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OPEN LANDFILL AS A SOURCE OF PUBLIC HEALTH RISK DUE TO ACCUMULATION OF TOXIC METALS (TMs) IN THE TOP SOIL

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Background: Metal contamination caused by various anthropogenic sources, which affect the environment has become a global health concern. In many countries, including Nigeria, open landfills continue to be a prevalent method of waste disposal, despite increasing awareness of their environmental impacts. Through natural processes, heavy metals are leached from waste containing metal components, which increases the risks to public health. **Objectives:** This study aims to: (i) determine the level of heavy metal contamination in the topsoil of an open landfill site in Abeokuta, Ogun State, Nigeria; (ii) assess the potential health risks to adults and children associated with exposure to toxic metals. It is envisaged that the study will fill the information gap to develop a strategy to mitigate the negative impacts of the open landfill site in Abeokuta on the environment and health to achieve Sustainable Development Goals (SDGs) 3 and 15. **Methods:** For the study, 18 samples in duplicate were collected from the landfills. Exactly, 1g of the sample was digested using the aqua regia method while TMs were analysed using Atomic Absorption Spectrometer. Geo-accumulation index (I-geo) and Enrichment factor (EF) were employed to determine degree of pollution while health risk assessment was estimated using US EPA predictive model, and Pearson correlation for source apportionment. **Results:** The mean TMs concentrations were found to be 0.825 mg/kg for Cd, 23.6 mg/kg for Pb, 12.3 mg/kg for Cu, 2.14 mg/kg for Ni and 335 mg/kg for Zn, which were within the recommended soil values. The I-geo index reveals moderate contamination from Cd – 0.27 mg/kg and Zn – 0.37 mg/kg while EF showed a moderate enrichment from Pb – 5.06 mg/kg and severe enrichment from Cd – 11.9 mg/kg and Zn – 15.1 mg/kg in the soil. The relationship between the TMs suggests an emergence from both natural and anthropogenic sources. Potential health risk assessment reveals that skin contact was the major pathway of exposure to TMs in the landfill, it also predicted a non-significant non-cancer risk and negligible cancer risk. **Conclusion:** The top soil in the open landfills at the time of the study are safe and pose no health risk.

Keywords: toxic metals; health risk; landfill; top soil; pollution; terrestrial ecosystems; SDGs 3; sustainable management.

INTRODUCTION

Landfilling is the most traditional method of solid waste disposal worldwide. Although it poses potential risks to both the environment and human health, its simplicity and affordability make it a common choice for managing municipal solid waste globally (Najafi et al., 2020; Wdowczyk & Szymańska-Pulikowska, 2021; Wang et al., 2022). Several studies have recorded elevated levels of various metals, including cadmium (Cd), lead (Pb), zinc (Zn), copper (Cu), and chromium (Cr), often exceeding background concentrations in the soil (Karimian et al., 2021; El Fadili et al., 2022; de Souza et al., 2023).

In Nigeria, open landfills continue to be a prevalent method of waste disposal, despite increasing awareness of their environmental impacts (Osifeso et al., 2025). Abeokuta, a city in Ogun State, Nigeria, is no exception. The landfills in Abeokuta accept municipal, industrial, and agricultural waste, much of which contains hazardous metals. Additionally, the proximity of residential areas to the landfill raises concerns about the long-term health risks associated with exposure to toxic metals (TMs) in the soil (Famuyiwa et al., 2025). A study on landfill contamination in Nigeria highlight significant TM pollution in the soil around landfills (Ajah et al., 2015). A study by Ogbaran & Uguru (2021) reported the concentration of TMs in landfills, ranking them as follows: iron (Fe) > lead (Pb) > nickel (Ni) > cadmium (Cd).

Assessing the health risks from metal pollutants is crucial, as exposure to toxic metals (TMs) like lead (Pb) can severely damage the immune, skeletal, nervous, and circulatory systems and inhibit enzyme functions. Long-term exposure to cadmium (Cd) is associated with serious health conditions, including lung cancer, prostate disorders, renal dysfunction, and fractures. Other toxic metals have also been linked to cancer (Olujimi et al., 2015; Alghamdi et al., 2019).

