

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/366819045>

Ecotoxicological and health risk assessment of toxic metals and metalloids burdened soil due to anthropogenic influence

Article in *Environmental Chemistry and Ecotoxicology* · January 2023

DOI: 10.1016/j.eneco.2022.12.002

CITATIONS

0

READS

31

8 authors, including:



Omobolaji O. Afolabi

University of Port Harcourt

11 PUBLICATIONS 16 CITATIONS

[SEE PROFILE](#)



Wali Elekwachi

University of Nigeria

37 PUBLICATIONS 95 CITATIONS

[SEE PROFILE](#)



Sunny Oghenefegor Asomaku

University of Port Harcourt

7 PUBLICATIONS 3 CITATIONS

[SEE PROFILE](#)



Nnamdi Chimaobi Ogbuehi

University of South Wales

6 PUBLICATIONS 5 CITATIONS

[SEE PROFILE](#)

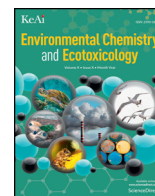
Some of the authors of this publication are also working on these related projects:



Ecotoxicological Risk Assessment of Remediated Oil Spill Site in Niger Delta, Nigeria. [View project](#)



Analysis of Risk perceptions to road accident amongst Nigerian Union of Road Transport Worker (NURTW) in Rivers State, Nigeria. [View project](#)



Ecotoxicological and health risk assessment of toxic metals and metalloids burdened soil due to anthropogenic influence

Omobolaji O. Afolabi^{a,*}, Elekwachi Wali^b, Sunny O. Asomaku^c, Olushola, I.T. Yemi-Jonathan^c, Nnamdi C. Ogbuehi^d, Lilian C. Bosco-Abiahu^e, Maureen C. Orji^f, Victoria O. Emelu^c

^a Institute of Natural Resources, Environment and Sustainable Development, University of Port Harcourt, Port Harcourt, Nigeria

^b Department of Geography, University of Nigeria, Enugu, Nigeria

^c Disaster Risk Management and Development Studies, University of Port-Harcourt, Nigeria

^d Public Administration, National Open University, Lagos, Nigeria

^e Department of Environmental Management, Federal University of Technology Owerri, Owerri, Nigeria

^f Development Studies, University of Passau, Passau, Germany

ARTICLE INFO

Keywords:

Health risk assessment
Ecological risk
Landfill
Carcinogenic metals
Heavy metals

ABSTRACT

Landfill area is one of developing countries' most common anthropogenically contaminated sites. The pressure of urbanization has led to increased waste generation in major cities, commonly deposited in landfills; hence, heavy metals contaminations are closer to the human environment than ever. The study assessed the environmental risk of Arsenic (As), Cadmium (Cd), Zinc (Zn), Manganese (Mn), Copper (Cu), Cobalt (Co), Chromium (Cr), Nickel (Ni), and Lead (Pb) in an abandoned landfill system and health-related risk using United State Environmental Protection Agency model. The Concentration of the elements descended as follows; Mn > Zn > Cr > Pb > Cu > Ni > Co > As > Cd and exceeded the WHO permissible limit. The Enrichment factor (EF) and potential ecological risk (ER) indicated no enrichment and low risk for all the elements except Cd (3.67, 426), with moderate enrichment and very high ecological risk. The hazard index (HI) value of the elements indicated no significant risk of non-carcinogenic effect for both Adults and Children except for Mn in Children with a value of 1.69×10^0 ; however, the HI value of the elements descended as; Co > Mn > Zn > As > Cd > Cu > Pb > Ni > Cr for adult and Mn > Cd > Co > Cr > As > Zn > Pb > Cu > Ni for children. The total carcinogenic risk (TCR) value of the toxic metals descended as Ni > Cd > Cr > As > Pb for both adults and Children, while the metals showed no carcinogenic to acceptable risk to humans. The Principal Component Analysis (PCA) indicated that the metals have similar sources and distribution which could be both lithogenic and anthropogenic influenced. Engaging the environment through sustainable practices will ensure efficient waste disposal and management.

1. Introduction

Solid waste management (SWM) remains challenging in many developing countries, including Nigeria. This challenge can be attributed to the ever-growing population, demand for urbanization and industrialization, inefficient utilization of resources, and poor governance. According to the World Bank Report [1], the amount of municipal solid waste (MSW) generated across South Asia, Latin America, and Sub-Saharan Africa will double or triple by the year 2050, making up 35% of the global MSW. MSW is among several human activities that have exposed the environment to many toxic substances [2], causing the various degree of impact on soil

[3,4], water [5–8], air [9,10], and not excluding human [11,12]. Waste generated in many urban areas of Nigeria comprises several materials and by-products [13,14] capable of releasing toxic agents such as lead, cadmium, mercury, cobalt, arsenic, and other toxic metals into the environment [15].

In Nigeria, the most used method of waste disposal is through the landfill system due to its simplicity and least cost of maintenance [16]; however, this method easily causes the release of toxic substances into the environment. Landfills or dumpsites remain one of the most common human-induced contaminated sites in many developing countries, including Nigeria; hence, toxic substances (such as carcinogenic heavy metals) are

* Corresponding author.

E-mail address: omobolaji.afolabi@uniport.edu.ng (O.O. Afolabi).



Production and hosting by Elsevier on behalf of KeAi

closer to the human environment than ever. This is generally due to poor landfill management and leachate contamination prevention, and some are cited close to the living environment, which is of significant concern to public health [17].

Reduced soil quality due to heavy metals contamination poses a risk to human health and the environment [18–20] due to their toxicity, even at low Concentration, environmental persistence, and bioaccumulation capacity [21]. Heavy metals can be transferred into the human body through skin contact (derma absorption), consumption of contaminated food (ingestion), and breathing (inhalation) [22]. Several studies have been conducted to estimate the magnitude of heavy metals in the environment and their potential risk to human health [23–27]. Management of environmental pollutants can be initiated through regular quantification of the environmental load of the pollutants [21]. According to Tanee and Eshalomi [28], the Concentration of heavy metals in the soil is a vital assessment to ascertain the risk level of the environmental medium and its status. Therefore, quantifying the heavy metals in the soil around and within the anthropogenically impacted area is essential and can help provide appropriate remedial measures [14,29,30]. Due to the inter-relation between human and their environment, there is a great possibility that the presence of pollutants in the environment can find its way into the human system through various means; therefore, risk assessment to quantify the Concentration of the pollutant in the environment should also consider the human exposure and risk factor. Health and environmental risk assessment of pollutants considered the potential adverse effects on the environment and human wellbeing based on the Concentration of the pollutants in the environment.

Aside from the use of physical, chemical, and biological parameters to determine the contamination/pollution status of heavy metals in the environment, various phenomena have been developed to determine the heavy metals risks and status in the environment and human risk

[25,31,32]. Recently, the pollution status of the environmental mediums has been assessed through robust parameters such as contamination factors (CF), geo-accumulation indexes (Igeo), and enrichment factors (EF) [33]. Similarly, human health risk is assessed through cancer risk (CR) and hazard index (HI) parameters as a means to ascertain the possible carcinogenic and non-carcinogenic risks to humans, respectively [25].

