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Bioaccessibility Studies of Potentially Toxic Elements in Dust From Offices

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ABSTRACT

Potentially toxic elements are commonly referred to as heavy metals which are toxic and cannot be broken down. Potentially toxic elements are known to have a negative impact on human health especially children through oral ingestion, dermal and inhalation. In this study, the total metal concentration was determined in dust samples from selected offices of some tertiary institutions. Four dust samples were collected from different locations using a brush and plastic scoop. Afterwards, dust samples were naturally air dried and sieved through a 45µm mesh sieve and then acid digested. Results of the Atomic Absorption Spectrophotometer (AAS) analysis of the dust samples revealed the order of accumulation of cadmium and manganese in all sample locations. Contamination factor of Cd and Mn in all the four tertiary institutions were of low concentration. Also, the carcinogenic and non-carcinogenic risk was calculated based on the model developed by United States Environmental Protection Agency. For human health risk, the order of decreasing risk were ingestion >dermal>inhalation. This study shows that dusts from offices have effect on humans working in the office as it is the accumulation of settled toxic elements and humans spend more time indoors than outdoors.

Keywords: dust, potentially toxic element, Cadmium, Manganese

INTRODUCTION

Potentially toxic elements are commonly referred to as heavy metals and can also be called (PTEs). According to Alloway (1995), heavy metal is a group name adopted for metals and metalloids which are associated with pollution and toxicity. However, toxicity is a function of the concentration to which a human or organism is exposed to. The Dangerous Substances Directive of the European Union (76/464/EEC) therefore defines potentially toxic elements (PTEs) as those elements which are toxic, persistent or bio-accumulative, as they are elements that cannot be broken down and therefore persist in the environment (Odujebe, 2017). Office dust which can be categorically called indoor dust is defined as fine-settled particles in an indoor environment (Azuma, 2020). The pollutants in office dust may originate from internal or external sources in which office dust acts as a media for potentially toxic elements deposition. These PTEs in dust can enter into the human body through ingestion, inhalation and dermal contact.

The International Agency for Research on Cancer (IARC) has classified aluminium (Al), cobalt (Co), copper (Cu), iron (Fe), nickel (Ni) and zinc (Zn) as non-carcinogenic elements, whereas arsenic (As), cadmium (Cd), chromium (Cr) and lead (Pb) are classified as both carcinogenic and non-carcinogenic elements (Bini and Wahsha, 2014). Potentially toxic elements such as As, Cd, Cr and Pb are widespread environmental pollutants which can cause harmful health effects, such as cancers. Some of their carcinogenic effects are respiratory illnesses, damage to the nervous system and slow growth development (Mahurpawar, 2015). The potentially toxic elements concentration in office dust can be altered by the building's dustiness and ventilation. In addition, dust can have health effects on humans as it is the accumulation of settled heavy metals from the environment. Since people spend more time indoors than outdoors, they are more exposed to these potential hazards.

The use of leaded petrol has been responsible for the global dispersion of lead aerosols. Even with the use of unleaded petrol by many countries of the world, lead pollution is still a threat to the human population particularly those who live in the cities where there is more release of Pb in the environment. It is important to note that in countries where leaded fuel is still in use, the combustion of such fuel in different engines is a potential pathway through which lead could be released into the environment (Awad et al., 2018). Also, the combustion of fossil fuel results in the dispersion of many elements in the air over a large area. The disposal of ash is a further source of potentially toxic elements in the atmosphere (Xiong et al., 2019). Agricultural fertilizers and pesticides which includes phosphatic fertilizers, slags from iron manufacturing, pesticides and herbicides contain various combinations of PTEs, either as impurities or active constituents (Padhye et al., 2023). Also, the disposal of urban and industrial wastes can lead to soil pollution from the deposition of aerosol particles emitted by the incineration of PTE-containing materials.

