soils in primary schools in Lagos (Nigeria) by Durowoju et al. (2018) indicated that inhalation is the second-largest carcinogenic risk pathway of dirt and dust after ingestion. Iskandar et al. (2014) showed a high concentration of Pb in the saliva of Malaysian primary school pupils. Similarly, a Pb concentration of > 10 µg/dL was recorded in about 70% of children between 6 and 35 months old (Jusko et al., 2008). Meanwhile, urine samples of schoolchildren in Dares Salaam (Tanzania) showed higher Pb and Cu levels in children whose schools are in industrial areas. In contrast, Zn and Fe showed higher concentrations in children whose schools are in non-industrial areas (Mahugija et al., 2018).

Chronic low-level exposure to heavy metals has been linked to several adverse effects, including the depletion of iron and vitamin C reserves, anaemia, immunosuppression, promotion of kidney impairment and neurotoxicity, vascular problems, and epidermal hyperpigmentation and keratosis (Yu et al., 2006; Navarro and Rohan, 2007; Mishra, 2009). Due to the severity, irreversibility, and protracted time needed to develop clinical symptoms, these manifestations harm human health. Furthermore, exposure to heavy metals, including Cd, As, and Pb, can cause carcinogenesis in many organs, including the skin, liver, lungs, and bladder. According to several studies (Xu et al., 2012; Huo et al., 2014; Liu et al., 2014; Xu et al., 2015; Zeng et al., 2016), trace metal contaminants like cadmium (Cd), chromium (Cr), and lead (Pb) have cumulative effects that result in renal illness, cancer, and many other harmful health impacts, including growth retardation in children.

Most studies on heavy metals have focused on urban roadside dust, elemental composition and source apportionment (Popoola et al., 2012, Addo et al., 2012); there are few works on metals in the dust from classroom facilities for toddlers in Nigeria, especially in Ogun State. The study by Olujimi et al. (2015) seems to be the only visible article available. Previous works focused on a limited number of metals, Pb, Cr, Cd and Mn. However, this study is different because it focuses on pupils in nursery and kindergarten classes of vulnerable and susceptible age groups. They cannot moderate what they ingest, inhale, and absorb through their skin.

Metals in the environment may get introduced into classrooms through wind action from dust on footpaths which kids walk to school and play around within the school compound/area (Kurt-Karakus, 2012). Thus, this study assessed the pollution levels in classroom dust through ecological risk indexes (geo-accumulation and pollution load index) and health risks assessment (carcinogenic and non-carcinogenic) to children through the three exposure routes. Thus, the objectives of this study were to (1) assess the level of contamination of classroom dust using pollution indexes, (2) assess the health risks through the exposure pathways and (3) identify which of the profiled elements poses the greatest threat to human health and ecosystem.

Methods

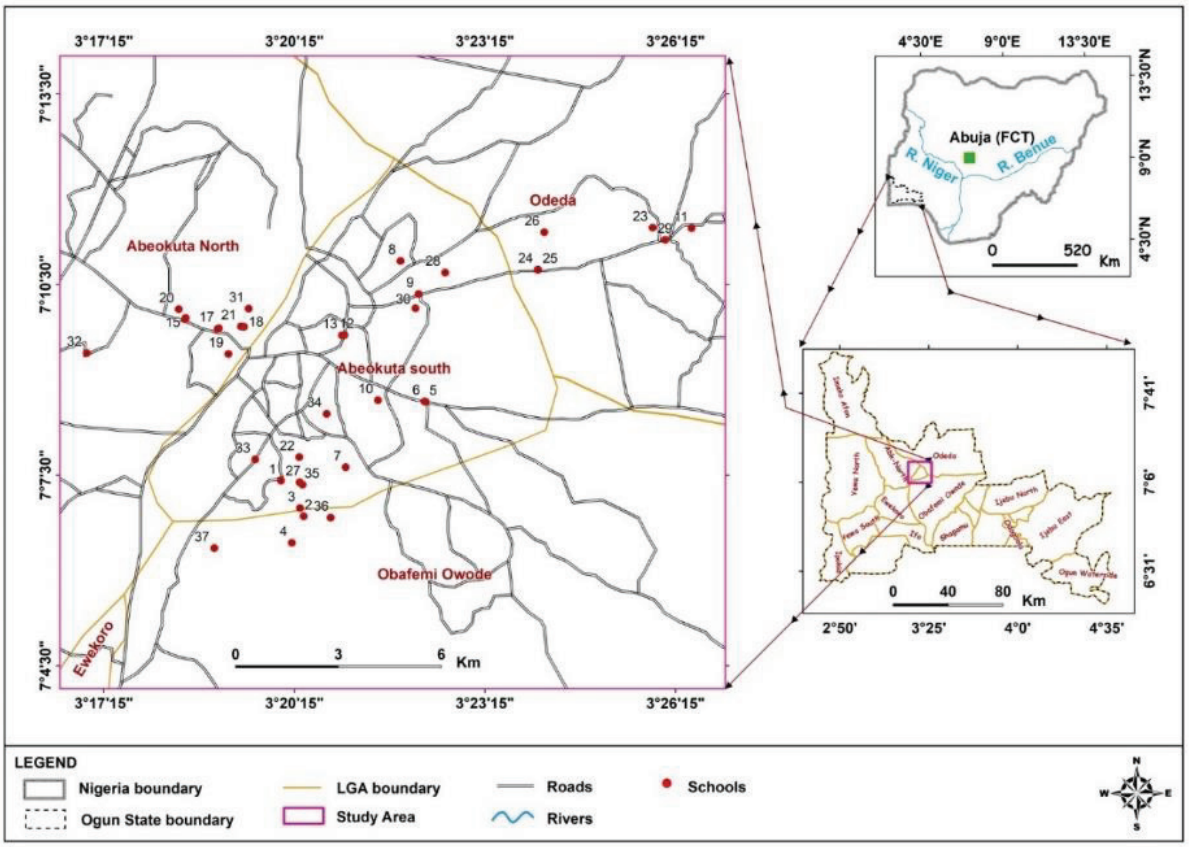
Study area

Abeokuta is the capital city of Ogun State, a fast-growing city and economy due to its proximity to Lagos, the business hub of Nigeria. The city is endowed with natural rocks, making quarry industries highly lucrative and increasing heavy-duty vehicle inflow and outflow. The state also acts as a link between Lagos and other states of the country. Abeokuta is the largest city in Ogun State and lies within latitudes 6° N to 8° N and longitudes 2° 30′ E and 5° E in southwestern Nigeria (*Fig. 1*). The city has many emerging industries, commercial centres and schools of various levels of learning, hospitals and residential buildings. For road accessibility, most schools are situated very close to central and access roads.