2. Method and materials

2.1. Study area

The dumpsites are located within the Obio/Akpor Local Government Area of Rivers State, a maritime state in the southern geopolitical zone of Nigeria. It is located between latitudes $4^{\circ}30'0''\text{N}$ and $5^{\circ}30'0''\text{N}$ and longitude $6^{\circ}30'0''\text{E}$ and $7^{\circ}30'0''\text{E}$. The landfill is located along the Eagle Cement Factory off the Rumuolumeni road, which housed both abandoned and active dumpsites. The abandoned dumpsite was selected for the study, located on the coordinate $4^{\circ}48'23.4''\text{N}$ and $6^{\circ}56'35.6''\text{E}$ (Fig. 1). The dumpsite was abandoned in 2014 after 12 years of establishment, and it is about 200 m long and 150 m wide with residential buildings and mechanic workshops scanty situated around the landfill. The Rivers State Environmental Sanitation Authority is currently using the active dumpsite.

2.2. Soil sample collection and laboratory analysis

The soil sample of interest was Anthrosoil (Anthropogenic soil). Anthrosoils are soils that have been influenced by human activities such as waste disposal. Using a hand auger, soil samples were collected within 0–15 cm depth at a point distance of 40 m, 80 m, and 120 m after an end-point was identified at the dumpsites. Ten (10) soil samples were randomly

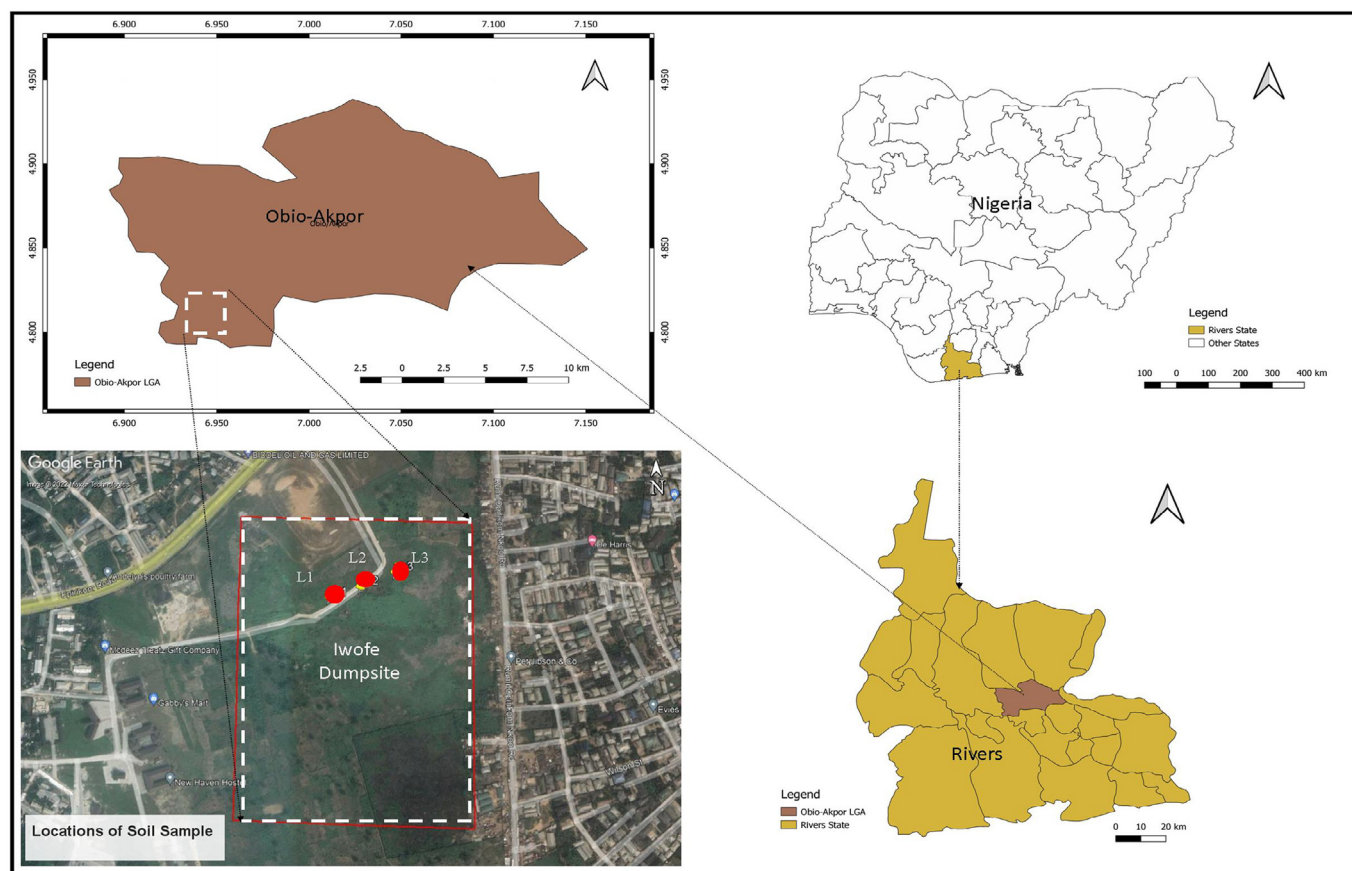


Fig. 1. Study area and sampling point location map.

collected at each point distance within a 10 m radius of the points and thoroughly mixed to form the composite soil sample for the point. At the end of sample collection, three (3) composite samples (made of 10 randomly collected samples from each points) were taken, bagged with polythene materials, labeled adequately, and taken to the laboratory analysis.

The collected samples were prepared for analysis using the acceptable and standard procedure described by [3]. The soil pH and electrical conductivity were determined using International Organization for Standardization (ISO 10390 and ISO 11265 respectively) method while the Concentration of heavy metals (As, Cd, Zn, Mn, Cu, Co, Cr, Ni, and Pb) from the digested soil was analysed using ISO 18227 method. The soil analysis was done at the University of Port Harcourt laboratory, and all heavy metals concentrations were expressed in mg/kg. All samples were analysed in triplicates, and the mean was estimated for accuracy and precision. The heavy metals concentration determination has a high accuracy level of 99.776% and can achieve higher sensitivity of >0.9 absorbance and precision that is <0.5% relative to the standard deviation (RSD).