Additionally, the careless (or unauthorised) dumping or disposal of PTE-containing items, ranging from electronic gadgets, miniature dry-cell batteries (Ni, Cd and Hg) to abandoned cars and car components (e.g. Pb acid batteries) can give rise to very high PTE concentrations in soils. The disposal of some domestic waste by burning on garden bonfires or burial in the garden can also result in localised high concentrations of PTEs, such as Pb, in soils used for growing vegetables. Hence, dust becomes a carrier of environmental contaminants, posing challenges to human health through exposure to these contaminants in soil. However, humans are exposed only to the bioaccessible fraction of the PTEs in dust, not the total concentration.

Bioaccessibility refers to the fraction of the total amount of a substance that is potentially available for absorption and this can be approached using general experimental techniques (Ng et al., 2015). Although the bioaccessible fraction of PTEs should be of ecological concern, most analysis done often focus on the total concentrations. Hence, this study is to assess human health risks as a result of exposure of (PTEs) in dust from offices by determining the oral, inhalation and dermal bioaccessibility concentrations of the PTEs.

MATERIALS AND METHODS

Sample Collection

A total of four randomly selected dust samples were collected from the sample locations using a plastic scoop and brush and put into a sealed labeled nylon. After collection, samples were sieved using the 45 µm mesh sieve, weighed and stored at room temperature before analysis.

Sample Coding and Coordinates

The dust samples were coded to avoid identification errors. The sample code consists of the abbreviated name of the school in which dust samples were collected and the sample number. OSI refers to Ogun State Institute of Health and Technology, llese; LASPO refers to Lagos State Polytechnic. LASU refers to Lagos State University; TASUED refers to Tai Solarin University of Education, Ogun State.

Physiochemical Assessment of Dust Samples

pH

The pH of the dust samples was determined using BS ISO 10390:2005 (BSI, 2005; Standard, 2005) method at soil to de-ionised water ratio of 1:5. The mixture was shaken and allowed to settle before the pH of the sample was taken using a pH meter. The pH meter was calibrated using 4, 7 buffer solution.

Organic Matter Content

This was determined by Loss on Ignition (LOI). Firstly, the moisture content was determined where 2g of dust was heated to 105°C for 5 hours in a muffle furnace, then cooled in the desiccators and weighed. The samples were then heated at 550 °C for 4 hours till completely ashed, allowed to cool in desiccators and weighed. The percentage of organic matter content was calculated as

$$\%\ \text{Moisture content} = \frac{A-B}{A} * 100 \text{ -------------------------- Equation 1}$$

$$\%\ \text{Ash content} = \frac{C*100}{B} \text{ -------------------------------------- Equation 2}$$

$$\%\ \text{Organic matter content} = 100 - \%\ \text{Ash content-------- Equation 3}$$

Where; A = pre-ignition weight (g), B = post-ignition weight (g), C = weight of ash (g).

Sample Preparation for Total PTE Determination

Aqua regia was prepared using Hydrochloric acid (HCl) and Nitric acid (HNO_3) in ratio 1:3 respectively, which was then added in 10 mL to 0.1 g of dust sample. The mixture was then placed on a hot plate and allowed to digest for about 2-3 hours till brown fumes disappeared, and the solution was evaporated to near dryness (Velavan, 2015). The resulting solution was then removed from the hot plate, allowed to cool, filtered through a Whatman filter paper into a 50 mL volumetric flask and made up to mark with de-ionised water.

Oral Bioaccessibility using Simplified Bioaccessibility Extraction Test (SBET) Method

The procedure was carried out by adding gastric juice containing a 0.4 M glycine solution (prepared by dissolving 30.3 g of glycine in 1 L of deionized water) and adjusting the pH to 1.5±0.2 using 12 M HCl. The mixture was then agitated in an end-over-end orbital shaker maintained at 37°C and 100 rpm for 1hr. After extraction was completed, some aliquot was removed with a disposable syringe attached to a 0.45 um cellulose acetate membrane filter, the filtrate was then transferred into sample bottles and preserved in a refrigerator.