Sample collection and processing

Thirty-seven (37) schools located along intracity and linkage access roads cutting through Abeokuta South, Abeokuta North, and Odeda Local governments of Ogun State were sampled, representing locations 1, 2, ... up to 37, respectively. These schools were selected based on the consent of the school's head to participate in the research. In each selected school, dust samples were swept from floors, windows, shelves, and other teaching materials in the nursery and kindergarten classrooms using a small plastic brush (20 cm long) and a small

Fig. 1. *Map of Ogun State showing the locations of the schools within the study*



stainless steel (50 mL size) scoop. Most of the sampled schools used natural ventilation by opening windows and doors. Few ones that had ceiling fans could not use them because of lack of electricity. The dust samples collected from classrooms in each school were bulked to represent each school and labelled. The samples were collected between November 2019 and January 2020. Initial sieving with a 2.0 mm sized sieve was done to remove large particles, then air dried and then sieved again with a 0.5 mm sized sieve; subsequently pulverised before making a 13 mm pellet from the bulk.

X-ray fluorescence spectroscopy (XRF) is a simple, fast, safe, non-destructive analytical technique. Therefore, by avoiding the potential for inaccuracies caused by incomplete dissolution and large dilutions, the complete analysis by XRF helps to ensure the accuracy and reliability of results. Heavy metal contents of dust samples were analysed at the Center for Energy Research and Development (CERD) Obafemi Awolowo University, Nigeria, using a portable AMPTEK Energy Dispersive Fluorescence (EDXRF) obtained from the USA. The EDXRF instrumentation includes the X-ray source, sample holder, detector, current and voltage amplifier, read-out computer and multi-channel analyser (MCA). A 300 mg finely pulverised sample was pressed into pellets using the Calver® model manual pelletising machine made in the USA. Each sample was inserted into the sample holder of the XRF system for simultaneous irradiation and spectrum acquisition. The irradiation was done with an X-ray fluorescence spectrometer equipped with a silver (Ag) anode at a voltage of 25kV and a current of 50 μA for 1000 counts in an external chamber setup. The equipment model is PX 2CR Power Supply, Amplifier for XR-100CR Si-pin Detector and pocket MCA 8000A. The solid-state Si-pin detector system detected characteristic X-rays from each sample, and spectrum acquisition was done using an Amptek model multi-channel analyser for display in the read-out system. Elemental analysis was done using the thick target mode of the International Atomic Energy Agency (IAEA) software (Quantitative Analysis of X-ray Iterative Least (Q-Axil) square.

Quality control

Before the analysis, the instrument calibration was checked with certified reference Soil-7 standard (purchased from NIST, Gaithersburg, USA). The instrument reproducibility was checked using in-house prepared standards of Ca, Fe, Pb, Zr, Sr, and K, while the results are presented in *Table 1*.

Table 1. *Elemental concentrations of certified reference materials Soil-7 standard*

Element	Certified Values (ppm)	Experimental Values (ppm)
Ca	163000	162328
Fe	25700	25670
Pb	60	56
Zr	185	187
Sr	108	107
K	12100	12130

Note: Wt %=ppm/10000

Pollution assessment indexes

Literature has reported several estimation parameters in assessing ecological risks consequent to heavy metals in dust, soils, and sediments. Hence, we characterised the ecological risks of heavy metals in the classroom dust samples using geoaccumulation (I_{geo}) and ecological risk indexes (Er_i).

Geoaccumulation index (I_{geo})

The geo-accumulation index (I_{geo}) evaluates the degree of metal pollution in dust samples. It is done by balancing the estimated metal levels (C_n) with background/reference concentrations (B_n) (Hakanson, 1980; Abrahim and Parker, 2008; Ogunkunle and Fatoba, 2014) with the use of a correction factor (a constant – 1.5) to minimise the effects of possible lithogenic variations (Gupta et al., 2014; Olujimi et al., 2015; Ogundele et al., 2019).

$$I_{geo} = \mathrm{Log}_2\left(\frac{C_n}{1.5\ x\ B_n}\right) \quad (1)$$

Where: C_n – estimated metal levels; B_n – background/reference concentrations.

The I_{geo} values are interpreted as follows:

$I_{geo} < 0$: unpolluted;

$0 < I_{geo} < 1$: unpolluted to moderately polluted;

$1 < I_{geo} < 2$: moderately polluted;

$2 < I_{geo} < 3$: moderately to strongly polluted;

$3 < I_{geo} < 4$: strongly polluted;

$4 < I_{geo} < 5$: strongly to extremely polluted;

$I_{geo} > 5$: extremely polluted (Ogundele et al., 2019).

Ecological risk index

The potential of heavy metals within the dust samples to elicit some ecological effects was assessed using the ecological risk index (Er_i). Er_i measures the potential ecological toxicity of each heavy metal based on its relative toxicity, where C_n is the heavy metal concentration in dust samples, and B_n is the concentration of the heavy metal in the reference sample. *Eri* measures the potential risk of the studied heavy metals within the dust sample (Soliman et al., 2015; Olatunde et al., 2020). Five metals were included in estimating Er_i, and the toxic response factors (TRF) for As, Cr, Cu, Ni and Zn are given as 10, 2, 5, 5 and 1, respectively (Wan et al., 2016; Tepanosyan et al., 2018). The degree of ecological risk potential posed by heavy metals was assessed as follows:

$Er_i < 40$: low risk;

$40 < Er_i \leq 80$: moderate risk;

$80 < Er_i \leq 160$; considerable risk;

$160 < Er_i \leq 320$: high risk;

$Er_i > 320$: very high risk.

An ER_i less than 150 indicates a low potential ecological risk from the studied heavy metals, a moderate risk when $150 < ER_i < 300$, a considerable risk when $300 < ER_i < 600$ and a high risk when $ER_i > 600$ (Tepanosyan et al., 2018).

$$Er_i = TRF * \left(\frac{C_n}{B_n}\right) \quad (2a)$$

Where: C_n – the estimated metal levels; B_n – background/reference concentrations; *TRF* – toxic response factor.

$$\mathrm{ERi} = \sum_{i=1}^{n} \mathrm{Er_i} \quad (2b)$$

Where: ERi is determined as the summation of all risk factors for metals in soil; *Eri* is the individual potential ecological risk factor.

Health risks assessments

The hazard and cancer risk indexes indicated the health risk posed by the heavy metals in the dust samples.

Non-carcinogenic risk assessment

The non-carcinogenic health risks are based on calculating the intake of metals in the contaminated dust through the three possible routes (inhalation, ingestion and absorption) in quantity capable of posing adverse health effects, especially chronic nature, to the children.