The composition of waste at dumping sites varies based on the specific characteristics of each neighbourhood. It is estimated that Nigeria generates approximately 20 kg of solid waste per person per year, which amounts to around 1.8 million tons annually (Onu et al, 2012). This significant waste production contributes to the accumulation of toxic metals in Nigerian soils, particularly if the solid waste contains metal components. Toxic metals undoubtedly pose health risks to local residents.

This study aims to: (i) determine the level of heavy metal contamination in the topsoil of an open landfill site in Abeokuta, Ogun State, Nigeria; (ii) assess the potential health risks to adults and children associated with exposure to toxic metals. It is envisaged that the study will fill the information gap to develop a strategy to mitigate the negative impacts of the open landfill site in Abeokuta on the environment and health to achieve Sustainable Development Goals (SDGs) 3 and 15.

MATERIALS AND METHODS

Research area

The current research was conducted in Abeokuta (7.1475° N, 3.3619° E) Ogun State, Nigeria. The city spans an approximate area of 40.63 km^2. Nestled within the Nigerian rainforest, Abeokuta is situated atop a basement complex composed of volcanic rocks, which are overlain by various layers of sedimentary rock. As the human population continues to grow, the volume of solid waste in Abeokuta is increasing (Osifeso et al., 2025). Approximately 50% of the daily solid waste generated in the city is collected by the Ogun State Environmental Protection Agency, concerned citizens, and private waste management companies. Waste is often discarded along the city's streets, with an average waste generation rate of 0.60 kg/person/day. The remaining 50% is either buried, incinerated, or disposed of in available land areas, as well as in lagoons, streams, and drainage systems (Famuyiwa et al., 2025).

The open landfill is situated between latitudes 07011.201° N and 07011.480° N, and longitudes 003021.001° E and 003022.250° E. The landfill, covering an area of about 119,000 m^2, is the largest solid waste disposal site in Abeokuta, Ogun State, Nigeria. The vegetation and stream flow in the study area are affected by the climate, which exhibits the wet and dry seasons typical of Nigeria's sub-humid and humid regions (Famuyiwa et al., 2025). Throughout the year, the average maximum temperature is 32 °C, while the annual average rainfall is 1237 mm. The map depicting the open landfill is illustrated in Figure 1.

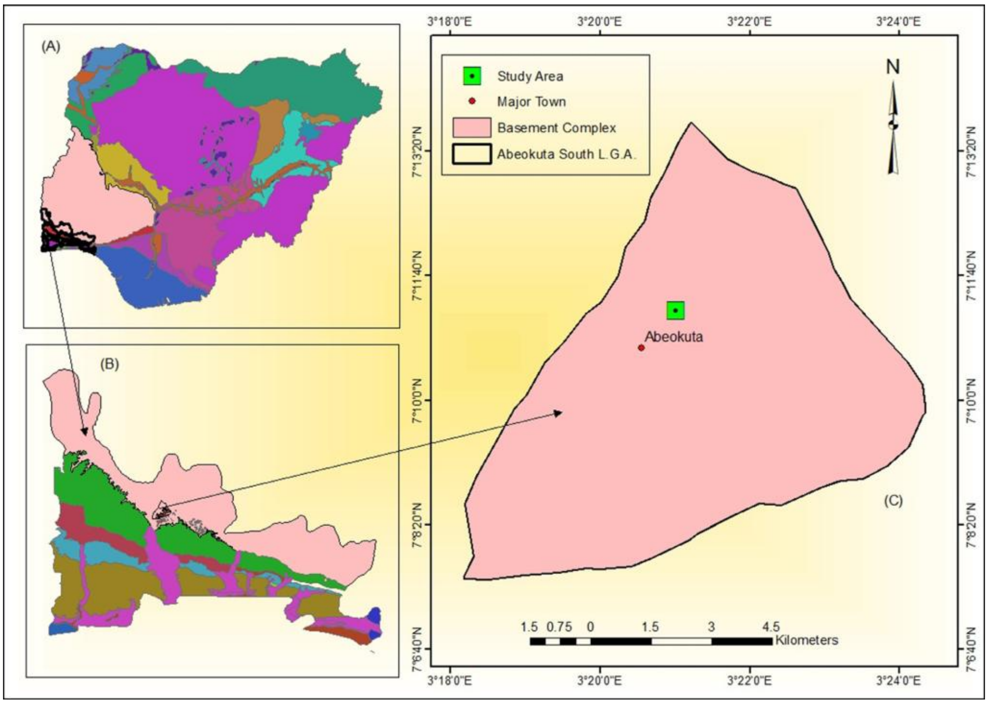


Figure 1. Map of Abeokuta showing the open landfill
(Famuyiwa et al., 2025; Osifeso et al., 2025, *Creative Commons Attribution License International CC-BY 4.0*)