2.3. Pollution assessment indices

Various quantitative indices were used to assess the heavy metal contamination in the soil of the abandoned dumpsite. These indices include:

i. Contamination Factor (CF)

CF was adopted to ascertain the extent of soil contamination with heavy metals. CF is expressed;

$$CF = C_n/B_n \quad (1)$$

Where; C_n = Concentration of heavy metals in soil samples and B_n = Background value of heavy metals in a natural state. The heavy metals are classified based on the CF as $CF < 1$: Low, $1 \leq CF < 3$: Moderate, $3 \leq CF < 6$: Considerable High, and $CF \geq 6$: Very High [34].

ii. Enrichment Factor (EF)

EF can differentiate between metals from anthropogenic activities and those from natural sources [35]. The enrichment factor of the metals was calculated as the ratio of elemental sediment concentration normalized to a reference Mn. EF is expressed as;

$$EF = \frac{C_x/C_{ref}}{B_x/B_{ref}} \quad (2)$$

Where; C_x = Concentration of HM content in the anthropogenic impacted soil, C_{ref} = Concentration of referenced metal in the anthropogenic impacted soil, B_x = Concentration of HM content in the undisturbed soil, and B_{ref} = Concentration of referenced metal in the undisturbed soil. The heavy metals are classified as $EF < 1$: Zero Enrichment, $1 \leq EF < 3$: Less Enrichment, $3 \leq EF < 5$: Moderate Enrichment, $5 \leq EF < 10$: Moderately Enrichment, $10 \leq EF < 25$: High Enrichment, $25 \leq EF < 50$: Very High Enrichment and $EF > 50$: Exceptionally High Enrichment [14].

iii. Geo-Accumulation Index (I_{geo})

I_{geo} estimated the contamination magnitude of the heavy metals in the anthropogenic impacted soil/sediment. I_{geo} is expressed thus;

$$I_{geo} = \log_2 \frac{HM_s}{1.5 \times HM_c} \quad (3)$$

Where; HM_s = Samples heavy metal concentration, HM_c = Reference heavy metal concentration and 1.5 = Constant. The heavy metals are classified as $I_{geo} \leq 0$: No Pollution, I_{geo} (0–1): Moderate Pollution, I_{geo} (1–2): Strong Pollution, I_{geo} (2–3): High Pollution, I_{geo} (3–4): Very High Pollution, I_{geo} (4–5): Severe Pollution, and $I_{geo} \geq 5$: Extreme Pollution [15,36].

iv. Pollution Load Index (PLI)

PLI was adopted to estimate the extent of pollution among the sampled soil/sediment from different locations based on the time factor. PLI is expressed as:

$$PLI = \sqrt[n]{CF_1 * CF_2 * CF_3 * \dots \dots \dots CF_n} \quad (4)$$

Where PLI = Pollution Load Index, CF = Contamination factor, and n = number of elements. The $PLI > 1$ indicates pollution, while $PLI < 1$ indicates no pollution [4].

v. Ecological Risk Index (ER_i)

ER_i is expressed as the given product of the contamination factor (CF) of the heavy metals and toxicological response factor (Tr) of each heavy metal [37], and its expressed as thus;

$$RI = CF_n \times T_r \quad (5)$$

Heavy metals' ER_i was classified as $ER_i < 30$: Low Ecological Risk, ER_i : 30–60: Moderate Ecological Risk, ER_i : 60–120: Considerable Ecological Risk, ER_i : 120–240: High Ecological Risk, and $ER_i > 240$: Significantly Ecological High Risk [15].

vi. Modified Ecological Risk Index (MERI)

MER_i is expressed as the given product of the enrichment factor (EF) of the heavy metals and toxicological response factor (Tr) of each heavy metal [14], and its expressed;

$$MRI = EF_n \times T_r \quad (6)$$

The heavy metal MER_i was classified as $MER_i < 40$: Low Ecological Risk, MER_i 40–80: Moderate Ecological Risk, MER_i 80–160: Considerable Ecological Risk, MER_i 160–320: High Risk, and $MER_i > 320$: Very High Ecological Risk [15].

vii. Potential Ecological Risk Index (PER_i)

PER_i is expressed as the summation of the enrichment factor (EF) of the heavy metals, and its expressed;

$$PERI = \sum_{i=1}^m Er^i \quad (7)$$

The heavy metal PER_i was classified as $PER_i < 150$: Low Ecological Risk, $150 \leq PER_i < 300$: Moderate Ecological Risk, $300 \leq PER_i < 600$: Considerable Ecological Risk, and $PER_i \geq 600$: Very High Ecological Risk [25].

2.4. Health risk assessment

Assessing the health risk due to exposure to heavy metals in soil can be carried through the daily dose (ADD), the non-carcinogenic target hazard quotient (THQ), hazard index (HI), and lifetime carcinogenic risk (LCR) coefficients for adults and children [38,39]. According to Edokpayi et al. [40], there are three (3) major human exposure pathways to heavy metals risk: inhalation via nose and mouth, direct ingestion, and dermal absorption through skin exposure. These exposure pathways are common through soil components.

2.4.1. Average daily dose (ADD)

Exposure doses for determining human health risk through these three pathways have been described in the literature [40–42] and can be

Table 1

Heavy metal concentration of present study compared with past studies.

LF	As	Cd	Zn	Mn	Cu	Co	Cr	Ni	Pb	Ref
EC	2–4	1.99–2.4	93.4–131	54.6–349	15.1–26.2	2.99–4.50	11.6–72.5	17.0–23.4	14.6–27.9	PS*
Isolo	5–16	BDL–4.9	25–1625	49–1673	13–498	–	41–125	–	34–1057	[3]
Rum	–	0.008–0.05	3.04–4.79	–	0.98–1.9	–	0.30–0.58	–	0.12–0.76	[4]
Ekiti	–	–	4.5–120.5	56–1221	2–12.5	–	40–8450	ND–0.03	7.5–65.5	[14]
Abak	–	0.10–0.14	42.21–84.21	–	10.35–56.26	–	–	–	12.90–19.51	[15]
WHO	–	0.003	–	–	2.0	–	0.01	0.05	0.1	–
BGV	1.8	0.15	71	56	25	40	35	20	20	[15]

LF: Landfill, EC: Eagle Cement Landfill/Iwofe Landfill, Rum: Rumuepirikom Landfill, Abak: Abakaliki Landfill, PS: Present Study, WHO: World Health Organization, BGV: Background Value.

calculated using Eq. (8) as adapted from the US EPA risk assessment guidance for superfund (RAGS) methodology [26,40,41].

$$\left. \begin{aligned} ADD_{ing} &= C_{soil} \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \\ ADD_{inh} &= C_{soil} \times \frac{IngR \times EF \times ED}{PEF \times BW \times AT} \\ ADD_{derm} &= C_{soil} \times \frac{SA \times AF \times ABF \times EF \times ED}{BW \times AT} \times 10^{-6} \end{aligned} \right\} \quad (8)$$

Where; ADD = Average daily dose through ingestion/inhalation/dermal absorption of soil (mg/kg/day); C_{soil} = concentration of the heavy metals in soil (mg/kg); IngR: Ingestion rate; InhR: Inhalation rate; EF: Exposure Frequency; ED: Exposure Duration; PEF: Particle Emission Factor; BW: Body Weight; AT: Averaging Time; SA: Exposed Skin Area; AF: Skin Adherence Factor and ABF: Dermal Absorption Factor. All values are presented in Supplementary Table 1.

i. Target Hazard Quotient (THQ) and Hazard Index (HI)

Total hazard quotient: THQ is the ratio of ADD (that is, exposure through ingestion/inhalation/dermal absorption of soil) and RfD (chronic reference dose for each metal in mg/kg BW/day), which is typically used to estimate the potential non-carcinogenic risk of metals exposure to humans in different pathways [26].

$$THQ = \frac{ADD (Ingestion \times Inhalation \times Dermal)}{RfD} \quad (9)$$

Where $THQ < 1$ considers the exposed population experience no significant health risk.