Dermal Bioaccessibility

The dust samples were extracted at sweat-to-dust ratio of 1:100 (Anselm et al., 2022). To initiate the test, 5mL of synthetic sweat was prepared at 36 ºC and was added to 0.1 g of each sample. Teflon tubes with PTFE caps containing samples were placed in an orbital shaker at 100 rpm inside a standard laboratory incubator at a preset temperature of 36 °C, which was chosen based on the median skin surface temperature for humans (Leal et al., 2018). The tests were allowed to run for 8 h (representing the industrial exposure scenario: the scenario for adult workers' exposure during an 8 h shift). After the completion of the tests, the tubes were first centrifuged at 10,000 × g for 10 min. Then, the supernatant was carefully collected by using automatic pipettes into a Luer-lok syringe (60 mL) fitted with a 0.45 um PVDF filter, and filtered to a 50-mL container, to which 0.5 mL HNO_3 was added for sample preservation. The samples were kept at 4 °C before analyses and analysed as soon as possible using AAS.

Inhalation Bioaccessibility

Prior to extraction, the simulated lung fluid was taken out of the fridge, and warmed in a water bath for 2 hours at 37 °C to mimic body temperature. The pH was checked to ensure it was 7.4±0.2. Triplicate sets of 0.1 g of the dust samples were weighed into labelled extraction tubes; 5 mL of simulated lung fluid was added to each of the samples, the sample mixture was then agitated for 10 seconds, extracted and then transferred into sample bottles. All samples were prepared in triplicates and HNO_3 was added to each sample so as to preserve it.

Assessment of Soil Contamination and Potential Ecological Risks

The degree of Cd contamination of the composite topsoil was determined as a summation of the individual PTE contamination factor (CF). The CF was gotten using Equation 4

$$\text{CF} = \frac{\text{Pseudototal PTE (mgkg}-1)}{\text{Soil background value (mgkg}-1)} \text{ --------------------- Equation 4}$$

$$\text{Hence, Cd} = \sum CF \text{ ------------------------------------- Equation 5}$$

The soil background values were gotten from world average value especially in the case of arsenic while the pseudototal values were gotten from this study. For the degree of contamination (Cd), values of 0-7, 8-15, 16-31 and ≥ 32 indicated low, moderate, high and very high degrees of contamination respectively.

Calculation of Percentage Bioaccessible and Dermal Absorbed Dosage (DAD)

The % bioaccessibility was calculated using:

$$\%\text{ bioaccessibility} = \frac{Measured\ PTE\ concentration\ (mg/kg)}{Pseudototal\ concentration\ of\ PTE(mg/kg)} \text{ ------------ Equation 6}$$

$$\text{DAD} = \frac{DAevent*EF*ED*EV*SA}{BW*AT} \text{ -- Equation 7}$$

where SA (cm^2): skin surface area available for contact (1575 cm^2 for industrial scenario with PPE, 2800 cm^2 for children and 570 cm^2 for adults without PPE); EF: exposure frequency (219 d.y' for industrial scenario, 260 d.y' for residential scenario); ED: exposure duration (taken as 25 years for industrial workers, 6 years for children); EF: event frequency (1 event.d'); BW: average body weight (70 kg for adults, 15 kg for children); AT: averaging time (ED *365)

$$DA_{\text{event}} = C_{\text{soil}}\text{*CF *AF *ABS}_{\text{d}} \text{ ---Equation 8}$$

where Cw (mg/ cm^3): the measured concentration of PTEs in the artificial sweat solutions (see supplementary material: Table S3); Kp (cm.h'): dermal permeability coefficient of PTEs in water (As, Cd, Cr, Cu, Fe, Mn: 1*103; Ni: 2*10*; Pb: 1*10*; Zn: 6*104 13);

t_{event} : h per event (event duration 8 hrs for industrial workers on the site; 2 hrs for the residential scenario for children playing); C_{soil}: total concentration in soil (mg.kg') (Table 1); CF: conversion factor (10); AF: adherence factor of soil to skin (mg. cm^2-event, taken as 0.2 13; ABSa: dermal absorption fraction (0.03 for As and 0.001 for other PTES The dermal reference values (RfD_{ABS}), which is the threshold value, were derived from oral reference values, using the equation 9

$$\text{RfD}_{\text{ABS}} = \text{RfD}_0 * \text{ABS}_{\text{GI}} \text{ --- Equation 9}$$

RESULTS

Physiochemical Data Analysis of the Dust Sample

Table 1 showed the physiochemical properties of dust samples taken from four different tertiary institutions (Lagos State University, Lagos State Polytechnic, Tai Solarin University of Education, Ijagun and Ogun State Institute of Health and Technology, Ilese). The pH of the dust samples ranged from 6.1 to 7.3 and the percentage of moisture content ranged from 0.2 to 0.5 %.