Soil collection and processing

The soil samples were collected randomly in July 2024 from 18 different points at the open landfill in Abeokuta, Ogun State, Nigeria. Soil was gathered from the landfill at each sampling point, where representative samples were taken from a depth of 0 – 10 cm using a hand auger. Before collecting the soil samples, careful removal of polythene bags, nylon and plant materials was done. This procedure was repeated at all sampling points, with approximately 500 g of the bulk sample collected from each site in duplicate. The soil samples were stored in sealed, airtight polythene bags and labelled appropriately.

Analysis of toxic metals

Before digestion, the samples underwent multiple reductions through a process of coning and quartering. Glass and plastic equipment were soaked in 5% nitric acid overnight and thoroughly rinsed with distilled water. The soil samples were air-dried for 3 days, after which they were crushed and sieved using a 1 mm mesh size. Next, the samples were digested with aqua regia (1 part HNO_3 to 3 parts HCl). Digestion flasks for each soil sample were dried in an oven at 35 °C for 15 min. Then, 1 g of each soil sample was placed into a labelled, oven-dried flask, and 20 mL of aqua regia was added. The mixture was gently stirred to ensure homogeneity and subsequently heated in a fume cupboard for several hours without a specific time reference. After cooling, the samples were filtered and diluted with deionized water to a total volume of 50 mL. The diluted samples were stored in labelled vials for analysis using an atomic absorption spectrophotometer.

Quality control

Quality control in the study was conducted according to the guidelines established by Umoren et al. (2024a). The recovery results of pseudo-total metals from the reference material showed a good match with the target values, within ± 10%. Using guidance materials was crucial to ensure both precision and accuracy in the employed methods. Reagent blanks were included to monitor any potential contamination. The consistency of the instrument was periodically checked by verifying the calibration standards after every tenth sample. A clear linear fit was achieved for the calibration curve for each toxic metal (TM).

Pollution assessment

Geo-Accumulation index (I-geo)

The I-geo for the TMs was calculated according to Famuyiwa et al. (2024) as stated in Equation 1:

$$\text{I-geo} = \text{Log } 2 \ \ (TMC_s/1.5 \cdot BTMC_{EC}), \tag{1}$$

I-geo is the geo-accumulation index; TMC_s is toxic metal (TMs) concentration, that is the level of TMs in the soil; $BTMC_{EC}$ is the background level TM in the earth's crust; 1.5 is the correction factor used to adjust the background data to account for lithogenic effect; The classification for I-geo is described as follows:

– I-geo < 0 – practically 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.

This classification helps to evaluate the level of pollution in the soil based on the presence of toxic metals.

Enrichment factor (EF)

The method for estimating the EF for the soil was according to Umoren et al. (2024a) as stated in Equation 2:

$$EF = \frac{TMC_s}{TMC_s^{ref}} / \frac{BTMC_{EC}}{BTMC_{EC}^{ref}}, \tag{2}$$

where EF is enrichment factor; TMC_s^{ref} is the level of TMs in the soil for the reference element; $BTMC_{EC}$ is the background level TM in the earth's crust for the reference element.

In the study, iron (Fe) was used as the reference element for normalization (Famuyiwa et al., 2024; Umoren et al., 2024a). There are five degrees of pollution based on the EF:

– EF – no enrichment;
– EF = 2 – 5 – moderate enrichment;
– EF = 5 – 20 – severe enrichment;
– EF = 20 – 40– very high enrichment;
– EF > 40 – extremely high enrichment.