Hazard Index (HI): HI is the sum of all expected HQs (non-carcinogenic risks) through different pathways and is employed to compute the total potential non-carcinogenic risks of various contaminants [26,43,44].

$$HQ = \frac{ADD}{RfD}; HI = \sum HQ = HQ_{ing} + HQ_{inh} + HQ_{derm} \quad (10)$$

When the value of $HI \leq 1$ indicates no significant risk of non-carcinogenic effects, however, when $HI > 1$, there is a probability of non-carcinogenic effects occurring, and the probability increases with a rising value of HI [26].

ii. Carcinogenic Risk (CR) Coefficients

The estimation is that carcinogenic heavy metals determine the health risk through different exposure pathways. It is calculated based on the formula below;

$$\left. \begin{aligned} CR &= ADD (Ing \times Inh \times Derm) \times CSF \\ TCR &= \sum CR = CR_{ing} + CR_{inh} + CR_{derm} \end{aligned} \right\} \quad (11)$$

Where CSF: Cancer Slope Factor. $TCR < 10^{-6}$, $TCR > 1 \times 10^{-4}$, and 1×10^{-6} to 1×10^{-4} indicate no carcinogenic risk, high risk of developing cancer, and acceptable risk to humans, respectively.

2.5. Statistical analysis

The source and distribution of HM across the environmental medium were analysed through statistical tools such as Pearson's Correlation Coefficient (PCC), Cluster analysis (CA), and Principal Component Analysis (PCA) using the Statistical Package for the Social Sciences (SPSS) version 21 platform.

3. Result and discussion

3.1. Soil properties, heavy metals concentration, and descriptive statistics

The descriptive statistics of soil properties and heavy metals Concentration across all the sampled locations were estimated, and the outcomes are presented in Supplementary Table 2. The soil properties parameters pH and EC ($\mu\text{S}/\text{cm}$) values ranged from 6.24 to 7.49 and 163 to 664, respectively. The pH values reduce away from the landfills and indicate the soil ranges from acidic to alkaline in nature. pH influences the movement of heavy metals from the soil to the plant [14], and in this case, there will be moderately-high movement from soil to plant. The reported pH values are slight than those reported by [4] for an abandoned landfill. The reported EC indicates dissolved solid Concentration, which is influenced by rainfall and evapotranspiration.

The concentration (mg/kg) of As, Cd, Zn, Ba, Mn, Cu, Co, Cr, Ni and Pb in soil ranged from 2.00 to 4.00, 1.99 to 2.40, 93.4 to 131, 54.6 to 349, 15.1 to 26.2, 2.99 to 4.50, 11.6 to 72.5, 17.0 to 23.4 and 14.6 to 27.9 respectively with mean $\pm$ SD concentration of 2.97 ± 1.00 , 2.13 ± 0.24 , 110.80 ± 18.96 , 196.20 ± 147.52 , 20.57 ± 5.55 , 3.86 ± 0.78 , 49.43 ± 33.03 , 19.73 ± 3.30 and 22.83 ± 7.19 respectively. The mean concentration of the heavy metals from the soil exceeded the allowable limit by WHO and in order of $Mn > Zn > Cr > Pb > Cu > Ni > Co > As > Cd$. Comparing the heavy metal concentration of the present study with past studies (Table 1) indicated that all concentrations reported therein are higher than those reported by [4,15], while the Concentration of As, Cr, Pb, Mn, and Cr reported by [3,14] were higher.

Table 2

Pollution assessment indices estimation.

Heavy Metals	CF	PLI	I_{geo}	EF*	ER_i	MER_i	PERI
As	1.65	1.58	0.04	0.5	16.5	5	49.4
Cd	14.2	14.12	0.98	3.67	426	110.1	1276.2
Zn	1.56	1.55	0.02	0.45	1.56	0.45	4.69
Mn	3.50	2.72	0.37	1	3.50	1	10.51
Cu	0.82	0.80	−0.26	0.24	4.1	1.2	12.33
Co	0.09	0.09	−1.19	0.03	0.45	0.15	1.425
Cr	1.41	1.08	−0.03	0.4	2.82	0.8	8.46
Ni	0.98	0.98	−0.18	0.28	4.9	1.4	14.8
Pb	1.14	1.09	−0.11	0.33	5.7	1.65	17.11

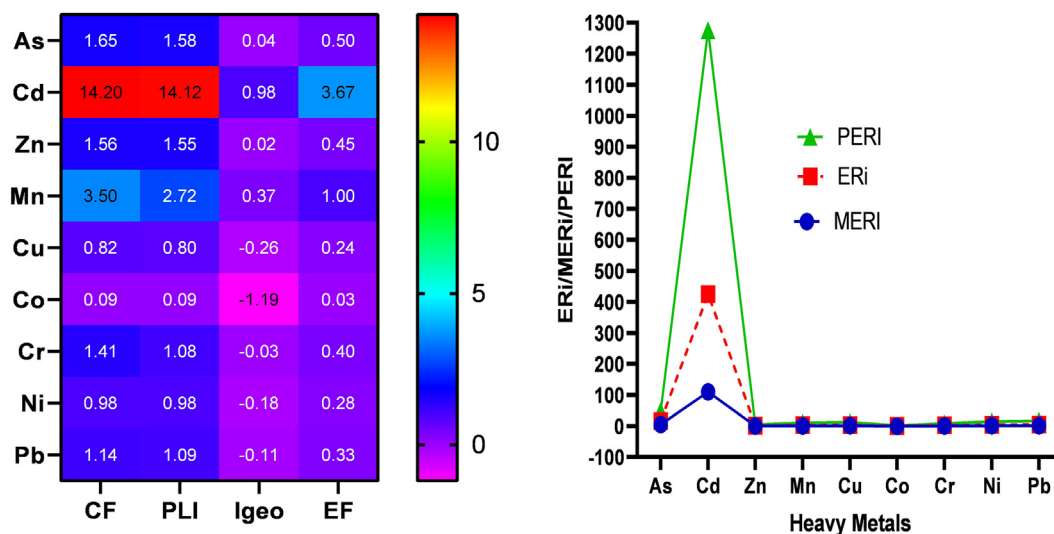


Fig. 2. Pollution assessment indices of heavy metals.

Table 3

Average daily dose for adults and children.

HM	Adult			Children		
	ADD _{ing}	ADD _{inh}	ADD _{derm}	ADD _{ing}	ADD _{inh}	ADD _{derm}
As	1.72×10^{-6}	2.53×10^{-10}	2.06×10^{-7}	3.07×10^{-6}	8.58×10^{-11}	2.58×10^{-7}
Cd	1.23×10^{-6}	1.81×10^{-10}	4.92×10^{-7}	2.20×10^{-6}	6.15×10^{-11}	6.17×10^{-9}
Zn	1.87×10^{-4}	2.34×10^{-10}	7.46×10^{-5}	1.34×10^{-3}	3.73×10^{-8}	3.74×10^{-6}
Mn	3.31×10^{-4}	4.87×10^{-8}	1.32×10^{-4}	2.37×10^{-3}	6.61×10^{-8}	6.63×10^{-6}
Cu	3.47×10^{-5}	5.11×10^{-9}	1.39×10^{-5}	2.48×10^{-4}	6.93×10^{-9}	6.95×10^{-7}
Co	6.52×10^{-6}	9.58×10^{-10}	2.60×10^{-6}	4.65×10^{-5}	1.3×10^{-9}	1.30×10^{-7}
Cr	2.86×10^{-5}	4.21×10^{-9}	1.14×10^{-5}	5.11×10^{-5}	1.43×10^{-9}	1.43×10^{-7}
Ni	1.14×10^{-5}	1.68×10^{-8}	4.56×10^{-6}	2.04×10^{-5}	5.70×10^{-10}	5.71×10^{-8}
Pb	1.32×10^{-5}	1.94×10^{-9}	5.27×10^{-6}	2.36×10^{-5}	6.59×10^{-10}	6.61×10^{-8}

Target Hazard Quotient (THQ) and Hazard Index (HI).