Table 1: Physiochemical properties of dust sample with respect to dust sample location

Samples	ILESE	LASPO	LASU	TASUED
pH	6.1	7.1	6.6	7.3
Moisture Content (%)	0.2	0.5	0.5	0.2

The result obtained from this study revealed that dust samples obtained from the LASPO and TASUED with pH 7.1 and 7.3 are slightly alkaline while ILESE and LASU with pH 6.1 and 6.6 are slightly acidic.

Pseudototal Concentration of Cd and Mn in Dust Sample (mg/kg).

Table 2 shows the pseudototal concentration of cadmium and manganese in the dust samples with respect to the dust sample location. The metal concentration (mg/kg) in dust samples from the offices ranged from 0.64 to 33.4 mg/kg Cd and 0.12 to 76.08 mg/kg Mn. The concentration of Mn in the various tertiary institutions examined was higher compared to the concentration of Cd. This could be as a result of windblown erosion of dust which is an important source of manganese. In the offices, exposure of manganese is most likely to occur by manganese-containing dust. LASPOTECH has a higher concentration of Mn and Cd compared to LASU, TASUED and ILESE, which could be as a result of the institution being cited in a rural area so high concentration of manganese is likely to occur.

Table 2: Pseudototal concentration of Cd and Mn in the dust sample (mg/kg) with respect to the sample location

Sample Location	Cd (mg/kg)	Mn(mg/kg)
ILESE	1.04	53.4
LASPO	1.44	76.08
LASU	0.64	38.04
TASUED	0.12	33.4

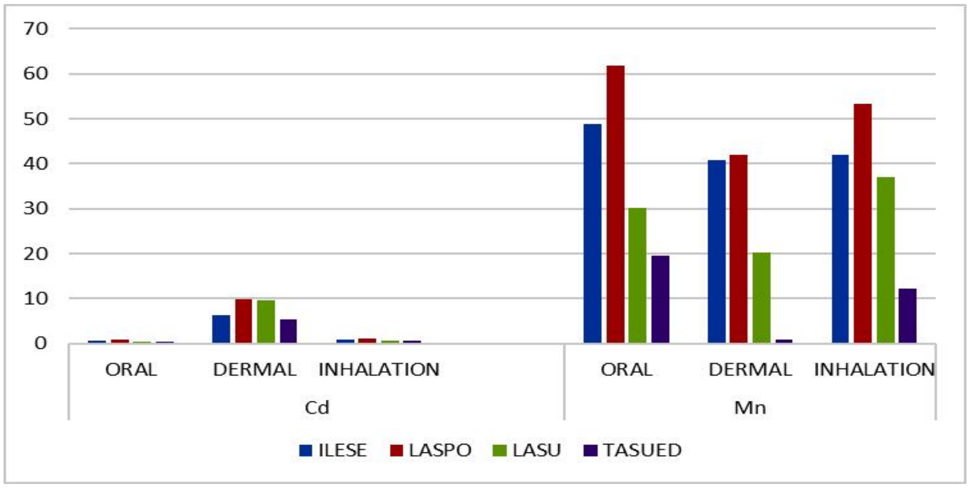

Figure 1: Mean concentration of Cd and Mn during bioaccessibility studies (mg/kg) of the dust samples with respect to the sample location.

Figure 1 shows the mean concentration of cadmium and manganese in the dust sample with respect to the sample location. The concentration of Cd and Mn for oral bioaccessible ranged from 0.40 -0.96 mg/kg and 19.65-61.92 mg/kg. The concentration of Cd and Mn for dermal bioaccessible ranged from 5.30 to 9.84 mg/kg and 0.80 to 42.02 mg/kg respectively. Also, the concentration of Cd and Mn for inhalation bioaccessible ranged from 0.59 -1.16 mg/kg and 12.23 - 53.44 mg/kg. From this result, it is evident that the level of Mn present in all the locations is higher than Cd. This could be because, for individuals working in the offices, the major route of exposure is inhalation of manganese-containing dust from office air. Also, the higher concentration of Mn in LASPOTECH compared to other tertiary institutions examined could be as a result of the institution being cited in a rural area, hence high concentration of manganese is likely to occur.