Probable health risk assessment

Human health risk assessment is risk characterization of the potential adverse health effects of human exposure to TMs. Furthermore, human exposure to TMs are mainly through ingestion, inhalation and dermal contact (Famuyiwa et al., 2024). The mean daily dose (MDD) of TMs was estimated using Equation 3 – 5.

$$MDD_{ingest} = \frac{C \cdot IngR \cdot MEF \cdot ED}{BW \cdot AT} \cdot 10^{-6}, \tag{3}$$

$$MDD_{inhale} = \frac{C \cdot InhR \cdot MEF \cdot ED}{PEF \cdot BW \cdot AT}, \tag{4}$$

$$MDD_{dermal} = \frac{C \cdot SAF \cdot SA \cdot ABS \cdot MEF \cdot ED}{BW \cdot AT} \cdot 10^{-6}, \tag{5}$$

where MDD is mean daily dose of exposure to TMs across various exposure pathways, including ingestion, inhalation, and dermal contact, mg/kg/day; C is the concentration of TMs in the soil; IngR is the daily ingestion rate; InhR is the daily inhalation rate; *M*EF is the exposure frequency over specific days each year; ED is the duration exposure; BW is body weight; AT is average time for evaluating both cancer and non-cancer metals; SA is skin exposed area; SAF is skin adherence factor; ABS dermal absorbance factor; PEF is particle emission factor.

The parameters utilized for human health risk assessment are summarized in Table 1.

Table 1. Parameters used for health risk assessment

Parameters	Units	Children	Adult
Body weight BW	kg	15	70
Exposure frequency *M*EF	days/year	180	365
Exposure duration ED	years	6	24
Ingestion rate IngR	mg/day	200	100
Inhalation rate InhR	m^3/day	7.63	20
Skin surface area SA	cm^2	2800	3300
Soil adherence factor SAF	mg/cm^2	0.2	0.7
Dermal absorption factor ABS	none	0.1	0.1 or 0.001 for Cd
Particulate emission factor PEF	m^3/kg	$1.36 \cdot 10^9$	$1.36 \cdot 10^9$
Average time AT	days	25550	25550

Non-Cancerous risk assessment

The hazard index (HI) method was used to assess the health risk due to exposure to TMs in the soil. Before calculating HI, a hazard quotient (HQ) based on non-cancer toxic risk was calculated for individual TMs using Equation 6:

$$HQ = \frac{MDD}{RfD}, \tag{6}$$

where HQ is hazard quotient; MDD is mean daily dose of exposure to toxic metals (TMs) across various exposure pathways, including ingestion, inhalation, and dermal contact, mg/kg/day; RfD is mean daily dose for the reference element.

To assess the overall potential of non-cancer risk posed by more than one TM, the calculated values of HQ for each TM were summed, which expressed the hazard index (HI):

$$HI = \sum HQ_i, \tag{7}$$

where HQ_i is hazard quotient for each exposure pathway.

To interpret the results of HQ and HI, values >1 indicate that there is a chance for non-cancer risk, and HI, values <1 indicate that there is no significant non-cancer risk (Famuyiwa et al., 2022; Famuyiwa et al., 2024; Umoren et al., 2024a).

Cancerous risk assessment

The method was used to assess the cancer risk (CR) of human exposure to TMs in the soil was conducted using the Equation 8:

$$CR = MDD \cdot CSF, \tag{8}$$

where CSF is the cancer slope factor, mg/kg·day.

$$TCR = \sum CR_i, \tag{9}$$

where CR_i is the cancer risk for each exposure pathway; TCR is the total cancer.

To interpret the results of TCR, the TCR value above the acceptable threshold ($1 \cdot 10^{-6}$ – $1 \cdot 10^{-4}$) indicates a potential cancer risk which increases the probability of the person developing cancer over their lifetime.

Data analysis

Data was analysed using statistical package for social sciences SPSS version 21 for descriptive statistics, Microsoft Excel 2013 was used for data visualization while Pearson correlation at 95% confidence level were determine the relationship between TMs.

RESULTS AND DISCUSSIONS

Concentration of toxic metals in soil

The concentrations of toxic metals (TMs) presented in Table 1 indicate the following: Iron (Fe) concentration ranges from 7490 to 16900 mg/kg, with a mean of 11000 ± 2,840 mg/kg. In the human body, iron plays a vital role. Iron (Fe) is present in protein structures like haemoglobin and myoglobin, which together constitute about 4 g of an adult's body weight. These proteins are essential for various metabolic functions in humans and are involved in the transport and storage of oxygen in muscles (Umoren et al., 2024c).

