Published by The College of Science & Information Technology (COSIT), TASUED, Vol. 18, No. 1, pp. 78-86.

COSIT, TASUED
Journal of Science and Information Technology (JOSIT)

Bioaccessibility Studies and Human Health Risk Assessment of Potentially Toxic Element in Soils from Dumpsites in Mowe, Sagamu, Iwaya, Ijagun and Ikija Areas of Ogun State

[1]✉Anselm O.H., [1]Badeji A.A., [2]Olagbuyiro I.M. and [1]Osinubi A.D.

[1]Department of Chemical Science, Tai Solarin University of Education, Ijagun
[2]Department of Research, Ace Initiative for Sustainable Development
Corresponding Author: anselmoh@tasued.edu.ng

Abstract

Potential toxic elements (PTEs) are naturally occurring, widespread substances in the human environment, which pose serious environmental problems, and threaten human health. The study aim is to examine inaccessibility studies on Cadmium and Manganese in the soil around dump sites and find out the level of PTEs present in soil samples of the dumpsites in Mowe, Ikija, Iwaya, Ijagun and Sagamu area of Ogun State. This study shows the impact of PTEs contamination in soil from dumpsites. In this study, the total concentration and bio-accessible concentrations of cadmium and manganese in soil samples were obtained from dump sites. The study showed that the total concentration of Cadmium (Cd) was between the range of 0.76 ± 0.1 to 2.78 ± 0.3 mg/kg and the concentration of Manganese (Mn) was between the range of 41.41 ± 0.5 to 69.85 ± 0.4 mg/kg. Contamination factor analysis indicated low contamination levels for both Cd and Mn (CF < 1) across all sites. Bioaccessibility studies revealed varying percentages for different exposure routes, with oral bioaccessibility ranging from 9.95% to 41.44% for both elements. Dermal and inhalation bioaccessibility showed similar ranges. Hazard quotient (HQ) calculations for all exposure pathways were well below 1, suggesting minimal health risks associated with these PTEs in the studied dumpsites. Conclusively, while Cd and Mn are present in the dumpsite soils, their concentrations and bioaccessibility do not pose significant immediate health concerns for the local population.

Keywords: Bioaccessibility, potentially toxic element, dumpsite, soil, soil contamination

INTRODUCTION

The global population of urban communities also rises day by day and increases at a much higher rate than the overall global population, as urbanisation is still an uncompleted process in less-developed areas (Ojo et al., 2017). This results in changes in the physical landscape of cities and more concentration and production of waste materials with elements that are probably toxic from human activities. As a result of the advancement in industrialisation in the last five decades, contaminated soil with potentially toxic elements (PTEs) is considered a critical environmental issue across the world (Zhang et al., 2023).

Cite as:
Anselm O.H., Badeji A.A., Olagbuyiro I.M. and Osinubi A.D. (2024). Bioaccessibility studies and human health risk assessment due to potentially toxic elements in soils from Mechanic Workshops in Ogun State. *Journal of Science and Information Technology (JOSIT),* Vol. 18 No. 1, pp. 78-86.

Potential toxic elements (PTEs) are those elements which are present in the environment having toxic nature, persistent and bio-accumulate in the human beings, animals and even plants (Luo et al., 2020). They are released into the ecosystem through geogenic and anthropogenic sources but their excess in the environment can be majorly attributed to anthropogenic sources such as; mining, smelting of metals, lead works, chemical factories, foundries, burning, transportation, illicit disposal of chemicals among others (Brenko et al., 2024). High concentration of PTEs in the environment poses many health concerns because they are toxic elements, ubiquitous, hardly transform into non-toxic forms and therefore are persistent in the environment for decades. Due to the water solubility nature of PTEs and the absence of adequate procedures for elimination of such elements from the body, most of the PTEs pose severe toxicity even when present in small concentrations (Brenko et al., 2024). Therefore, its impact on human health is an outcome of the fact that the body cannot digest them, and they accumulate in the body leading to health risks.