The first variable of concern is the exposure-point concentration ($C_{95\%UCL}$) which represents the estimate of reasonable maximum exposure and is estimated as the upper limit of the 95% confidence limit for the mean values of each monitored element. The exposure point was calculated using *Equation 3*, where X refers to the arithmetic mean of the log-transformed data and S is the standard deviation of the log-transformed data. Also, H is the value from the H-statistic table (Gilbert, 1987), and n is the number of samples (Olujimi et al., 2015). It subsequently represents the C used to calculate the other non-carcinogenic risk variables.

$$C_{95\%UCL} = \exp\left(\mathrm{X} + 0.5 \times S^2 + \frac{\mathrm{S} \times \mathrm{H}}{\sqrt{n}-1}\right) \quad (3)$$

In addition, the average daily dose (ADD) was calculated using *Equations 4a, b*, and *c* for ingestion, inhalation, and dermal routes, respectively. ADD (mg/kg/day) is the risk dosage based on the measured concentration of elements computed in mg/kg/day for the children. All the in-built parameters are described and referenced.

$$ADD_{ing} = \mathrm{C} \times \left(\frac{\mathrm{IngR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}\right) \times 10^{-6} \quad (4a)$$

$$ADD_{inh} = \mathrm{C} \times \left(\frac{\mathrm{InhR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{PEF} \times \mathrm{BW} \times \mathrm{AT}}\right) \quad (4b)$$

$$ADD_{dermal} = \mathrm{C} \times \left(\frac{\mathrm{SL} \times \mathrm{SA} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}\right) \times 10^{-6} \quad (4c)$$

By dividing the average daily dose (ADD) of each heavy metal by its unique reference dose/reference concentration (RfD/RfC) for each of the exposure routes, we were able to calculate the hazard quotients (HQ1, 2, and 3) for the heavy metals monitored for ingestion, inhalation, and dermal risks, respectively. The embedded functions used for calculating the HQ (USEPA, 2011a; Olujimi et al., 2015) are described in *Table 2*.

$$HQ1 = \frac{ADD_{ing}}{RfD_{ing}} \quad (5a)$$

$$HQ2 = \frac{ADD_{inh}}{RfC_{inh} \times 100\ \mu g\ mg^{-1}} \quad (5b)$$

$$HQ3 = \frac{ADD_{dermal}}{RfD_{dermal} \times ABS} \quad (5c)$$

The hazard index is the final value for the non-carcinogenic risk assessment. The summation of the individual HQ for each metal hazard quotient gives the HI.

$$\mathrm{HI} = \sum_{i=1}^{n} (HQ)i \quad (6)$$

HI > 1 is above the acceptable limit and will produce non-carcinogenic health effects, whereas HI < 1 is within the acceptable limit. Therefore, the non-carcinogenic risk scale is classified as negligible (risk level 1; HI ≤ 0.1), low risk (risk level 2; HI ≥ 0.1 < 1), medium risk (risk level 3; HI ≥ 1 < 4) and high risk (risk level 4; HI > 4). The possibility of having long-term health hazards tends to increase as the HI value spikes (Wang, 2012; Ogundele et al., 2019).

Cancer risk (CR) was quantified and characterised separately from non-carcinogenic effect (HQ) using *Equation 7*. A person's cancer risk is the likelihood of developing cancer due to lifetime exposure to a potentially carcinogenic hazard (Olujimi et al., 2015). USEPA categorises the likelihood of carcinogenic risks as < 10^{-4}, 10^{-4}–10^{-6}, and > 10^{-6} to be negligible, acceptable, sufficiently large, and necessitating remediation, respectively (Gu and Gao 2018; Ogundele et al., 2019). However, the generally accepted value is ≤ 1 × 10^{-6}, which means that, on average, the chance is that approximately 1 per 1 000 000 will develop cancer because of exposure to the carcinogen (Lim et al., 2008; Adamu et al., 2014).

$$CR = ADD_{ing} \times SF_o = IUR \times ADD_{inh} = \\ = ADD_{dermal} \times \left(\frac{SF_o}{ABS}\right) \quad (7)$$

Table 2. *Exposure parameters used for the health risks assessment through different exposure pathways*

Parameters	Symbol	Value	References
Heavy metal concentration	$C_{95\%UCL}$	The upper limit of the 95% confidence limit of the mean concentration of each metal in this study (mg/kg)	Olujimi et al. (2015)
Ingestion rate	IngR	200 mg	USEPA (2011a)
Exposure duration	ED	6 years	WHO (2015)
Exposure frequency	EF	180 days/year	Li et al. (2013)
Bodyweight	BW	15 kg	USEPA (2001); WHO (2015)
Average time for non-carcinogenic	AT	ED (6) x 365 days= 2190	USEPA (2001)
Conversion factor	CF	$1{\cdot}10^{-6}$ kg/mg	Zheng et al. (2015)
The surface area of the skin	SA	2800 cm^2	Hu et al. (2012)
Skin adherence factor	SL	0.07 mg/cm^2/day	USEPA (2001)
Dermal absorption factor	ABS	0.001	Du et al. (2013)
Inhalation rate	InhR	7.6 mg/kg/day children,	Olujimi et al. (2015)
Particle emission factor	PEF	$1.36{\cdot}10^{-9}$ m^3/kg	USEPA (2001)
Reference dose	RfD	mg/kg/day	USEPA (2001)
Reference concentration	RfC	mg/m^3	USEPA (2011b)
Oral slope factor	SF_o	(mg/kg/day)	USEPA (2011b)
Inhalation unit risk	IUR	µg/m^3	USEPA (2011b)

Results and Discussion

Heavy metal concentrations across the locations

Table 3 presents in mg/kg the mean, minimum, maximum, standard deviations, and analysis of variance of means at $P < 0.05$. The distribution patterns of the monitored metals are Ca > K > Fe > Ti > Mn > Co > Sc > V > Cr > Ni > Zn > Se > Ge > As > Br > Rb > Cu > Ga > Sr at Abeokuta South; K > Ca > Fe > Ti > Mn > V > Sc > Ni > As > Cr > Se > Zn > Co > Ge > Br > Rb > Cu > Ga > Sr at Abeokuta North; and Ca > K > Fe > Ti > Sc > Mn > V > Cr > Zn > Ni > Co > Se > As > Ge > Rb > Br > Cu > Ga > Sr at Odeda. The peak metal levels at Abeokuta South, Abeokuta North and Odeda were 21.05%, 36.84% and 42% of the metals, respectively. The ANOVA revealed significant variations among the mean values of Ca, Co, Ni, Zn, As, and K across the locations. About 31.58% of the metals (Co, As, Cr, Sc, Ge and Se) seem to be from anthropogenic sources because the observed levels are higher than the ones from natural soils and crust.

The average Ca concentration ranged from 4034.22 mg/kg at Abeokuta North to 15995.09 mg/kg at Odeda. The highest mean (268.28 mg/kg) recorded in Mn was at Abeokuta South, double the levels recorded at both Abeokuta North and Odeda. However, there appears to be no significant difference in the Mn levels monitored across the locations. Fe concentration ranged from 1758.95 mg/kg at Abeokuta North to 2409.62 mg/kg at Odeda, with no statistically significant difference. Co ranged from 27.13 mg/kg at Abeokuta North to 153.90 mg/kg at Abeokuta South. The highest concentration (49.30 mg/kg) of nickel was at Abeokuta North, higher than the earth soil (40 mg/kg) and lower than the level in the earth crust (58 mg/kg).

This study's highest Cu concentration (12.50 mg/kg) was at Abeokuta North, while the highest mean level of Zn (42.91 mg/kg) was observed at Odeda. The observed As concentrations ranged between 14.13 mg/

kg to 40.35 mg/kg, higher than the background average for earth crust and soils. The highest As level was observed at Abeokuta North.