3.2. Environmental risk assessment

Various pollution assessment indices were estimated based mean Concentration of heavy metals in soils and presented in Table 2 and Fig. 2. The estimated CF and ER for individual locations are presented in

Supplementary Table 3. The CF values of As, Cd, Zn, Mn, Cu, Co, Cr, Ni, and Pb were 1.65, 14.2, 1.56, 3.50, 0.82, 0.09, 1.41, 0.98, and 1.14, respectively. Metals such Cu, Co, and Ni as CFs of low contamination factor ($CF < 1$), As, Zn, Cr, and Pb as CFs of moderate contamination factor ($CF < 3$), while Mn and Cd indicated considerable high contamination factor

Table 4

Target hazard quotient (THQ) and hazard index (HI) for adult and children.

	HM	THQ _{ing}	THQ _{inh}	THQ _{derm}	HI = ΣHQ	Comment
Adult	As	5.73×10^{-3}	2.06×10^{-6}	1.68×10^{-3}	7.41×10^{-3}	NSR
	Cd	2.46×10^{-3}	3.18×10^{-7}	9.84×10^{-4}	3.44×10^{-3}	NSR
	Zn	6.23×10^{-4}	7.8×10^{-10}	1.24×10^{-1}	1.25×10^{-1}	NSR
	Mn	2.36×10^{-1}	3.48×10^{-5}	7.30×10^{-2}	3.09×10^{-1}	NSR
	Cu	8.68×10^{-4}	1.28×10^{-7}	1.16×10^{-3}	2.03×10^{-3}	NSR
	Co	3.26×10^{-4}	1.68×10^{-4}	4.56×10^{-1}	4.56×10^{-1}	NSR
	Cr	9.53×10^{-3}	1.47×10^{-4}	3.8×10^{-3}	1.35×10^{-2}	NSR
	Ni	5.7×10^{-4}	8.16×10^{-7}	8.4×10^{-4}	1.41×10^{-3}	NSR
	Pb	9.43×10^{-3}	5.51×10^{-7}	1.01×10^{-2}	1.95×10^{-2}	NSR
Children	As	1.02×10^{-2}	6.98×10^{-7}	2.10×10^{-3}	1.23×10^{-2}	NSR
	Cd	4.4×10^{-2}	1.08×10^{-7}	1.23×10^{-5}	4.40×10^{-2}	NSR
	Zn	4.46×10^{-3}	1.24×10^{-7}	6.23×10^{-3}	1.07×10^{-2}	NSR
	Mn	1.69	4.72×10^{-5}	3.68×10^{-3}	1.69	SR
	Cu	6.2×10^{-3}	1.73×10^{-7}	5.79×10^{-5}	6.26×10^{-3}	NSR
	Co	2.33×10^{-3}	2.28×10^{-4}	2.28×10^{-2}	2.54×10^{-2}	NSR
	Cr	1.7×10^{-2}	5.0×10^{-5}	4.77×10^{-5}	1.71×10^{-2}	NSR
	Ni	1.02×10^{-3}	2.77×10^{-8}	1.06×10^{-5}	1.03×10^{-3}	NSR
	Pb	1.69×10^{-2}	1.87×10^{-7}	1.26×10^{-4}	1.7×10^{-2}	NSR

NSR: No Significant Risk, SR: Significant Risk.
Carcinogenic Risk (CR) Coefficients.

Table 5
estimated risk of carcinogenic metals in adult and children.

	HM	CR _{ingestion}	CR _{inhalation}	CR _{Derm}	TCR	Comment
Adult	As	2.58×10^{-6}	1.91×10^{-9}	3.11×10^{-7}	2.89×10^{-7}	NCR
	Cd	1.85×10^{-5}	1.36×10^{-7}	7.38×10^{-8}	1.87×10^{-5}	SAR
	Cr	1.43×10^{-5}	8.85×10^{-8}	4.79×10^{-7}	1.49×10^{-5}	SAR
	Ni	1.94×10^{-5}	7.57×10^{-9}	4.10×10^{-8}	1.95×10^{-5}	SAR
	Pb	1.12×10^{-7}	9.74×10^{-9}	4.48×10^{-10}	1.22×10^{-7}	NCR
Children	As	4.61×10^{-6}	3.41×10^{-9}	3.90×10^{-7}	5×10^{-6}	NCR
	Cd	3.30×10^{-5}	2.43×10^{-8}	9.25×10^{-8}	3.31×10^{-5}	SAR
	Cr	2.56×10^{-5}	1.58×10^{-8}	6.01×10^{-7}	2.62×10^{-5}	SAR
	Ni	3.47×10^{-5}	1.35×10^{-8}	5.14×10^{-8}	3.48×10^{-5}	SAR
	Pb	2.01×10^{-7}	1.48×10^{-10}	5.62×10^{-10}	2.01×10^{-7}	NCR

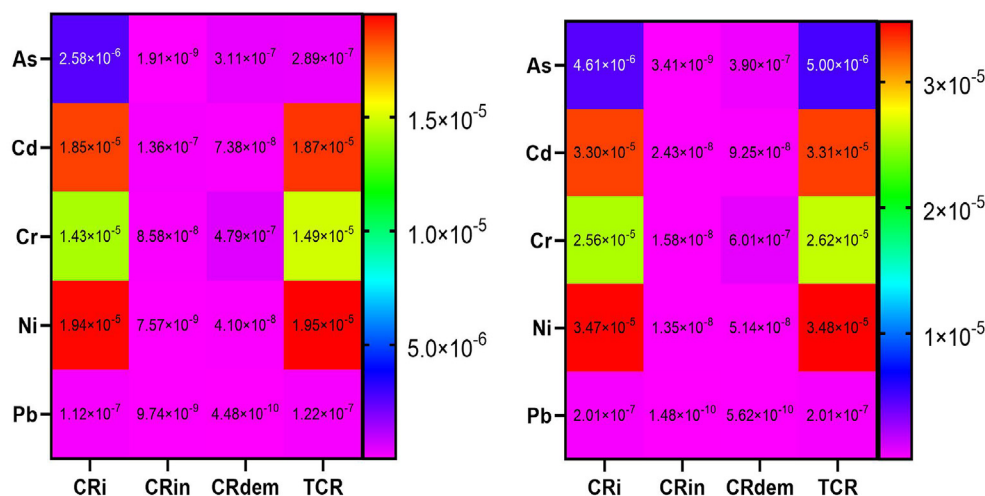


Fig. 3. Estimated risk of carcinogenic metals in adult and children. Source and Distribution of Heavy Metal.