Cadmium, lead and mercury for instance are PTEs and are xenobiotics that are not essential for biological processes in the body. Lead, Pb and Cd are recognised toxic metals that has been linked to cancer, brain damage, cardiovascular diseases and kidney diseases (Yan et al., 2021). Therefore, PTEs like arsenic cadmium, lead and mercury are considered priority PTEs of public health since they are highly toxic and have no biochemical use to the body even at trace levels (Mafulul et al., 2023). Other PTEs including Cu, Ni, Mn, Fe, Cr, V, Mo, and Zn are needed in trace amounts. They represent an essential component in various metabolic processes and contribute to the normal activity of various enzymes in the body but are lethal when present in high concentrations in the body (Ahmed Laskar & Younus, 2019). Soil is regarded as one of the environmental reservoirs of these PTEs, maybe because most anthropogenic activities are carried out on soils. Meanwhile, pollution of agricultural soil and farm crops by toxic elements as a consequence of rapid industrialisation and urbanisation is of major concern. This is because contaminated foods pose health hazards and the toxic content negatively impacts the soil (Yahaya et al., 2020). The PTEs are not only taken in the form of particles ingested or inhaled but also through ingestion of plants that grow in PTE-contaminated soil (Yan et al., 2021). Therefore, inhabitants residing in areas with contaminated soil may possibly be at risk of exposure to PTEs in the contaminated soil via oral, dermal or inhalation route. Most importantly, children are at higher risk of these exposures especially via the oral route because they tend to put objects in their mouths.

As a result of its proximity to Lagos, Ogun is experiencing increased populations, possible expansive informal settlement, and the practice of using any piece of land available for living and soil for farming. This also implies increase in anthropogenic activities and waste disposal hence the need to access human health risk that may be associated with exposure to PTEs around the dumpsites. Earlier studies determined the concentrations of PTEs in dumpsite soils in different parts of the country. Onwukeme and Eze (2021) and Ademola et al. (2015) among others provided useful background information on the concentrations of PTEs in soil from dumpsites, nevertheless, there is limited understanding of the concentrations of some of the PTEs that can be taken up by human orally, dermally or via inhalation which is the bioaccessible concentrations. While most studies focused on the total concentrations, human are more prone to health risk as a result of the bioaccessible concentrations. Therefore, this study's objectives are to determine the total and bioaccessible concentrations of Cd and Mn in the soils from five large dumpsites in Ogun State and evaluate the potential risks of the contaminants to human health through different exposure routes. Hence the total concentration of Cd and Mn and their bioaccessible concentrations in the soil around the major dumpsites in Mowe, Ikija, Iwaya, Ijagun and Sagamu which are among the major dumpsites in Ogun State will be determined.

MATERIALS AND METHOD

Sampling

Six samples were collected randomly each at five locations namely, Sagamu, Ikija, Iwaya, Mowe and Ijagun, being five of the major dumpsites in Ogun State. Thirty (30) soil samples were collected from five locations at each sampling point. Samples were collected at depths ranging from 0-5cm using plastic auger and hand gloves. All samples were air-dried at room temperature for 4 days and the samples were grinded to powder and sieved through a 45-micrometre mesh sieve.

Physico-Chemical Analysis of the Soil Samples

1. pH

The pH was determined at a soil-to-deionised water ratio of 1:5.

2. Moisture contents

2g of soil sample was heated at 105°C for 24 h in an oven, cooled and then weighed until constant weight was obtained.

The percentage moisture content is calculated using Equation (1):

Percentage moisture content $= \frac{(w-d)}{w} \times 100$ (1)

where w is the weight while wet and d is the weight while dry.

Sample Preparation for Total PTEs Determination

One gramme of soil was weighed into a 50 mL beaker and 20 mL of aqua regia (HCl: HNO_3, 3: 1 v/v) and covered with a watch glass. The beaker with the sample mixture was allowed to digest on a hot plate for 2 to 3 hours till the brown fumes disappear and the solution is evaporated to near dryness. The resulting solution is then removed from the hotplate, allowed to cool, filtered through a Whatman filter paper into a 50 mL volumetric flask and made up to mark with deionised water. This was done in triplicates and transferred to cleaned dried plastic bottles before analysis.

Oral Bioaccessibility via Simple Bioaccessibility Extraction Test (SBET) Method

This is a one-phase extraction process carried out by adding gastric juice containing 0.4 M glycine solution (prepared by adding 30.3 g of glycine to 1 litre of deionised water) adjusted with 1 M HCl dropwisely to pH 1.5 ± 0.2. 0.5 g of sample was placed in a High-Density Polyethylene (HDPE) screw top tube and 50 ml gastric solution was added. The mixture was agitated in an end-over-end orbital shaker at 37°C and 100 rpm for 1h. After extraction was completed, aliquot was removed with a disposable syringe attached to a 0.45 µm cellulose acetate membrane filter. The filtrate was then transferred into a centrifuge tube and stored in a refrigerator at 4°C. The pH value of each sample solution was taken at the beginning and the end of the extraction to ensure it was within the required range (pH 1.3±0.2 to 1.7± 0.1) before filtration. The extraction was also carried out in triplicate for each sample.