The highest K level (8996.75 mg/kg) was at Odeda, lower than the background average for the earth's crust and soil. The mean concentrations of Cr ranged from 36.92 mg/kg to 53.55 mg/kg, with the highest at Odeda. Cr is widely distributed across the study locations because there is no significant difference higher than the background average for the earth's crust and soil.

Scandium (Sc) ranged within 64.18–180.89 mg/kg, 6–8 times higher than the background average for the earth's crust and soil values. Similarly, the titanium (Ti) level was highest (1140.38 mg/kg) at Odeda, and lowest (730.96 mg/kg) at Abeokuta North, and these values are lower than the background average for the earth's crust and soil levels. The highest vanadium (V) level (85.39 mg/kg) was at Abeokuta North schools. The highest (24.75 mg/kg) was at Abeokuta North, and the least (14.44 mg/kg) was at Odeda. This study records the highest Se (36.37 mg/kg) across the Abeokuta North locations. Br levels ranged from 9.92 mg/kg at Odeda to 14.88 mg/kg at Abeokuta North.

For rubidium, the mean Rb ranged from 11.79 mg/kg to 14.34 mg/kg at Abeokuta South and Odeda, respectively. These values are lower than the expected background levels and within the daily Rb intake of 1 and 5 mg (Lenntech, 2017). For strontium, the highest Sr level (7.12 mg/kg) was at Abeokuta South locations, about 48 times lower than the background levels.

Table 3. *Mean values for each metal in dust samples for each sampled location (mg/kg)*

Elements	Abeokuta South (n = 23)				Abeokuta North (n = 8)				Odeda (n = 6)			
	Mean	Min	Max	Stddev	Mean	Min	Max	Stddev	Mean	Min	Max	Stddev
Ca	9140.70^{ab}	961.16	48720	11729.84	4034.22^{a}	1.21	9351.43	18621.25	15995.09^{c}	4973.3	37490	13520.9
Mn	268.28	18.26	4292	877.57	96.84	65.27	155.96	386.1	116.01	65.54	237.94	62.8
Fe	1887.73	89.29	4543.94	888.66	1758.95	1020.95	3572.31	6916.95	2409.62	1631.3	3230.74	641.66
Co	153.90^{a}	15.17	539.23	134.35	27.13^{b}	10.7	70.91	106.09	30.82^{b}	24.64	44.12	6.93
Ni	31.00^{a}	11.14	59.32	13.37	49.30^{b}	32.67	100.73	192.22	32.29^{a}	17.63	45.87	9.84
Cu	10.11	3.12	46.98	10.53	12.5	4.64	30.13	49.35	9.69	5.36	13.72	3.59
Zn	22.27^{a}	7.78	49.66	11.41	36.31^{a}	16.61	82.38	142.98	42.91^{b}	16.41	115.57	36.31
As	14.13^{a}	1.75	69.24	16.57	40.35^{b}	1.84	108.98	163.39	19.73^{a}	3.78	37.24	13.62
K	5608.49^{a}	1393.96	13820	3124.1	5146.66^{a}	3232.66	9211.2	20399.36	8996.75^{b}	4974	16910	4096.16
Cr	39.88	9.27	223.83	42.62	36.92	25.35	74.53	143.83	53.55	21.1	116.97	39.45
Sc	128.75	0	1429.77	308.66	64.18	31.79	164.44	278.06	180.89	54.05	530.7	180.9
Ti	865.64	60.95	2405.17	655.94	730.96	270.72	1431.81	2942.5	1140.38	592.22	1723.16	444.63
V	67.4	9.27	223.83	43.4	85.39	56.83	152.71	337.34	68.21	40.85	109.67	24.92
Ga	8.65	0	48.95	10.51	11.23	5.83	25.29	43.98	7.47	5.7	9.82	1.8
Ge	15.84	1.96	69.24	14.17	24.75	12.87	57.02	96.69	14.44	8.66	22.25	5.12
Se	21.22	4.69	53.93	13.05	36.37	20.6	103.47	138.52	23.1	10.59	30.86	7.19
Br	12.01	3.43	43.03	8.63	14.88	3.03	41.95	59.03	9.92	6.09	13.75	2.66
Rb	11.79	0	29.98	10.23	13.25	4.73	50.08	75.09	14.34	0	36.82	13.66
Sr	7.12	0	33.82	10.7	0	0	0	0	6.39	0	38.34	15.65

Same letters along the rows mean no significant different at P > 0.05, Duncan Multiple Range Test

Table 4. *Pollution assessments (Geoaccumulation and Ecological risk indexes)*

Metals	$I_{geo}1$	$I_{geo}2$	$I_{geo}3$	TRF	Er_i1	Er_i2	Er_i3
Ca	10.31	12.13	11.12				
Mn	–2.79	–1.26	–4				
Fe	7.65	10.55	8				
Co	2.06	2.55	–0.26				
Ni	–2.07	1.6	–2.01	5	1.79	22.75	1.86
Cu	–3.23	0.07	–3.29	5	0.8	7.89	0.77
Zn	–2.39	1.31	–1.45	1	0.29	3.72	0.55
As	3.1	7.61	3.58	10	128.4	2934.27	179.33
K	11.46	14.33	12.14				
Cr	–2.51	0.38	–2.09	2	0.53	3.9	0.71
Sc	1.74	3.74	2.23				
Ti	10.23	12.99	10.63				
V	–2.09	1.25	–2.08				
Ga	–1.62	1.76	–1.83				
Ge	2.72	6.37	2.59				
Se	–1.82	1.96	–1.7				
Rb	–2.66	1.02	–2.38				
Sr	–5.88	0	–6.04				
ER_i					131.8	2972.54	183.22

Ca, Fe, K, Na, and Ti have been similarly identified in classroom dust samples as dominant elements in previous studies (Gemenetzis et al., 2006; Tran et al., 2012; Olujimi et al., 2015). It has been reported that high concentrations of Ca in classroom dust are associated with chalk usage (Fromme et al., 2008; Tran et al., 2012; Olujimi et al., 2015). Brake or tyre dust has been linked with Zn pollution (Harrison et al., 2012; Taiwo et al., 2014a). Also, the emission of vanadium has been traced to vehicular emission through the combustion of heavy fuel (Taiwo et al., 2014b). However, the study by Taiwo et al. (2016) confirmed that dust from unpaved roads had significantly higher Zn concentrations than paved roads. The study of Qiao et al. (2013) identified high Zn and Cu concentrations as environmental indicators for urbanisation. Similarly, this claim was also supported by Adewunmi et al. (2017) in Ibadan (Nigeria), where between 2- to 4-times greater values were found for Cu, Zn and Fe in urban schools than semi-rural ones. However, spatial mapping carried out by Ogunkunle and Fatoba (2014) has traced Zn and Cr soil enrichment to cement production activities. It is worth noting that Fe, Cu, Cr and Ni were detected in high quantity around quarry sites in Ikolx10-Ekiti (Nigeria) (Ayodele et al., 2014). Many quarry sites exist in and around Abeokuta environs due to the abundance of quartzite gneiss complex, which produces good granite materials (Oguntoke et al., 2009). Similarly, Olujimi et al. (2015) suggested that the possible sources of pollution in these study areas may be linked to cement industries at Ibese and Ewekoro, welding activities, and construction works around the sites. Durowoju et al. (2018) also affirmed that high concentrations of heavy metals could be because of the probable nearness of the schools to bus stops, uncontrolled auto workshops, gas stations, industrial facilities and paint chippings.