($CF > 3$) and very high contamination factor ($CF > 6$). The CFs of the soil heavy metals descended in order of $Cd > Mn > As > Zn > Cr > Pb > Ni > Cu > Co$. The PLI values of As, Cd, Zn, Mn, Cr, and Pb are >1 , indicating a polluted soil with heavy metals, while Cu, Co, and Ni are <1 , implying that the metals are no pollution to the soil. As noted by Alsafran (26), I_{geo} is used to evaluate the extent of metals in polluted soil, and for this study, the I_{geo} for As, Cd, Zn, Mn, Cu, Co, Cr, Ni, and Pb was 0.04, 0.98, 0.02, 0.37, -0.26 , -1.19 , -0.03 , -0.18 and -0.11 respectively. The I_{geo} values descended as $Cd > Mn > As > Zn > Cr > Pb > Ni > Cu > Co$ while metals such as Cu, Co, Cr, Ni, and Pb are classified as “no pollution”; however, As, Cd, Zn, and Mn exhibited “moderate pollution” to the soil.

The EF is concerned with the extent of anthropogenic influence in the heavy metal pollution of an area. In this study, metals such as As, Zn, Cu, Co, Cr, Ni, and Pb have $EF < 1$ hence zero enrichment, while Mn and Cd have $EF \leq 1$ and ≥ 3 , therefore has less and moderate enrichment, respectively. The implication has been that $EF > 1$ can be attributed to the influence of anthropogenic activities while $EF \leq 1$ can be attributed to natural

phenomena such as weathering [25]. In general, the EF of the studied soil descended as $Cd > Mn > As > Zn > Cr > Pb > Ni > Cu > Co$.

The ER in this present study indicated that As, Cd, Zn, Mn, Cu, Co, Cr, Ni, and Pb have the value of 16.5, 426, 1.56, 3.50, 4.1, 0.45, 2.82, 4.9, and 5.7 respectively. All metals in the soil showed low ecological risk with $ER_i < 30$ except Cd with $ER_i > 240$, indicating significantly high ecological risk. The MER_i and PER_i of the study ranged from 0.15 to 110.0 and 4.69 to 1276.2, respectively, indicating low ecological risk for all the metals in the soil except Cd with MER_i of moderate risk and PER_i of very high ecological risk.

3.2.1. Health risk assessment

3.2.1.1. Average daily dose (ADD). In individual soils, ADD for metals (As, Cd, Zn, Mn, Cu, Co, Cr, Ni, and Pb) were estimated for three exposures (ADD_{ing} , ADD_{inh} , and ADD_{Derm}) and presented in Supplementary Table 4.

Table 7
Rotation component matrix of HM across the environmental mediums.

	PC1	PC2
Co	0.997	
Cu	0.976	0.217
Mn	0.967	0.256
Zn	0.949	0.315
Cr	0.897	-0.441
Pb		0.998
Cd	0.191	-0.981
Ni	0.547	0.837
As	-0.699	0.715
Eigenvalues	5.146	3.584
% of Variance	60.176	39.824
Cumulative %	60.176	100.000

Table 6
Pearson's correlation coefficient (PCC) analysis.

	As	Cd	Zn	Mn	Cu	Co	Cr	Ni	Pb
As	1.000								
Cd	-0.836	1.000							
Zn	-0.438	-0.128	1.000						
Mn	-0.493	-0.066	0.998	1.000					
Cu	-0.527	-0.026	0.995	0.999	1.000				
Co	-0.749	0.262	0.924	0.946	0.958	1.000			
Cr	-0.943	0.605	0.712	0.755	0.780	0.927	1.000		
Ni	0.217	-0.717	0.783	0.743	0.715	0.485	0.121	1.000	
Pb	0.756	-0.991	0.258	0.197	0.158	-0.132	-0.494	0.803	1.000

The mean ADD for the three exposures for adults and children was presented in Table 3, which shows that the ADD descended as follows: $ADD_{ing} > ADD_{Derm} > ADD_{inh}$, for both adults and children. The outcome implies that adults and children are more exposed to heavy metals in the soil through ingestion and dermal than inhalation, which shares similarities with the finding of [25,26].

The THQ and HI of the metals in the soil were presented in Table 4, and the supporting estimation for the THQ was presented in Supplementary

Table 5. The THQ for adults indicated values ranged from 8.68×10^{-4} to 2.36×10^{-1} for THQ_{ing} , 7.8×10^{-10} to 1.68×10^{-4} for THQ_{inh} , and 9.84×10^{-4} to 9.84×10^{-4} for THQ_{Derm} . The trend of THQ-adult descended as $THQ_{Derm} > THQ_{ing} > THQ_{inh}$ while the overall $THQ < 1$ indicates that the exposed population experience no significant health risk. The THQ for children indicated values ranged from 6.2×10^{-3} to 1.69 for THQ_{ing} , 2.77×10^{-8} to 2.28×10^{-4} for THQ_{inh} , and 5.79×10^{-5} to 2.28×10^{-2} for THQ_{Derm} . The trend of THQ-children descended as