Inhalation Bioaccessibility Test

Before extraction, the simulated lung fluid was allowed to thaw and heated in a water bath for 2 hours at 37°C to mimic body temperature. The pH was checked to ensure it was 7.4. Triplicate sets of 0.2 g of the generated soil samples were weighed into labelled extraction tubes; 20 mL of simulated lung fluid was added to leach the samples. The samples were agitated for 10 seconds and pH checked. The pH was adjusted with a dropwise addition of 1 M NaOH and 1 M HCl. Extraction was carried out at 37°C for 4 hours.

Dermal Bioaccessibility Test

This was carried out by extracting the samples with simulated sweat solutions at pH 4.7 and particle size of 45 µm (Anselm et al., 2022). The dust samples were extracted at a sweat-to-dust ratio of 1:100. To initiate the test, 20 mL of synthetic sweat was prepared at 36°C and was added to 2 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 temperature of 36°C, which was chosen based on the median skin surface temperature for humans (Anselm et al., 2022). The tests were allowed to run for 8 h. (representing the industrial exposure scenario: the scenario for adult workers' exposure during an 8 hrs. 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 filtration. The samples were kept at 4 °C before analyses using Atomic Absorption Spectrometry (AAS).

Assessment of Soil Contamination

1. **Contamination factor**

The degree of contamination of the composite topsoil was determined as a summation of the individual PTE contamination factor (CF). The CF was obtained using Equation 2.

$$\text{CF} = \frac{(Pseudutotal\ PTE\ concentration)}{(Soil\ background\ value)} \quad (2)$$

2. **Calculation of % bioaccessibility and Dermal Absorbed Dosage (DAD)**

The % bioaccessibility was calculated using equation 3 while the dermal absorbed dosage was calculated using equation 4.

$$\%bioaccessibility = \frac{Measured\ PTE\ concentration\ \left(\frac{mg}{kg}\right)}{Pseudototal\ concentration\ of\ PTE\ \left(\frac{mg}{kg}\right)} \quad (3)$$

$$\text{DAD} = \frac{DA_{event}*EF*ED*EV*SA}{BW*AT} \quad (4)$$

where SA (cm^2): skin surface area available for contact (1575 cm^2 for an industrial scenario with PPE, 2800 cm^2 for children and 5700 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)

The dermal absorbed dose per event (DA_{event}, mg. cm^{-event}) used in Equation 4 was calculated using equations (5) and (6) for water and soil approaches respectively:

$$DA_{event} = K_p * C_w * t_{event} \quad (5)$$

$$DA_{event} = C_{soil} * \text{CF} * \text{AF} * ABS_d \quad (6)$$

where Cw(mg/cm^3): the measured concentration of PTEs in the artificial sweat solutions (see supplementary material: Table S3); K,($cm.h^1$): dermal permeability coefficient of PTEs in water (As, Cd, Cr, Cu, Fe, Mn,: $1*10^3$; Ni: 2*10; Pb: $1*10^4$; Zn: $6*10^4$); t_{event}: h per event (event duration 8 h for industrial workers on the site; 2 h for 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; ABS: 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 equation 7

$$RfD_{ABS} = RfD_o * ABS_{GI} \quad (7)$$

RESULTS AND DISCUSSION

Physiochemical Analysis of Soil Samples

Physiochemical analysis shows the result of pH, moisture content and organic matter content of the different samples investigated. The value obtained for pH ranged from 7.5±0.05 to 8.0±0.02, indicating that the soil samples are slightly alkaline. The value of moisture content ranged from 0.5 to 1 % in the soil samples, showing relatively dry conditions. Table 1 shows the physiochemical results of different sampling areas.

Table 1. Physiochemical analysis of soil samples with respect to soil sample areas.