Pollution assessments

I_{geo}, Er_i and ER*i* of the studied sites are presented in *Table 4*. In Abeokuta South (1) and Odeda (3), 55.56% and 61.11% of the monitored metals have negative I_{geo} values and are unpolluted. Meanwhile, at Abeokuta North (2), 33.33% of the monitored metals fall within the moderately polluted and extremely polluted categories. All the monitored locations are unpolluted concerning Mn and strongly polluted concerning Ca, Fe, K, and Ti with As at Abeokuta North. The mean I_{geo} level for As among the monitored classified carcinogens (Co, Ni, As and Cr) is the highest, ranging between 3.10–7.61.

The Er_i calculated based on the TRF of As, Cr, Cu, Ni, Pb, and Zn also showed that only As was relatively significant across the locations with a value of 128.42 (considerable), 2934.27 (very high), and 179.33 (high) ecological risk potential, respectively. In addition, the ER*i* depicted low, very high, and considerable in locations 1, 2, and 3, respectively.

Health risks assessments

The exposure assessment results represented by the average daily doses through the ingestion, inhalation and dermal used to calculate both cancer and non-cancer risks are presented in *Table 5.*

Table 6 shows that the non-carcinogenic and cancer risk values (HI) are < 1, indicating no immediate non-carcinogenic health risks. For the non-carcinogenic ef-

Table 5. *Assessment of the exposure to mg/kg/day of elements via inhalation, ingestion, and dermal routes*

Elements	ADD inhalation			ADD ingestion			ADD Dermal		
	mg/kg/day								
Locations	1	2	3	1	2	3	1	2	3
Ca	$1.10{\cdot}10^{-6}$	$3.90{\cdot}10^{-6}$	$1.93{\cdot}10^{-6}$	0.06	0.21	0.11	$5.41{\cdot}10^{-4}$	$1.91{\cdot}10^{-3}$	$9.47{\cdot}10^{-4}$
Mn	$3.24{\cdot}10^{-8}$	$9.36{\cdot}10^{-8}$	$1.40{\cdot}10^{-8}$	$1.76{\cdot}10^{-3}$	$5.09{\cdot}10^{-3}$	$7.63{\cdot}10^{-4}$	$8.82{\cdot}10^{-4}$	$4.58{\cdot}10^{-5}$	$6.87{\cdot}10^{-6}$
Fe	$2.28{\cdot}10^{-7}$	$1.70{\cdot}10^{-6}$	$2.91{\cdot}10^{-7}$	$1.24{\cdot}10^{-2}$	0.09	0.02	$6.21{\cdot}10^{-3}$	$8.33{\cdot}10^{-4}$	$1.43{\cdot}10^{-4}$
Co	$1.86{\cdot}10^{-8}$	$2.62{\cdot}10^{-8}$	$3.73{\cdot}10^{-9}$	$1.01{\cdot}10^{-2}$	$1.43{\cdot}10^{-3}$	$2.03{\cdot}10^{-4}$	$5.06{\cdot}10^{-4}$	$1.28{\cdot}10^{-5}$	$1.82{\cdot}10^{-6}$
Ni	$3.75{\cdot}10^{-9}$	$4.77{\cdot}10^{-8}$	$3.90{\cdot}10^{-9}$	$2.04{\cdot}10^{-4}$	$2.59{\cdot}10^{-3}$	$2.12{\cdot}10^{-4}$	$1.02{\cdot}10^{-4}$	$2.33{\cdot}10^{-5}$	$1.91{\cdot}10^{-6}$
Cu	$1.22{\cdot}10^{-9}$	$1.21{\cdot}10^{-8}$	$1.17{\cdot}10^{-9}$	$6.65{\cdot}10^{-5}$	$6.57{\cdot}10^{-4}$	$6.37{\cdot}10^{-5}$	$3.32{\cdot}10^{-5}$	$5.92{\cdot}10^{-6}$	$5.74{\cdot}10^{-7}$
Zn	$2.69{\cdot}10^{-9}$	$3.51{\cdot}10^{-8}$	$5.19{\cdot}10^{-9}$	$1.46{\cdot}10^{-4}$	$1.91{\cdot}10^{-3}$	$2.82{\cdot}10^{-4}$	$7.32{\cdot}10^{-5}$	$1.72{\cdot}10^{-5}$	$2.54{\cdot}10^{-6}$
As	$1.71{\cdot}10^{-9}$	$3.90{\cdot}10^{-8}$	$2.38{\cdot}10^{-9}$	$9.29{\cdot}10^{-5}$	$2.12{\cdot}10^{-3}$	$1.30{\cdot}10^{-4}$	$4.64{\cdot}10^{-5}$	$1.91{\cdot}10^{-5}$	$1.17{\cdot}10^{-6}$
K	$6.78{\cdot}10^{-7}$	$4.98{\cdot}10^{-6}$	$1.09{\cdot}10^{-6}$	$3.69{\cdot}10^{-2}$	0.27	$5.92{\cdot}10^{-2}$	$1.84{\cdot}10^{-2}$	$2.44{\cdot}10^{-3}$	$5.32{\cdot}10^{-4}$
Cr	$4.82{\cdot}10^{-9}$	$3.57{\cdot}10^{-8}$	$6.47{\cdot}10^{-9}$	$2.62{\cdot}10^{-4}$	$1.94{\cdot}10^{-3}$	$3.52{\cdot}10^{-2}$	$1.31{\cdot}10^{-4}$	$1.75{\cdot}10^{-5}$	$3.17{\cdot}10^{-6}$
Sc	$1.56{\cdot}10^{-8}$	$6.21{\cdot}10^{-8}$	$2.19{\cdot}10^{-8}$	$8.47{\cdot}10^{-4}$	$3.38{\cdot}10^{-3}$	$1.19{\cdot}10^{-2}$	$4.23{\cdot}10^{-4}$	$3.04{\cdot}10^{-5}$	$1.07{\cdot}10^{-5}$
Ti	$1.05{\cdot}10^{-7}$	7.07·10–^{7}	$1.38{\cdot}10^{-7}$	$5.69{\cdot}10^{-3}$	$3.85{\cdot}10^{-3}$	$7.49{\cdot}10^{-2}$	$2.85{\cdot}10^{-3}$	$3.46{\cdot}10^{-4}$	$6.75{\cdot}10^{-5}$
V	$8.15{\cdot}10^{-9}$	$8.26{\cdot}10^{-8}$	$8.24{\cdot}10^{-9}$	$4.43{\cdot}10^{-4}$	$4.49{\cdot}10^{-3}$	$4.49{\cdot}10^{-4}$	$2.22{\cdot}10^{-4}$	$4.04{\cdot}10^{-5}$	$4.04{\cdot}10^{-6}$
Ga	$1.05{\cdot}10^{-9}$	$1.09{\cdot}10^{-8}$	$9.02{\cdot}10^{-10}$	$5.69{\cdot}10^{-5}$	$5.91{\cdot}10^{-4}$	$4.91{\cdot}10^{-5}$	$2.84{\cdot}10^{-5}$	$5.32{\cdot}10^{-6}$	$4.42{\cdot}10^{-7}$
Ge	$1.92{\cdot}10^{-9}$	$2.39{\cdot}10^{-8}$	$1.74{\cdot}10^{-9}$	$1.04{\cdot}10^{-4}$	$1.30{\cdot}10^{-3}$	$9.49{\cdot}10^{-5}$	$5.21{\cdot}10^{-5}$	$1.17{\cdot}10^{-5}$	$8.54{\cdot}10^{-7}$
Se	$2.56{\cdot}10^{-9}$	$3.52{\cdot}10^{-8}$	$2.79{\cdot}10^{-9}$	$1.40{\cdot}10^{-4}$	$1.91{\cdot}10^{-3}$	$1.52{\cdot}10^{-4}$	$6.98{\cdot}10^{-5}$	$1.72{\cdot}10^{-5}$	$1.37{\cdot}10^{-6}$
Br	$1.45{\cdot}10^{-9}$	$1.44{\cdot}10^{-8}$	$1.20{\cdot}10^{-9}$	$7.90{\cdot}10^{-5}$	$7.83{\cdot}10^{-4}$	$6.52{\cdot}10^{-5}$	$3.95{\cdot}10^{-5}$	$7.04{\cdot}10^{-6}$	$5.87{\cdot}10^{-7}$
Rb	$1.43{\cdot}10^{-9}$	$1.83{\cdot}10^{-8}$	$1.73{\cdot}10^{-9}$	$7.76{\cdot}10^{-5}$	$9.95{\cdot}10^{-4}$	$9.43{\cdot}10^{-5}$	$3.88{\cdot}10^{-5}$	$8.96{\cdot}10^{-6}$	$8.49{\cdot}10^{-7}$
Sr	$8.60{\cdot}10^{-10}$	0	$7.72{\cdot}10^{-10}$	$4.68{\cdot}10^{-5}$	0	$4.20{\cdot}10^{-5}$	$2.34{\cdot}10^{-5}$	0	$3.78{\cdot}10^{-7}$