Exposure to lead (Pb) can cause lead poisoning, which adversely affects the human body, potentially resulting in issues in the brain, intestines, and stomach (Umoren et al., 2024a). Lead (Pb) concentration spans from 4.17 to 93.1 mg/kg, with a mean of 23.6 ± 24.0 mg/kg. However, all samples were within the soil guideline values (SGV) by the UK – 450 mg/kg, Canada – 140 mg/kg, and Dutch intervention levels 530 mg/kg. Nickel (Ni), although present in small amounts, is utilized by the human body for nourishment (Taiwo et al., 2019). Nickel concentration in the study varies from 0.86 to 4.15 mg/kg, with a mean of 2.14 ± 1.08 mg/kg. All samples were within the soil guideline values (SGV) by the UK (130 mg/kg). Nickel is a carcinogen that can result in teratogenic effects, pulmonary embolism, chronic bronchitis, heart issues, and cancers of the prostate nose and throat (Umoren et al., 2024b).

Copper (Cu) is an essential trace element needed for health within specific limits (Nair et al., 2014). Copper (Cu) concentrations range from 0.82 to 25.5 mg/kg, with a mean of 12.3 ± 6.81 mg/kg. the Cu concentration in all samples were within the SDV for the Canada (140 mg/kg) and the Dutch (190 mg/kg). Cadmium (Cd) ranks as the sixth most dangerous element according to ATSDR (Negahdari et al., 2021). cadmium (Cd) concentrations range from 0.14 to 2.86 mg/kg, with a mean of 0.825 ± 0.756 mg/kg. All samples all samples were within the SDV for UK – 150 mg/kg, Canada – 22 mg/kg and the Dutch – 12 mg/kg.

Zinc is a crucial trace mineral; as even minor quantities are important for human well-being. Excessive zinc exposure may lead to symptoms such as nausea, diarrhoea and vomiting (Willoughby & Bowen, 2014). Zinc (Zn) concentration ranges from 170 to 549 mg/kg, with a mean of 335 ± 101 mg/kg. Ten samples, accounting for 55.6%, were higher than or very close to the Canadian SGV – 360 mg/kg, yet within the Dutch – 720 mg/kg. Manganese (Mn) concentration ranges from 27.7 to 112 mg/kg, with a mean of 49.4 ± 23.0 mg/kg. Manganese (Mn) is a widely occurring element in the Earth's crust and is commonly found throughout the environment (Shrivastava & Mishra, 2011). Overall, the findings suggest that while some metals, particularly zinc and iron, exhibited higher concentrations in certain samples, none exceeded the SGVs established by regulatory authorities in the UK, Canada, and the Netherlands.

Degree of pollution

The evaluation of pollution levels was conducted using the geo-accumulation index I-geo and the enrichment factor EF. The I-geo values, presented in Table 2, indicate that the landfill top soil is moderately polluted with Cd (0.27) and Zn (0.37). In contrast, the soil is unpolluted with Pb (-0.10), Ni (-1.68), Mn (-0.41), Cu (-0.74) and Fe (-0.81). The trend for these toxic metals is as follows: Zn > Cd > Pb > Cu > Fe > Mn > Ni. Furthermore, EF reveal that four of the toxic metals (Fe, Ni, Cu, and Mn) in the landfill soil exhibit minimal enrichment while Pb shows moderate enrichment, Cd and Zn demonstrate severe enrichment. The trend for these toxic metals appear in the same pattern with the I-geo values: Zn > Cd > Pb > Cu > Fe > Mn > Ni.

Table 2. Descriptive statistic, geo-accumulation index (I-geo) and enrichment factor (EF)

TMs, mg/kg	Mean± Std. Dev.	Range, Min-Max	Soil Guideline Values (SGV)			I-geo	EF	Degree of pollution
			UK	CSGV	DIV			
Fe	11000 ± 2840	7486 – 16880	–	–	–	-0.81	1	Unpolluted/ No enrichment
Pb	23.6±24.0	0.208 – 93.7	450	140	530	-0.10	5.06	Unpolluted/ Moderate enrichment
Ni	2.14±1.08	0.135 – 4.60	130	–	–	-1.68	0.14	Unpolluted/ No enrichment
Cu	12.3±6.81	0.297 – 25.7	–	140	190	-0.74	1.17	Unpolluted/ Minimal enrichment
Cd	0.825±0.756	0.124 – 2.87	150	22	12	0.27	11.9	Moderately polluted/ Severe enrichment
Zn	335±101	170 – 549	–	360	750	0.37	15.1	Moderately polluted / Severe enrichment
Mn	49.4±23.0	18.9 – 113	–	–	–	-1.41	0.25	Unpolluted/ No enrichment