	Sample Locations				
Parameters	**Ijagun**	**Ikija**	**Iwaya**	**Mowe**	**Sagamu**
pH	7.8±0.10	7.5±0.05	8.0±0.02	7.6±0.08	7.7±0.01
Moisture Content (%)	1.5±0.7	0.5±0.3	0.5±0.1	1.5±0.4	1±0.09

Total Concentration (mg/kg) in the Soil samples

Total concentration in the soil of study areas showed the concentration of Cd and Mn in the soil samples. The concentration of Mn ranged from 41.41±0.5 to 69.85±0.4 mg/kg and Cd ranged from 0.76 ± 0.1 to 2.78 ± 0.3 mg/kg in the soil samples of each location as shown in Table 2. The low concentration of this metal in soil from dumpsites might be due to its mobility in soil systems.

Contamination Factor Value (CF value) of PTEs in the Soil Samples

The contamination factor was derived by comparing the total concentration of Cd and Mn with the guideline value of 4.0 mg/kg and 300 mg/kg respectively. The CF values for the Cd and Mn in the soil samples are < 1, signifying low contamination as shown in Table 3. Also, the manganese contamination in the selected area was in the increasing order of Mowe < Ikija < Ijagun < Iwaya < Sagamu, while for Cd, the increasing order of contamination was Mowe < Ijagun < Ikija < Iwaya < Sagamu.

Table 2. Total concentration (mg/kg) of Cd and Mn in the soil of study areas.

Sample Location	Cd (mg/kg)	Mn (mg/kg)
Ijagun	1.78± 0.2	65.99±0.2
Ikija	1.76±0.1	69.85±0.4
Iwaya	2.01±0.2	49.25±0.4
Mowe	0.76±0.1	69.54±0.3
Sagamu	2.78±0.3	41.41±0.5
Average World Soil	1.1	418
Onwukeme and Eze (2021) on the Identification of heavy metals source within selected active dumpsites in southeastern Nigeria	0.600	603.075
Ademola et al. (2015) on the determination of heavy metals in soil samples from some waste dumpsites in Lagos and Ogun state, south-western Nigeria	0.8	-

Table 3. Contamination factor value (CF value) of PTEs in soil samples.

Sample Location	Cd (mg/kg)	Mn (mg/kg)
Ijagun	0.45	0.22
Ikija	0.44	0.23
Iwaya	0.50	0.16
Mowe	0.19	0.23
Sagamu	0.70	0.14

The mean bioaccessible concentration of Mn and Cd (mg/kg) through oral, inhalation and dermal routes in the soil from the dumpsites

The mean concentration of Mn and Cd (mg/kg) through oral, inhalation and dermal routes showed that the oral bioaccessible concentrations of Mn and Cd in all the locations ranged from 11.57±0.08 mg/kg to 20.91±0.09 mg/kg and 0.20±0.005 mg/kg to 0.71±0.04 mg/kg respectively as shown in Table 4. The dermal bioaccessible concentrations of Mn and Cd ranged from 10.76±0.05 mg/kg to 20.70±0.002 mg/kg and 2.54±0.01 mg/kg to 4.52±0.08 mg/kg respectively. Also, the bioaccessible concentrations of Mn and Cd via the inhalation pathway ranged from 11.92±0.07 mg/kg to 22.92±0.01 mg/kg and 0.30±0.05 mg/kg to 0.71±0.08 mg/kg respectively. Therefore, the bioaccessible concentrations of Cd present in all five (5) locations were lower than the bioaccessible concentrations of Mn. While Mn is naturally abundant in soil, the presence of Cd in the soil samples could be due to corrosion of metal, batteries and indiscrimination dumping waste products on the soil (Ajah et al., 2015).

Table 4. Mean Concentration of Mn and Cd (mg/kg) through oral, inhalation and dermal exposure routes.

Sample Location	Dermal		Inhalation		Oral	
	Cd (mg/kg)	Mn (mg/kg)	Cd (mg/kg)	Mn (mg/kg)	Cd (mg/kg)	Mn (mg/kg)
Ijagun	0.25±0.01	10.76±0.05	0.31±0.03	14.11±0.006	0.20±0.02	11.57±0.08
Ikija	0.32±0.08	20.70±0.002	0.40±0.07	22.92±0.01	0.58±0.07	20.60±0.01
Iwaya	0.22±0.003	15.18±0.09	0.40±0.02	14.17±0.09	0.20±0.005	17.89±0.04
Mowe	0.64±0.06	16.47±0.01	0.30±0.05	11.92±0.07	0.30±0.03	20.91±0.09
Sagamu	0.62±0.04	14.62±0.07	0.71±0.08	18.27±0.02	0.71±0.04	17.16±0.06

Percentage (%) bioaccessibility of PTEs in the soil samples

The percentage bioaccessible of Cd for oral ranged from 9.95 to 39.47%; Mn for oral ranged from 17.50 to 41.44%; for dermal, Cd ranged from 14.27 to 50.52%; Mn for dermal ranged from 16.30 to 35.30%, Mn for inhalation ranged from 17.14 to 44.12% and for Cd ranged from 17.41 to 39.47% as displayed in Table 5.