Contamination Factor Value (CF value) of Cd and Mn in Dust Samples

Table 3 shows the contamination factor which was derived by comparing the total concentration of Cd and Mn in the sample locations with WHO soil guideline values of 4.0 mg/kg and 300 mg/kg respectively. Contamination factor value of Cd ranged from 0.03 to 0.36 and Mn ranged from 0.11 to 0.25. The CF <1 indicates low contamination, 1< CF <3 moderate contamination, 3< CF <6 considerable contamination and CF >6 very high contamination. For the degree of contamination (Ca), values of 0 -7, 8-15, 16-31 and ≥ 32 indicated low, moderate, high and very high degrees of contamination respectively (Kashyap et al., 2019). Using the WHO soil guideline value which for manganese is 300 mg/kg and cadmium is 4.0 mg/kg, Table 4 shows the cadmium and manganese contamination in all tertiary offices was low (CF<1). Additionally, cadmium and manganese contamination in the sample followed the order: TASUED<LASU<ILESE<LASPO

Table 3: Contamination factor value (CF value) of Cd and Mn in dust samples with respect to the sample location

Sample Location	Cd	Mn
ILESE	0.26	0.18
LASPO	0.36	0.25
LASU	0.16	0.13
TASUED	0.03	0.11

Percentage (%) Bioaccessibility of Cd and Mn in Dust Samples

The percentage (%) bioaccessibility of Cd and Mn in the dust sample with respect to sample location. The percentage Bioaccessible of Cd and Mn for dermal ranged from 34.2 to 68.2% and 47.2 to 76.6%. For oral exposure route, the percentage bioaccessible of Cd and Mn ranged from 41.7 to 81.2% and 58.8 to 91.5% respectively while for inhalation exposure route, percentage bioaccessible of Cd and Mn ranged from 52.5 to 79.3 % and 36.7 to 97.2 % respectively.

Daily Exposure Dose of Cd and Mn Based on Exposure Pathway (mg/kg)

Figure 2 shows that the human absorption of Mn and Cd in all the sample location cannot be hazardous to human health and this is because the daily exposure dose of human absorption of Cd and Mn through oral, inhalation, and dermal processes were within the permissible limit.

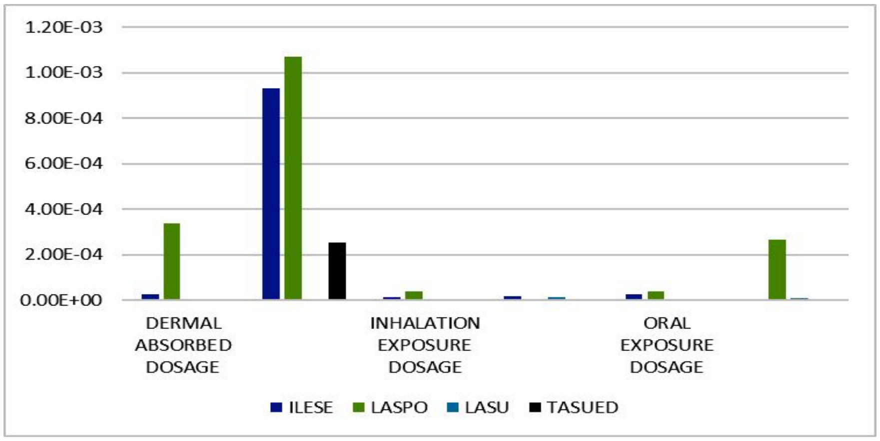

Figure 2: Daily exposure dose of Cd and Mn-based on different exposure pathway.

Hazard quotient (HQ) of Cd and Mn in the dust sample

Similarly, Figure 3 shows that for the HQ, the population around the dust samples are not prone to adverse health effect from exposure to the PTEs examined (Manganese and Cadmium) through oral, dermal or inhalation pathways. This is because the levels of these elements were within the permissible limits.