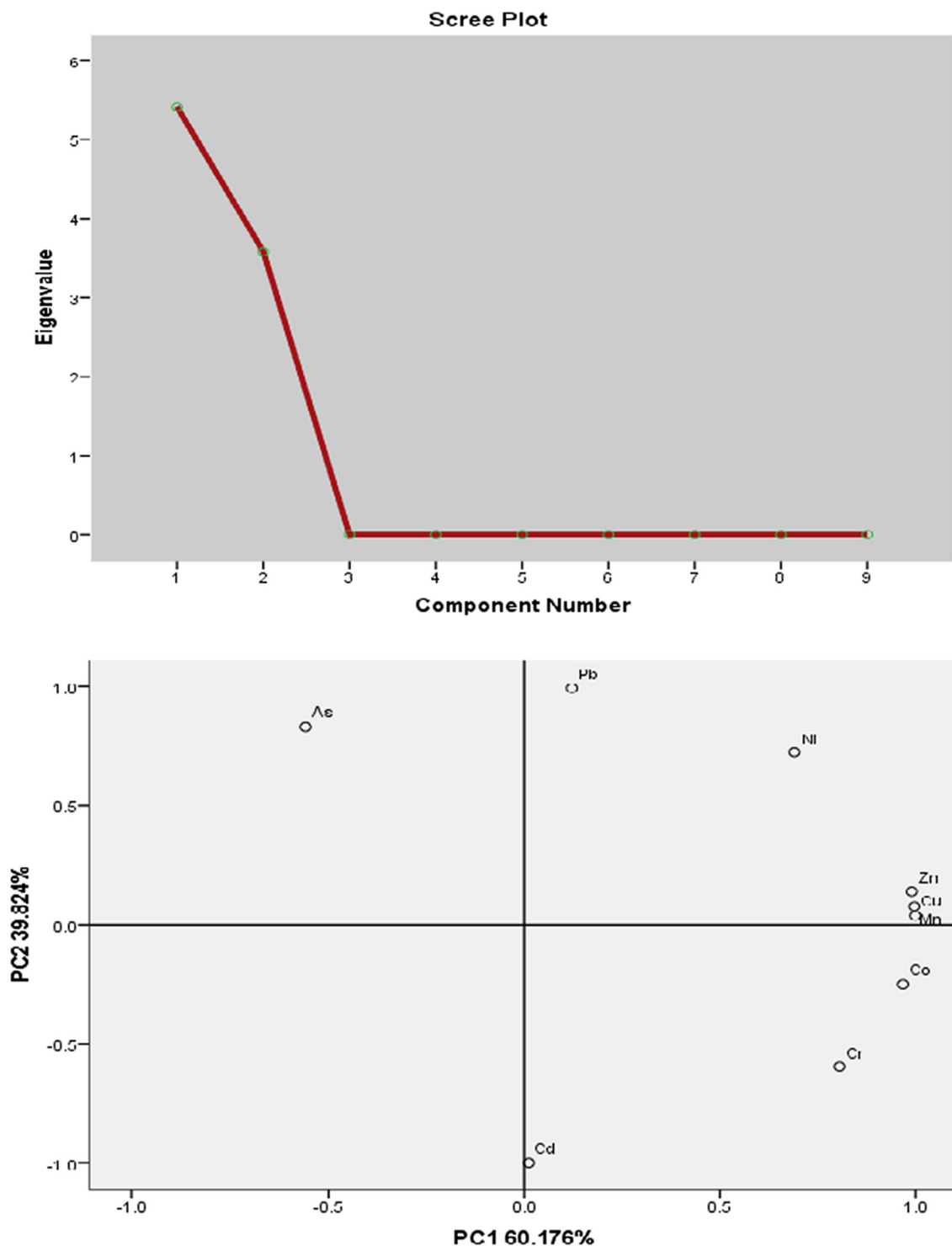


Fig. 4. Scree plot of eigenvalues after PCA and rotated component matrix of HMs. Based on HCA, four groups were identified based on Euclidean distance and absolute correlation distance using similarity as the criterion (Fig. 5). The first group was As, Cd, Co, Cu, Ni, and Pb, the second was Cr and Cd, the third was Zn, and the fourth was distinctly associated with Mn. The outcome revealed various levels of lithogenic and anthropogenic origins of the related metals.

$THQ_{ing} > THQ_{Derm} > THQ_{inh}$ while the overall $THQ < 1$ indicates that the exposed population experience no significant health risk. The HI values for the adult ranged from 1.41×10^{-3} to 4.56×10^{-1} and descended as follows $Co > Mn > Zn > Pb > Cr > As > Cd > Cu > Ni$ for all the metals in the soil. The HI revealed that all metals values are < 1 , implying no significant risk of non-carcinogenic effects. The HI values for the children ranged from 1.03×10^{-3} to 1.69 and descended as follows $Mn > Cd > Co > Cr > Pb > As > Zn > Cu > Ni$ for all the metals in the soil. The HI revealed that all metals values are < 1 , implying no significant risk (NSR) of non-carcinogenic effects except Mn, with HI of 1.69 indicating significant risk (SR) of non-carcinogenic effects in children.

CR was estimated risk of carcinogenic metals (As, Cd, Cr, Ni, Pb) in the soil of the abandoned landfill was presented in Table 5 and Fig. 3, while supporting estimation was presented in Supplementary Table 6. The CR for adults ranged from 1.12×10^{-7} to 1.94×10^{-5} for CR_{ing} , 1.91×10^{-9} to 1.36×10^{-7} for CR_{inh} , 4.48×10^{-10} to 4.79×10^{-7} for CR_{derm} . The trend of CR-adult descended as $CR_{ing} > CR_{inh} > CR_{derm}$. The TCR-adult for As, Cd, Cr, Ni, and Pb have values 2.89×10^{-7} , 1.87×10^{-5} , 1.49×10^{-5} , 1.95×10^{-5} , and 1.22×10^{-7} , respectively. Carcinogenic metals such as Cd, Cr, and Ni are deemed no carcinogenic risk (NCR) where $TCR < 10^{-6}$ while As and Pb was deemed significant acceptable risk (SAR) where $TCR: 1 \times 10^{-6}$ to 1×10^{-4} . TCR-adult of the abandoned soil carcinogenic metals descended as follow: $Ni > Cd > Cr > As > Pb$. The CR for children ranged from 2.01×10^{-7} to 3.47×10^{-5} for CR_{ing} , 1.48×10^{-10} to 2.43×10^{-8} for CR_{inh} , 5.62×10^{-10} to 6.01×10^{-7} for CR_{derm} . The trend of CR-adult descended as $CR_{ing} > CR_{derm} > CR_{inh}$. The TCR-children for As, Cd, Cr, Ni, and Pb have values 5×10^{-6} , 3.31×10^{-5} , 2.62×10^{-5} , 3.48×10^{-5} , and 2.01×10^{-7} , respectively. Carcinogenic metals such as Cd, Cr, and Ni are deemed no carcinogenic risk (NCR) where $TCR < 10^{-6}$ while As and Pb was deemed significant acceptable risk (SAR) where $TCR: 1 \times 10^{-6}$ to 1×10^{-4} . TCR-adult of the abandoned soil carcinogenic metals descended as follow: $Ni > Cd > Cr > As > Pb$.

Heavy metals' source and distribution patterns were analysed using the PCA and HCA analysis. The PCA analysis, including Pearson's correlation coefficient (PCC), rotation component matrix of HM, and screen plot, are summarised and presented in Tables 6–7 and Fig. 4. Pearson correlation mix indicated that As has significant positive relationship (> 0.7) with Pb with an r -value of 0.756 and a weak positive relationship (< 0.7) with Ni ($r = 0.217$). Furthermore, a significant positive relationship exists between Zn with Mn, Cu, Co, Cr and Ni, Mn with Cu, Co, Cr and Ni, Cu with Co, Cr and Ni, Co with Cr, and between Ni with Pb. All other heavy metals relationships are either weak positive relationships or negative relationships. All metals of strong correlation indicated similar sources and distribution patterns [7].

The principal component (PC1) indicated 60.176% of the variance while all the HM as strong positive correlations (Co: 0.997, Cu: 0.976, Mn: 0.967, Zn: 0.949, Cr: 0.897) while Pb showed no correlation and Cd, Ni and As revealed a weak correlation (0.191, 0.547) and negative correlation respectively. The eigenvalues indicated that the PC1 has > 1 and constitutes 60.176% of the total variance.

The principal component (PC2) indicated 39.824% of the variance, while the HM with strong positive correlations includes Pb (0.998), Ni (0.837), and As (0.715), while other HM showed weak positive and negative correlation except for Co with no correlation. The eigenvalues indicated that the PC2 has > 1 and constitutes 100.00% of the total variance. PCC analysis which showed a significant positive correlation among HMs illustrated similarities in their sources and distributions. Ustaoglu et al. [45] noted that a strong correlation between and among HMs could imply the same sources and distribution pattern, while a lack of correlation implies the opposite. Therefore, HM such as Co, Cu, Mn, Zn, and Cr are said to have similar sources, and it is lithogenic, which explains their weak and no correlation with HM such as Pb, Cd, Ni, and As. Similarly, the strong correlation between Pb, Ni, and As revealed a similar source and pattern, and it is an anthropogenic source explaining the weak and no correlation with HM such as Co, Cu, Mn, Zn, and Cr.