Table 5. Percentage (%) bioaccessibility of PTEs in the soil samples.

	Dermal (%)		Inhalation (%)		Oral (%)	
Sample Location	Cd	Mn	Cd	Mn	Cd	Mn
Ijagun	14.27	16.31	17.41	21.38	11.36	17.50
Ikija	18.18	29.63	22.73	32.81	32.96	29.49
Iwaya	10.95	30.82	19.90	28.77	9.95	36.33
Mowe	84.21	23.68	39.47	17.14	39.47	30.07
Sagamu	22.30	35.54	25.54	44.12	25.54	41.44

Daily exposure dose of PTEs based on exposure pathway

Daily exposure dose of PTEs in Figure 1 showed the human absorption of Cd and Mn in all sample locations and all the sample locations cannot be hazardous to human health due to the daily dosage of human absorption through oral, dermal and inhalation processes in all the sample location which are not above the daily dosage standard within the range 10^4 to 10^{11}.

Hazard quotient (HQ) of PTEs in soil samples

Adverse health effects are unlikely to occur if HQ < 1, but if HQ >1 it indicates probable adverse health effects, and if HQ > 10, it indicates high chronic risk (USEPA, 2007). The HQ results of this indicated that the populace of these areas were not at risk of cancer caused by Cd or Mn upon ingestion of soil, or contact with soil of the area as the HQ values were < 1 as shown in Figure 2. However, the consumption of plants grown in the area may lead to adverse effects as a result of possible bioaccumulation of the PTEs in them.

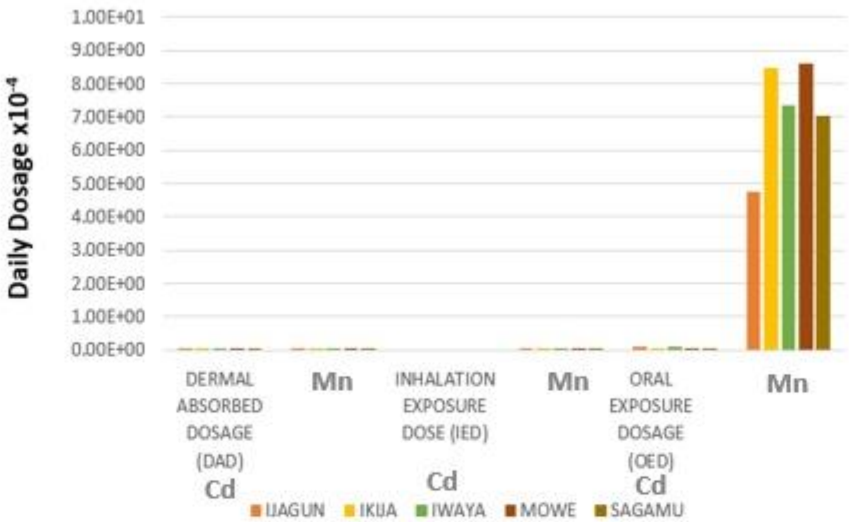

Figure 1. Daily exposure dose of PTEs based on exposure pathway (mg/kg).