Note: UK (https://www.gov.uk/government/organisations/environment-agency), Environment Agency (2013); CSGV (https://ccme.ca/en/current-activities/canadian-environmental-quality-guidelines), Canada (2009); DIV (https://support.esdat.net/Environmental%20Standards/dutch/annexs_i2000dutch%20environmental%20standards.pdf), New Dutch List (2000)

Correlation matrix

The connections between TMs can offer important insights regarding their origins and movement through the environment. As stated by Umoren et al. (2024a; 2024b), strong positive correlations among toxic metals (TMs) usually suggest that the sources of pollution are similar. In contrast, weak or negative correlation coefficients typically indicate different pollution sources, which can generally be linked to natural factors. The correlation coefficient between the TMs are shown in Table 3. Iron (Fe) showed a strong relationship with Ni ($r = 0.782$, $p < 0.01$), Cu ($r = 0.513$, $p < 0.01$), and Zn ($r = 0.857$, $p < 0.01$). It also had a moderate correlation with Mn ($r = 0.359$, $p < 0.05$). lead (Pb) demonstrated a moderate and significant relationship with Zn ($r = 0.335$, $p < 0.05$) and a strong relationship with Mn ($r = 0.737$, $p < 0.01$).

Table 3. Correlation matrix of toxic metals in soil

	Fe	Pb	Ni	Cu	Cd	Zn	Mn
Fe	1						
Pb	0.249	1					
Ni	0.782**	0.256	1				
Cu	0.513**	0.290	0.405*	1			
Cd	0.073	0.206	0.039	0.473**	1		
Zn	0.857**	0.335*	0.613**	0.648**	0.144	1	
Mn	0.359*	0.737**	0.514**	0.318	0.154	0.320	1

Note: ** – correlation is significant at the 0.01 level; * – correlation is significant at the 0.05 level

Ni was significantly and moderately correlated with Cu ($r = 0.405$, $p < 0.05$), Pb ($r = 0.613$, $p < 0.01$), and Mn ($r = 0.514$, $p < 0.01$). Copper also had a moderate correlation with Cd ($r = 0.473$, $p < 0.05$) and a stronger relationship with Zn ($r = 0.648$, $p < 0.01$). Overall, Fe is related to the majority of the TMs, indicating a strong interconnectedness among these metals. This suggests that the TMs originates from both anthropogenic and natural sources.

Probable health risk assessment

Mean daily dose (MDD)

The mean daily exposure to toxic metals in soil from the open landfill, as presented in Table 4, indicates that the primary source of exposure is dermal contact. Adults are more susceptible to exposure from Fe, Cu, and Cd, while children are particularly vulnerable to Pb, Ni, Zn and Mn. The hazard index HI values, shown in Table 5 reveal that all the (Figure 2a, 2b) have value < 1, indicating non-cancer risk. The hazard index follows this pattern:

Pb > Ni > Zn > Mn > Cu > Cd.

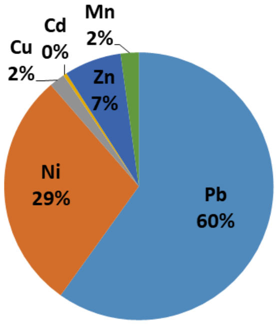
Total cancer risk TCR values presented in Table 6 demonstrate that the toxic metals, including Pb, Ni and Cd are all below $1 \cdot 10^6$. This suggests a negligible. The pattern of cancer risk identified shows a trend of Pb > Cd > Ni.