Abeokuta South = 1, Abeokuta North = 2 and Odeda = 3

Table 6. *Reference doses/concentration of each element with the calculated cancer and non-cancer risk values*

Elements	Concentration (mg/kg)	RfD_{ing} (mg/kg/day)	RfC_{inh} (mg/m^3)	RfD_{der} (mg/kg/day)	HQ_{ing}	HQ_{inh}	HQ_{der}	HI	CR
Abeokuta South	$C_{95\%\ UCL}$								
Mn	0.18	0.14	$5.00 \cdot 10^{-2}$	0.14	$8.22 \cdot 10^{-6}$	$4.23 \cdot 10^{-12}$	$6.3 \cdot 10^{-6}$	$1.5 \cdot 10^{-5}$	
Fe	0.38	0.70	$9.50 \cdot 10^{-5}$	$7.90 \cdot 10^{-6}$	$3.54 \cdot 10^{-6}$	$4.81 \cdot 10^{-9}$	0.7896	0.7896	
Co	0.07	$3.00 \cdot 10^{-4}$	$5.11 \cdot 10^{-5}$	$3.00 \cdot 10^{-4}$	$1.62 \cdot 10^{-3}$	$1.75 \cdot 10^{-9}$	$1.69 \cdot 10^{-3}$	$3.31 \cdot 10^{-3}$	$8.05 \cdot 10^{-14}$
Ni	0.59	$1.10 \cdot 10^{-2}$	$5.91 \cdot 10^{-5}$	$4.00 \cdot 10^{-4}$	$3.55 \cdot 10^{-4}$	$1.21 \cdot 10^{-8}$	$2.50 \cdot 10^{-}4$	$6.10 \cdot 10^{-4}$	$1.72 \cdot 10^{-14}$
Cu	0.36	$4.00 \cdot 10^{-2}$	$3.71 \cdot 10^{-2}$	$4.00 \cdot 10^{-2}$	$5.88 \cdot 10^{-5}$	$1.17 \cdot 10^{-11}$	$8.30 \cdot 10^{-7}$	$6.00 \cdot 10^{-5}$	
Zn	0.52	0.30	0.30	0.30	$1.15 \cdot 10^{-5}$	$2.11 \cdot 10^{-12}$	$2.40 \cdot 10^{-7}$	$1.20 \cdot 10^{-5}$	
As	0.17	$3.00 \cdot 10^{-4}$	$1.50 \cdot 10^{-2}$	$3.00 \cdot 10^{-4}$	$3.62 \cdot 10^{-2}$	$1.33 \cdot 10^{-11}$	$1.50 \cdot 10^{-4}$	$3.77 \cdot 10^{-3}$	$7.13 \cdot 10^{-5}$
Cr	0.39	$3.00 \cdot 10^{-3}$	0.10	$7.50 \cdot 10^{-5}$	$8.55 \cdot 10^{-4}$	$4.71 \cdot 10^{-12}$	$1.75 \cdot 10^{-3}$	$2.60 \cdot 10^{-3}$	$2.92 \cdot 10^{-6}$
Ti	0.17	4.00	4.00	$4.50 \cdot 10^{-5}$	$2.75 \cdot 10^{-7}$	$5.05 \cdot 10^{-14}$	$6.35 \cdot 10^{-2}$	$6.35 \cdot 10^{-2}$	
Abeokuta North									
Mn	0.57	$1.40 \cdot 10^{-1}$	$5.00 \cdot 10^{-2}$	0.14	$2.66 \cdot 10^{-5}$	$1.37 \cdot 10^{-11}$	0.00642	$6.45 \cdot 10^{-3}$	
Fe	0.76	$7.00 \cdot 10^{-1}$	$9.50 \cdot 10^{-5}$	$7.90 \cdot 10^{-6}$	$7.16 \cdot 10^{-6}$	$9.72 \cdot 10^{-9}$	$6.5 \cdot 10^{-6}$	$1.4 \cdot 10^{-5}$	
Co	0.81	$3.00 \cdot 10^{-4}$	$5.11 \cdot 10^{-5}$	$3.00 \cdot 10^{-4}$	$1.77 \cdot 10^{-2}$	$1.91 \cdot 10^{-8}$	$3.9 \cdot 10^{-6}$	$1.77 \cdot 10^{-2}$	$8.80 \cdot 10^{-13}$
Ni	0.67	$1.10 \cdot 10^{-2}$	$5.91 \cdot 10^{-5}$	$4.00 \cdot 10^{-4}$	$4.01 \cdot 10^{-2}$	$1.37 \cdot 10^{-8}$	$9.4 \cdot 10^{-6}$	$4.10 \cdot 10^{-4}$	$1.95 \cdot 10^{-14}$