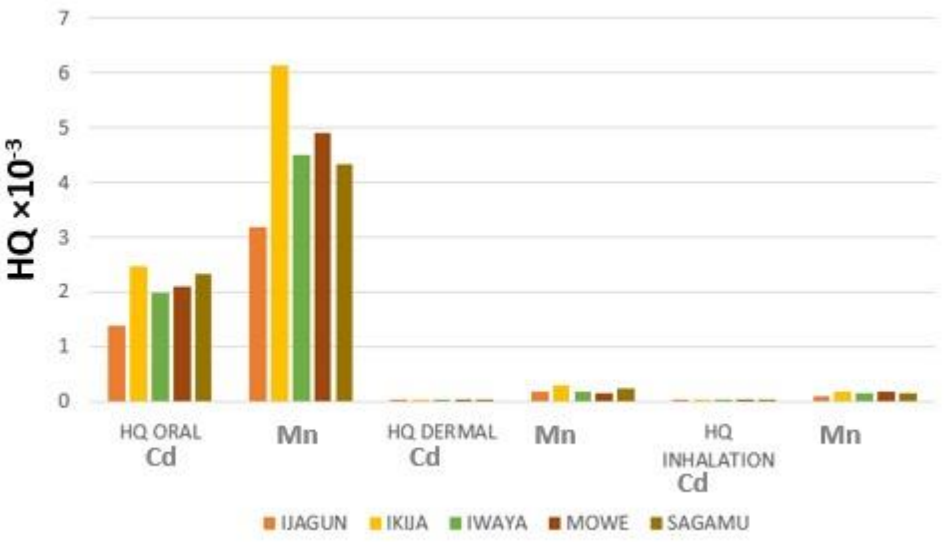

Figure 2. Hazard quotient (HQ) of PTEs in soil samples with respect to soil samples area.

DISCUSSION

Table 2 showed the concentration of Mn and Cd in the soil samples and indicated that the manganese concentration in the soil of the study area falls between the natural background levels. The concentrations of cadmium in the soil ranged from 0.76±0.1 to 2.78±0.3 mg/kg. This current study on dumpsites in Ogun State reveals higher cadmium concentrations (0.76±0.1 - 2.78±0.3 mg/kg) compared to the mean of 0.8 mg/kg reported by Ademola et al. (2015) for similar sites in Lagos and Ogun states.

The observed differences in cadmium concentrations between this current study and Ademola et al. (2015) may be attributed to several factors. Temporal changes in waste composition and disposal practices could have led to increased cadmium accumulation over time. Variations in local industrial activities near the studied dumpsites might contribute to higher metal inputs. Additionally, site-specific soil characteristics, such as pH and organic matter content, can influence metal retention and mobility.

Although cadmium levels are elevated above background, they generally remain below thresholds of immediate health concern. These values were also below the average world soil value as shown in Table 1. The contamination factor compares the total concentration of Cd and Mn concentration to the soil guideline values of 4.0 mg/kg and 300 mg/kg respectively. The contamination factors of Mn and Cd in all five (5) locations have low contamination factor CF<1 which was in line with the low contamination concentration reported by Ademola et al (2015). Also, the comparative analysis of Cd and Mn concentrations in dumpsite soils from Ogun State revealed intriguing disparities with previous studies. While Cd levels (0.76±0.1-2.78±0.3 mg/kg) align with NESREA standards and are comparable to other reports (Onwukeme and Eze, 2021; Ademola et al., 2015), Mn concentrations (41.41±0.5 - 69.85±0.4 mg/kg) are markedly lower than those found in similar investigations and global averages. The observed low contamination factors and hazard quotients especially for Mn suggest minimal risk associated with these metals in the studied dumpsites, despite the variability in concentrations across different studies.

Table 4 showed the concentrations of Mn and Cd (mg/kg) through oral, inhalation and dermal exposure routes in all five locations and the level of cadmium present in all the locations is lower than the Mn. Adverse health effects are unlikely to occur if HQ < 1, but if HQ > 1 it indicates probable adverse health effects, and HQ > 10 indicates high chronic risk (USEPA, 2007). Table 7 indicated that the populace of these areas are not at risk of cancer as a result to exposure to Cd and Mn in the soil through oral ingestion, inhalation or dermal contact.

CONCLUSION

This study revealed total concentrations of Cd ranging from 0.76±0.1 to 2.78±0.3 mg/kg and Mn from 41.41±0.5 to 69.85±0.4 mg/kg in dumpsite soils across five locations in Ogun State. Contamination factors for both elements were consistently low (CF < 1), indicating minimal enrichment. Bioaccessibility studies showed varying percentages for different exposure routes, with oral bioaccessibility ranging from 9.95% to 41.44% for both Cd and Mn. Hazard quotient (HQ) calculations for all exposure pathways were well below 1, suggesting minimal health risks. Cd contamination levels varied across sites, following the order: Mowe < Ijagun < Ikija < Iwaya < Sagamu while Mn followed the increasing order of Mowe < Ikija < Ijagun < Iwaya < Sagamu. Overall, the results indicated that while Cd and Mn are present in the dumpsite soils, their current levels do not pose significant immediate health concerns for the local population.