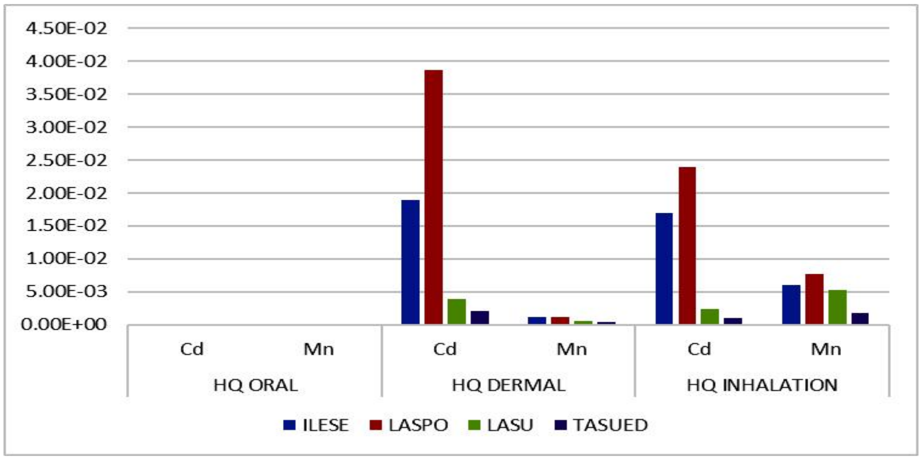

Figure 3: Hazard quotient (HQ) of Cd and Mn in the dust sample with respect to sample location

Meanwhile, when an HQ value is < 1, there is no risk to the population, but if the values exceed one, there may be a serious concern for potential non-carcinogenic effect (Rezaei et al., 2019). Also, the US Environmental Protection Agency considers acceptable for regulatory purposes a cancer risk in the range of 10^{-1} to 10^{-4}.

DISCUSSION

The levels of Cd and Mn were evaluated in dusts from offices in four tertiary institutions. This study is aimed at providing information on the associated risks that may arise from exposure of humans working in offices to these toxic elements in dusts. The dust samples were digested with aqua regia and analyzed for toxic element concentration by atomic absorption spectrophotometer (AAS). The metal concentrations (mg/kg) in dust from offices ranged from 0.12 to 1.44 mg/kg for Cd and 33.4 to 76.08 mg/kg for Mn. Also, the contamination factor of Manganese and cadmium in the four tertiary institution was low. The cadmium (Cd) and manganese (Mn) with the highest levels of 1.44 mg/kg and 76.08 mg/kg respectively were obtained from samples of Lagos State Polytechnic (LASPOTECH) dust. It is possible that the problem could be ascribed to the fact that LASPOTECH is based in a rural area, which involves manganese exposure through the activity of windblown dust and soil particles that are known sources of manganese.

These bioaccessibility studies examined the portion of PTEs which is potentially absorbed by the body in oral, dermal, and inhalation exposure pathways. The results demonstrated differences in percentage bioaccessibility for Cd and Mn corresponding to various exposure routes. It was observed that the maximum bioaccessibility of Cd was mostly through the inhalation route which was (52.5% to 79.3%) and then comes the rest which includes oral (41.7% to 81.2%) and dermal (34.2% to 68.2%) routes. The highest percentage of bioaccessibility for the inhalation route on the other hand was observed for the Mn element (36.7% to 97.2%), followed by oral (58.8% to 91.5%) and dermal (47.2% to 76.6%) routes. This results is in agreement with that documented by Li's group on the exposure of street sweepers to cadmium, lead, and arsenic in dust based on variable exposure duration in zinc smelting district, northeast China. Their report revealed that the ingestion of street dust represents a more significant source of cadmium (Cd) and lead (Pb) exposure compared to dietary intake (Li et al., (2021).