Cu	0.59	$4.00 \cdot 10^{-2}$	$3.71 \cdot 10^{-2}$	$4.00 \cdot 10^{-2}$	$9.76 \cdot 10^{-5}$	$1.94 \cdot 10^{-11}$	0.00024	$3.30 \cdot 10^{-4}$	
Zn	0.35	$3.00 \cdot 10^{-1}$	$3.00 \cdot 10^{-1}$	0.30	$7.74 \cdot 10^{-6}$	$1.42 \cdot 10^{-12}$	0.00516	$5.17 \cdot 10^{-3}$	
As	0.15	$3.00 \cdot 10^{-4}$	$1.50 \cdot 10^{-2}$	$3.00 \cdot 10^{-4}$	$3.18 \cdot 10^{-3}$	$1.17 \cdot 10^{-11}$	$5.7 \cdot 10^{-6}$	$3.18 \cdot 10^{-3}$	$4.14 \cdot 10^{-9}$
Cr	0.31	$3.00 \cdot 10^{-3}$	$1.00 \cdot 10^{-1}$	$7.50 \cdot 10^{-5}$	$6.75 \cdot 10^{-4}$	$3.72 \cdot 10^{-12}$	$1.3 \cdot 10^{-6}$	$6.80 \cdot 10^{-4}$	$2.43 \cdot 10^{-8}$
Ti	0.62	4.00	4.00	$4.50 \cdot 10^{-5}$	$1.03 \cdot 10^{-6}$	$1.89 \cdot 10^{-13}$	$1.6 \cdot 10^{-5}$	$1.70 \cdot 10^{-5}$	
Odeda									
Mn	0.71	0.14	$5.00 \cdot 10^{-2}$	0.14	$3.33 \cdot 10^{-5}$	$1.71 \cdot 10^{-11}$	$4.9 \cdot 10^{-8}$	$3.3 \cdot 10^{-5}$	
Fe	0.62	0.70	$9.50 \cdot 10^{-5}$	$7.90 \cdot 10^{-6}$	$5.83 \cdot 10^{-6}$	$7.92 \cdot 10^{-9}$	0.01814	$1.82 \cdot 10^{-2}$	
Co	0.35	$3.00 \cdot 10^{-4}$	$5.11 \cdot 10^{-5}$	$3.00 \cdot 10^{-4}$	$7.58 \cdot 10^{-3}$	$8.18 \cdot 10^{-9}$	$6.1 \cdot 10^{-6}$	$7.59 \cdot 10^{-3}$	$3.76 \cdot 10^{-13}$
Ni	0.65	$1.10 \cdot 10^{-2}$	$5.91 \cdot 10^{-5}$	$4.00 \cdot 10^{-4}$	$3.89 \cdot 10^{-3}$	$1.33 \cdot 10^{-8}$	$4.7 \cdot 10^{-6}$	$3.90 \cdot 10^{-4}$	$1.89 \cdot 10^{-14}$
Cu	0.43	$4.00 \cdot 10^{-2}$	$3.71 \cdot 10^{-2}$	0.04	$7.02 \cdot 10^{-5}$	$1.39 \cdot 10^{-11}$	$1.4 \cdot 10^{-8}$	$7.00 \cdot 10^{-5}$	
Zn	0.52	0.30	0.30	0.30	$1.13 \cdot 10^{-5}$	$2.08 \cdot 10^{-12}$	$8.5 \cdot 10^{-9}$	$1.10 \cdot 10^{-5}$	
As	0.02	$3.00 \cdot 10^{-4}$	$1.50 \cdot 10^{-2}$	$3.00 \cdot 10^{-4}$	$4.16 \cdot 10^{-4}$	$1.53 \cdot 10^{-12}$	$3.9 \cdot 10^{-6}$	$4.20 \cdot 10^{-4}$	$2.03 \cdot 10^{-13}$
Cr	0.64	$3.00 \cdot 10^{-3}$	0.10	$7.50 \cdot 10^{-5}$	$1.41 \cdot 10^{-3}$	$7.75 \cdot 10^{-12}$	$4.2 \cdot 10^{-5}$	$1.45 \cdot 10^{-3}$	$5.40 \cdot 10^{-12}$
Ti	0.52	4.00	4.00	$4.50 \cdot 10^{-5}$	$8.52 \cdot 10^{-7}$	$1.57 \cdot 10^{-13}$	$1.51 \cdot 10^{-3}$	$1.51 \cdot 10^{-3}$	

Fig. 2a. *Percentages of individual metals to overall non-cancer risks in children across the three sampled locations*

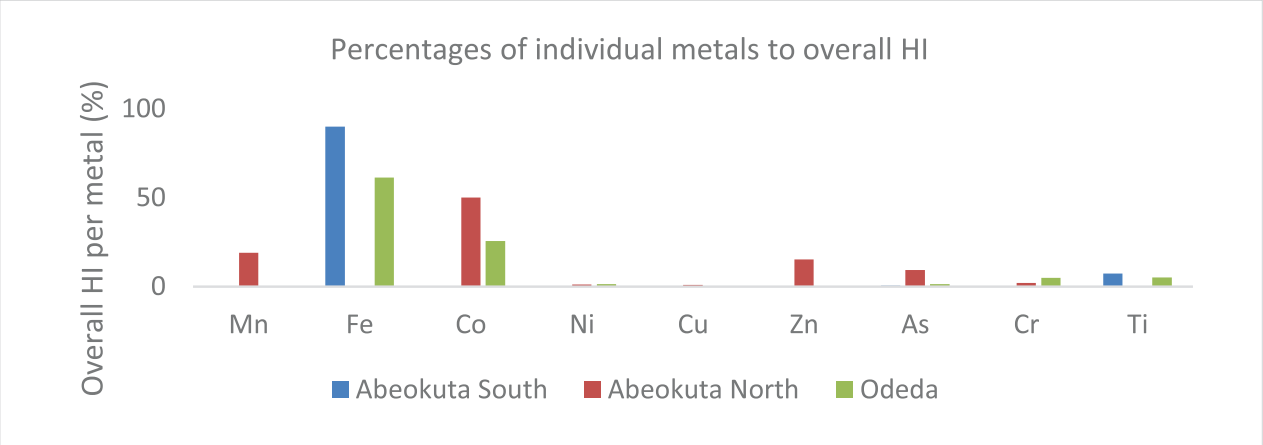
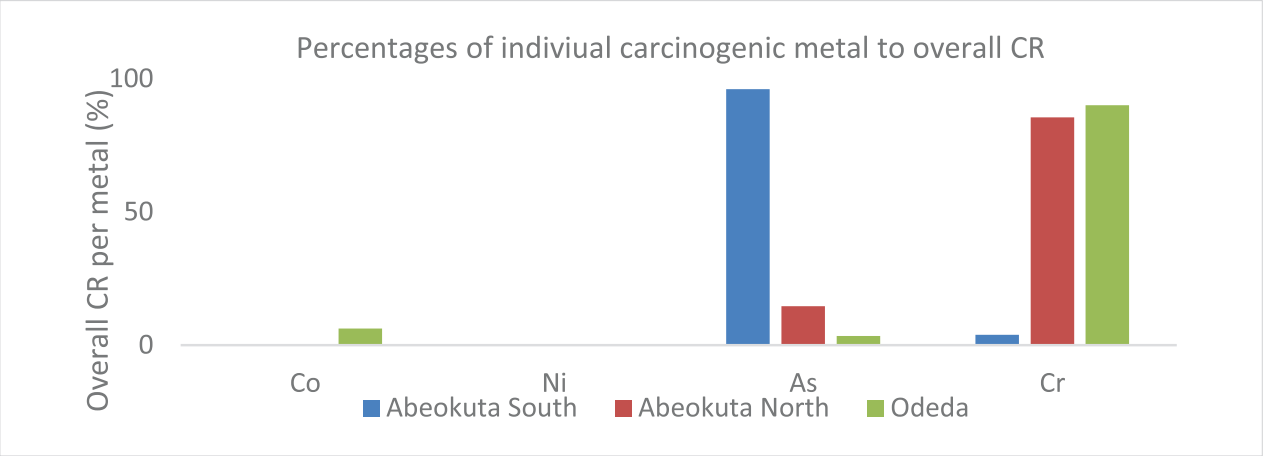