Table 4. Mean daily dose exposure of TMs in soil

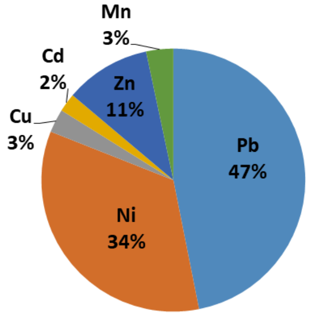
Receptor	Exposure route	Toxic metals						
		Fe	Pb	Ni	Cu	Cd	Zn	Mn
Adult	MDD_{ingest}	2.66E-02	5.71E-05	5.18E-06	2.98E-05	2.00E-06	8.11E-04	1.20E-04
	MDD_{inhale}	5.32E-09	1.14E-11	1.04E-12	5.95E-12	3.99E-13	1.62E-10	2.39E-11
	MDD_{dernal}	6.15E-01	1.32E-03	1.20E-04	6.88E-04	4.61E-08	1.87E-02	2.76E-03
Children	MDD_{ingest}	6.21E-02	1.33E-04	1.21E-05	6.95E-05	4.66E-06	1.89E-03	2.79E-04
	MDD_{inhale}	2.36E-09	5.06E-12	4.59E-13	2.64E-12	1.77E-13	7.19E-11	1.06E-11
	MDD_{dernal}	1.74E-01	3.73E-04	3.38E-05	1.94E-04	1.30E-08	5.30E-03	7.81E-04

Table 5. Non cancer risk of exposure too TMs in soil

Receptor	Exposure route	Toxic metals					
		Pb	Ni	Cu	Cd	Zn	Mn
Adult	HQ_{ingest}	1.90E-04	4.71E-05	7.45E-04	2.00E-03	2.70E-03	8.57E-04
	HQ_{inhale}	–	1.76E-08	–	3.99E-10	–	4.78E-10
	HQ_{dernal}	3.77E-01	2.73E-01	1.72E-02	1.84E-03	6.23E-02	1.97E-02
	$\sum HQ_i = HI$	3.77E-01	2.73E-01	1.79E-02	3.84E-03	6.50E-02	2.06E-02
Children	HQ_{ingest}	4.43E-04	1.10E-04	1.74E-03	4.66E-03	6.30E-03	1.99E-03
	HQ_{inhale}	–	7.77E-09	–	1.77E-10	–	2.12E-10
	HQ_{dernal}	1.07E-01	7.68E-02	4.85E-03	5.20E-04	1.77E-02	5.58E-03
	$\sum HQ_i = HI$	1.07E-01	7.69E-02	6.59E-03	5.18E-03	2.40E-02	7.57E-03



a



b

Figure 2. Percentage contribution of individual metals to hazard index HI in soil: a – adult HI; b – children HI

Table 6. Cancer risk of exposure to TMs in soil

Receptor	Exposure route	Toxic metals		
		Pb	Ni	Cd
Adult	CR_{ingest}	4.85E-07	–	–
	CR_{inhale}	–	3.22E-12	2.51E-12
	CR_{dernal}	–	–	–
	$\sum CR_i = TCR$	4.85E-07	3.22E-12	2.51E-12
Children	CR_{ingest}	1.13E-06	-	-
	CR_{inhale}	–	1.42E-12	1.12E-12
	CR_{dernal}	–	–	–
	$\sum CR_i = TCR$	1.13E-06	1.42E-12	1.12E-12

CONCLUSION

The study revealed that the concentrations of TMs in the top soil from the open landfill were within the soil guideline values for the UK, Canada, and the Netherlands. Although exhibiting severe enrichment with Cd and Zn. Furthermore, the obvious relationships between the TMs suggest an emergence from natural and anthropogenic origin. However, the population is not at risk of non-cancer or cancer-related diseases due to the exploitation of the open landfill site in Abeokuta, Ogun State, Nigeria. Further studies should investigate other metals and emerging contaminants. Additionally, the surrounding water sources be monitored.

Author's statements

Contributions

Conceptualization: O.D.U., C.G.O., O.O.A.; Data curation: all authors; Investigation: O.D.U., C.G.O., O.O.A.; Methodology: all authors; Resources: C.E., E.O.E.; Software: all authors; Supervision: O.D.U.; Visualization: J.O., L.A.B.; Writing – original draft: O.O.A.; Writing – review & editing: all authors.

Declaration of conflicting interest

The authors declare no competing interests.

Financial interests

The authors declare they have no financial interests.

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Data availability statement

No data were used for the current study.

AI Disclosure

The authors declare that generative AI was not used to assist in writing this manuscript.

Ethical approval declarations

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