Han and co-workers also reported that for dust samples collected from various parks and squares of an industrial city in semi-arid area of China, the pollution levels of Ba, Co Cr, Cu, Pb, V, Cd, and Hg ranged from unpolluted to moderately polluted. The health risk assessment of their study signified that ingestion is the primary exposure pathway to heavy metals present in the dust, with dermal absorption being the secondary route (Han et al., 2017). In addition, our result confirms the previous studies which noted the divergent bioavailability of PTEs that was influenced by the exposure pathway and the physicochemical properties of the dust particles (Marinho-Reis et al., 2020). Hence, PTE's bioaccessibility varies, with some dust particles having low bioaccessiblity hence lesser exposure routes than the three pathways while some are of high bioaccessibility. Higher bioaccessibility of particles can be related to smaller particle size of dust which helps particles to penetrate deeper into the respiratory system and absorption is increased even via dermal and oral exposure routes (Anselm et al., 2022).

The contamination factor (CF) determinations revealed low levels of Mn and Cd contamination (CF < 1) across all sampling locations. Meanwhile, the Cd and Mn contamination followed the order: TASUED <- LASU <- ILESE <- LASPOTECH. The outcome of this study is in accordance with what had previously been reported as the higher level of soil Cd pollution in urban and industrial areas compared to the rural areas (Shifaw, 2018). Incidentally, low levels of contamination can also cause potential health risks depending on the population such as children and folks with underlying health conditions. For instance, a study on the pollution and health risk assessment of road dust from Osogbo metropolis, Osun state, Southwestern Nigeria conducted by Taiwo and others showed that the Hazard Quotient (HQ) and Hazard Index (HI) values of metals (Zn, Mn, Cu, Pb, Ni, Na, Cd, Cr, C, As and V) were less than 1.0 for both children and adults, indicating no adverse effects. However, the cumulative Cancer Risk (CR) for children exceeded the permissible limit, suggesting a potential risk of cancer development (Taiwo et al., 2018).

Meanwhile, the results on assessment of health risks associated with road dusts in major traffic hotspots in Abeokuta metropolis, Ogun state, Southwestern, Nigeria by the same group showed that the Hazard Index (HI) values of Cr, Cd, Pb and Ni were less than 1.0 for adults but exceeded 1.0 for children, suggesting that children are at a higher risk of metal exposure from road dust compared to adults. The results of the calculations of the daily exposure doses combined with the hazard quotient (HQ) analysis indicated that the absorption of Cd and Mn by oral, inhalation and dermal ways were within acceptable levels, as the HQ values were less than one. This findings are in consonant with that reported by Ma and co-workers on the health risk assessment and source apportionment of mercury, lead, cadmium, selenium, and manganese in Japanese women through various daily life routes (diet, soil, house dust, and indoor air): an adjunct study to the Japan environment and children's study.

Their results showed that the primary source of intake for all these elements was identified as diet and the hazard quotient for Cadmium and Manganese were below the permissible limit (Ma et al., 2020). Also, the result agrees with previous findings that indicate low levels of non-carcinogenic risk from PTE exposure indoors (Keshavarzi et al., 2018). Nevertheless, one is faced with the concerns and limitations that risk models may at times be incapable of comprehensively portraying the complications regarding real-world scenarios of environmental exposure and individual peculiarities. In addition, the study did not consider the possible enhancement in overall medical risk due to a sum of multiple PTE exposures which may be synergistic or additive in nature (Yousaf et al., 2017).

CONCLUSION

Office dust which can be categorically called indoor dust can have effect on human health as it is the accumulation of settled toxic element in the environment. As humans spend more time indoors than outdoors, exposure to this dust becomes more significant. Health risk assessment including non-carcinogenic risk estimation via different pathway to exposure for Cd and Mn presented hazard quotient of less than one. Non carcinogenic risk were found to be below the threshold for public health and permissible for ambient exposures. The inclusion of health risk assessment in this study assisted in contributing health- risk information of potentially toxic element in dusts from offices as well as public awareness on the severity of air pollution. Clearly, potentially toxic element in indoor dust can have impact on life, although in this case it is below acceptable values but constant exposure may possibly lead to bioaccumulation of these PTEs in humans. Hence, it is recommended that laws should be passed by government to fight environmental contamination to aid the comfortability of lives of individuals working in offices. Planning and awareness are also important steps in the prevention of indoor air pollution and to reduce the spread of these toxic elements in dust.

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