Fig. 2b. *Percentages of individual metals to overall cancer risks in children across the three locations*



fects, the main exposure route to Ni, Cu, Zn, As in dust particles at Abeokuta South was ingestion, and Mn, Fe, Co, Cr and Ti was dermal. At Abeokuta North, the dermal exposure route had high values of HQ for Mn, Cu, Zn and Ti, while the HQ ingestion was the highest for Fe, Co, Ni, As and Cr. Meanwhile, at Odeda, the highest HQ values were in the dermal route for only Fe and Ti, while others were in the ingestion routes. Kurt-Karakus (2012) in Istanbul (Turkey) and Nkansah et al. (2015) in Ghana recorded pathways for the non-carcinogenic risk exposure in the order ingestion > dermal contact > inhalation. The HI values for elements for children decreased in the order of Fe > Ti > As > Co > Cr > Ni > Cu > Mn > Zn in Abeokuta South, Co > Mn > Zn > As > Cr > Ni > Cu > Ti > Fe at Abeokuta North and Fe > Co > Ti > Cr > As > Ni > Cu > Mn > Zn at Odeda. The metals contributing the greatest non-cancer risk effects are Fe at Abeokuta South and Odeda and Co at Abeokuta North (*Fig. 2a*).

In addition, CR values across the locations were below 0.0001, depicting no immediate carcinogenic risk effects, as Nkansah et al. (2015) observed. Cancer risk indexes for Co, Ni, As and Cr at Abeokuta South were $8.05{\cdot}10^{-14}$, $1.72{\cdot}10^{-14}$, $7.13{\cdot}10^{-5}$ and $2.92{\cdot}10^{-6}$; at Abeokuta North, they were $8.80{\cdot}10^{-13}$, $1.95{\cdot}10^{-14}$, $4.14{\cdot}10^{-9}$ and $2.43{\cdot}10^{-8}$, and at Odeda they were $3.76{\cdot}10^{-13}$, $1.89{\cdot}10^{-14}$, $2.03{\cdot}10^{-13}$ and $5.40{\cdot}10^{-12}$, respectively. *Fig. 2b* shows that As contributed 96% to cancer effects in the classrooms at Abeokuta South, while Cr accounted for 85% and 90% of total cancer effects at Abeokuta North and Odeda, respectively. The calculated health risks show no potential cancer risks.

Recent years have seen the emergence of risk assessment as a potent tool in investigating environmental and/or occupational dangers (Nieuwenhuijsen et al., 2006).

Conclusions

The elemental profile of dust from 37 nursery and kindergarten classrooms was assessed. Metal concentrations were determined using X-ray fluorescence (XRF) spectrophotometry. Potential risks to the health of children and the ecosystem were calculated for exposure-point metal concentrations, average daily doses (ADD), hazard quotients (HQ), hazard indexes (HI), cancer risks (CR), geo-accumulation indexes (I_{geo}), and ecological risk indexes (Er_i and ER*i*). Odeda has the highest number of elements with peak mean values. The mean values of Ca, Co, Ni, Zn, As and K varied significantly across the locations. Results indicated that Ca, K, Fe and Ti ranked the first four metals with the highest concentration in different orders across the three locations. This study concludes that Co, As, Cr, Sc, Ge and Se levels are due to anthropogenic activities. There is negligible moderate and extreme elemental pollution in Abeokuta South and Abeokuta North. Dust samples for Abeokuta South posed the least ecological risk, while that of Abeokuta North posed the greatest risk. At Abeokuta South, Abeokuta North, and Odeda, respectively, Fe, Co, and Cr are the metals that contribute most to non-cancer risk effects. Arsenic is responsible for 96% of the cancer-causing effects in classrooms at Abeokuta South. In contrast, Cr is responsible for 85% and 90% of the cancer-causing effects at Abeokuta North and Odeda. The overall C_L were 459.32, 2922.36 and 716.92 for locations 1, 2 and 3, respectively. The Er_i showed significant ecologically risky As level across all the locations with 128.42 (considerable), 2934.27 (very high) and 179.33 (high), with low, very high and considerable ecological risk index (ER*i*) in locations 1, 2 and 3, respectively. At Abeokuta North, the dermal exposure route had high values of HQ for Mn, Cu, Zn and Ti, while the HQ ingestion was the highest for Fe, Co, Ni, As and Cr. Meanwhile, at Odeda, the highest HQ values were in the dermal route for only Fe and Ti, while others were in the ingestion routes. The HI values for elements for children decreased in the order of Fe > Ti > As > Co > Cr > Ni > Cu > Mn > Zn in Abeokuta South, Co > Mn > Zn > As > Cr > Ni > Cu > Ti > Fe at Abeokuta North and Fe > Co > Ti > Cr > As > Ni > Cu > Mn > Zn at Odeda. The metals contributing the greatest non-cancer risk effects are Fe at Abeokuta South and Odeda and Co at Abeokuta North. The CR shows no cancer risk threat across the locations.

The results obtained in this study largely suggest that the schools' location and window or door opening for ventilation could be possible routes for heavy metals contamination of classroom dust. Therefore, locating schools in pristine areas with low traffic, regular cleaning, improved ventilation of classrooms, and regular renovation of old schools are recommended to simultaneously address the inseparable health goals for students.

In general, to reduce children's exposure to heavy metals poisoning caused by contaminated dust, more attention should be directed towards the general cleanliness of the schools' environment, such as good housekeeping practices, following the safe way of disposing of wastes properly, and good maintenance of ventilation systems; besides, children should be encouraged to wash their hands frequently to reduce ingestion of contaminated dust. Consequently, a wash hand basin with a constant water supply should be provided in front of each classroom. The pupils must be educated to appreciate handwashing and the need to desist from putting their hands on surfaces and dipping their mouths and noses.

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