While the current PTE concentrations do not indicate immediate health concerns, it is crucial to implement regular monitoring programs for these dumpsites. The observed variability in Cd contamination across sites (Mowe < Ijagun < Ikija < Iwaya < Sagamu) and Mn contamination variability (Mowe < Ikija < Ijagun < Iwaya < Sagamu) suggested that PTE accumulation are possibly influence by specific factors such as variability in the activities around the dumpsites. Therefore, this study recommends conducting more comprehensive studies that include a wider range of PTEs and consider seasonal variations in soil chemistry and waste composition. Furthermore, given the potential for long-term accumulation of PTEs in dumpsite soils, it is recommended that stricter waste management policies should be developed and enforced. These should focus on proper segregation of waste, particularly electronic and industrial waste that may contribute to PTE contamination. Additionally, public awareness programmes should be implemented to educate local communities about the potential risks associated with dumpsite soils and promote safe practices when interacting with these areas.

REFERENCES

Ademola, A. K., Olaoye, M. A., & Abodunrin, P. O. (2015). Radiological safety assessment and determination of heavy metals in soil samples from some waste dumpsites in Lagos and Ogun state, south-western, Nigeria. *Journal of Radiation Research and Applied Sciences*, *8*(1), 148-153.

Ahmed Laskar, A., & Younus, H. (2019). Aldehyde toxicity and metabolism: the role of aldehyde dehydrogenases in detoxification, drug resistance and carcinogenesis. *Drug metabolism reviews*, *51*(1), 42-64.

Ajah, K. C., Ademiluyi, J., & Nnaji, C. C. (2015). Spatiality, seasonality and ecological risks of heavy metals in the vicinity of a degenerate municipal central dumpsite in Enugu, Nigeria. *Journal of Environmental Health Science and Engineering*, *13*, 1-15.

Anselm, O. H., Davidson, C. M., Oyeyiola, A. O., & Oluseyi, T. O. (2022). Effects of artificial sweat formulation and extraction temperature on estimation of the dermal bioaccessibility of potentially toxic elements in a contaminated soil from an e-waste recycling site. *Geosciences*, *12*(1), 31.

Brenko, T., Ružičić, S., Radonić, N., Puljko, M., & Cvetković, M. (2024). Geochemical factors as a tool for distinguishing geogenic from anthropogenic sources of potentially toxic elements in the soil. *Land*, *13*(4), 434.

Luo, X., Ren, B., Hursthouse, A. S., Jiang, F., & Deng, R.-j. (2020). Potentially toxic elements (PTEs) in crops, soil, and water near Xiangtan manganese mine, China: Potential risk to health in the foodchain. *Environmental Geochemistry and Health*, *42*(7), 1965-1976.

Mafulul, S. G., Joel, E. B., & Gushit, J. (2023). Health risk assessment of potentially toxic elements (PTEs) concentrations in soil and fruits of selected perennial economic trees growing naturally in the vicinity of the abandoned mining ponds in Kuba, Bokkos Local Government Area (LGA) Plateau State, Nigeria.

Environmental Geochemistry and Health, *45*(8), 5893-5914.

Ojo, S. S., Tpl, D. B., & Pojwan, M. A. (2017). Urbanization and urban growth: Challenges and prospects for national development. *Journal of Humanities and Social Policy*, *3*(1), 65-71.

Onwukeme, V. I., & Eze, V. C. (2021). Identification of heavy metals source within selected active dumpsites in southeastern Nigeria. *Environmental Analysis, Health and Toxicology*, *36*(2).

Yahaya, T. O., Ogundipe, O. A., Abdulazeez, A., Usman, B., & Danjuma, J. (2020). Bioaccumulation and Health Risk Assessment of Heavy Metals in Three Vegetables Consumed in Lagos, South-West Nigeria: doi. org/10.26538/tjnpr/v4i1. 3. *Tropical Journal of Natural Product Research (TJNPR)*, *4*(1), 14-20.

Yan, L., Franco, A.-M., & Elio, P. (2021). Health risk assessment via ingestion and inhalation of soil PTE of an urban area. *Chemosphere*, *281*, 130964.

Zhang, X., Zou, G., Chu, H., Shen, Z., Zhang, Y., Abbas, M. H., Albogami, B. Z., Zhou, L., & Abdelhafez, A. A. (2023). Biochar applications for treating potentially toxic elements (PTEs) contaminated soils and water: a review. *Frontiers in Bioengineering and Biotechnology*, *11*, 1258483.