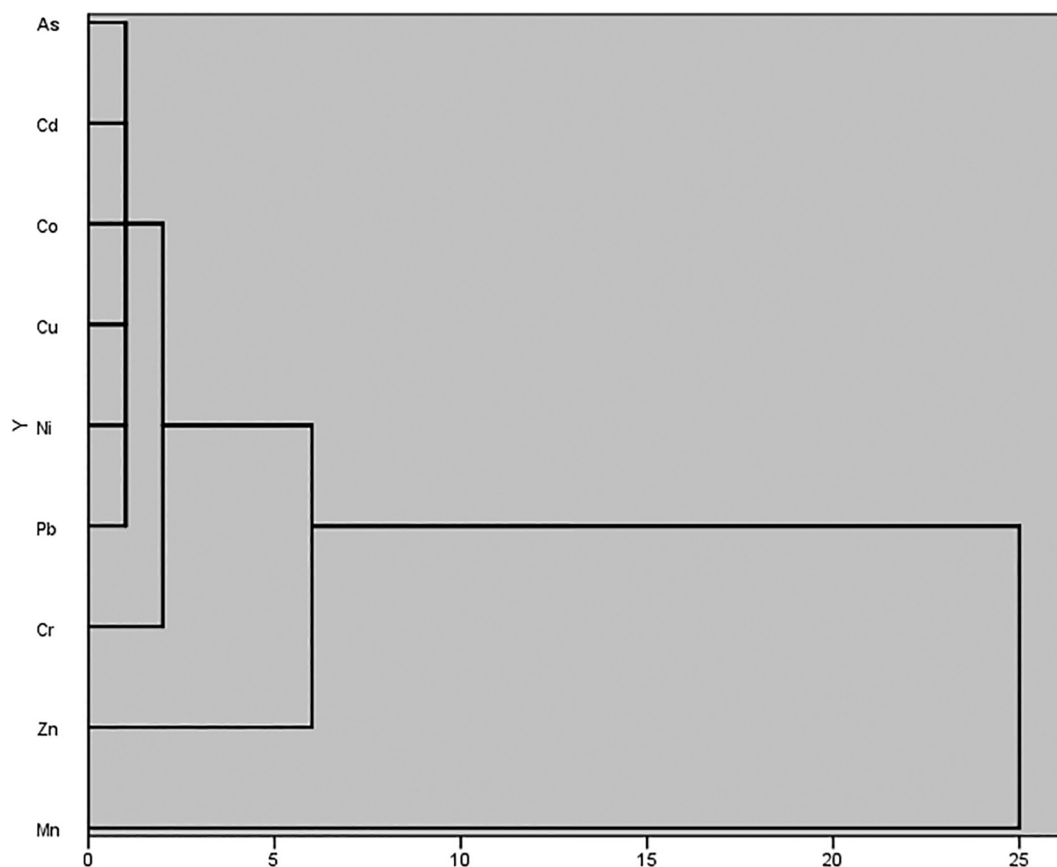


Fig. 5. Dendrogram of a complete linkage of all the parameters.

4. Conclusion

The soil quality is impacted due to the landfill activities, and heavy metals tested exceeded the WHO acceptable standard. The pollution status of the soil can be deemed contaminated as the heavy metals showed low, moderate, to high CF. Regarding EF and ER factors, the soil indicated no enrichment and low ecological factor except for Cd with moderate EF and low ER. Although the soil is deemed contaminated and shows no significant risk of non-carcinogenic effects to adults and children; however, Mn was estimated to have a significant risk on children. The soil showed no carcinogenic effect on adults and children as the assessment indicated no risk to acceptable risk. Overall, the soil from the anthropogenically impacted site was contaminated and not fit for human activities. Therefore, there is a need for environmental management and remediation action before using such an environment. However, engaging the environment through sustainable practices will ensure efficient waste disposal and management.

Credit authorship

Afolabi, O. O. Conceptualization, Methodology, Writing- Original Draft, Data Curation, Formal Analysis, Software, **Wali, E., Asomaku, S. O., Emelu, V. O and Yemi-Jonathan, O. I. T.** Conceptualization, Data Curation, Methodology, Formal Analysis, **Emelu, V. O and Orji, M. C., Bosco-Abiahu, L. C.** Formal Analysis, Resources, Project Administration, Validation Formal Analysis, Data Curation, **Yemi-Jonathan, O. I. T.-Orji, M. C., and Oghuehi, N. C.** Writing-Review and Editing, Data Curation, Resources, Visualization. All authors have read and agreed to the published version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.enceco.2022.12.002>.

References

- [1] World Bank Report, What a Waste: An Updated Look into the Future of Solid Waste Management, World Bank, NW Washington, DC, 2018 (1818 H Street20433 USA).
- [2] B. Clasen, R.M. Lisbôa, Ecotoxicological tests as a tool to assess the quality of the soil, *Intechopen* (2016) 13–33, <https://doi.org/10.5772/intechopen.82192>.
- [3] A.M. Odukoya, Contamination assessment of toxic elements in the soil within and around two dumpsites in Lagos, Nigeria. *Ife J. Sci.* 17 (2) (2015) 357–361.
- [4] O.O. Afolabi, S.O. Eludoyin, Evaluation of heavy metals and contamination status of soil around abandoned and active Nigerian dumpsites, *J. Geo. Environ. Earth Sci. Int.* 25 (10) (2021) 1–11, <https://doi.org/10.9734/JGEESI/2021/v25i1030310>.
- [5] I.T. Enitan, A.M. Enitan, J.O. Odiyo, M.M. Alhassan, Human health risk assessment of trace metals in surface water due to leachate from the municipal dumpsite by pollution index: a case study from Ndawuse River, Abuja, Nigeria. *Open Chem.* 16 (2018) 214–227, <https://doi.org/10.1515/chem-2018-0008>.
- [6] C.K. Tay, M. Dorleku, L.K. Doamekpor, Human exposure risks assessment of heavy metals in groundwater within the Amanse and Adansi districts in Ghana using pollution evaluation indices, *W. African J. App. Ecol.* 27 (1) (2019) 23–41.
- [7] L. Chheang, N. Thongkon, T. Sriwiriayarat, S.P. Thanasupsin, Heavy metal contamination and human health implications in the Chan Thnal reservoir, Cambodian. *Sustainabil.* 13 (2021) 13538, <https://doi.org/10.3390/su132413538>.
- [8] O.O. Afolabi, E. Wali, E.C. Ihunda, M.C. Orji, V.O. Emelu, L.C. Bosco-Abiahu, N.C. Ogbuehi, S.O. Asomaku, O.A. Wali, Potential environmental pollution and human health risk assessment due to leachate contamination of groundwater from anthropogenic impacted site, *Environmen. Challeng.* 9 (2022), 100627 <https://doi.org/10.1016/j.enceco.2022.100627>.
- [9] S.T. Odonkor, T. Mahami, Microbial air quality in neighborhoods near landfill sites: implications for public health, *J. Environ. Public Health* (2020) 4609164, <https://doi.org/10.1155/2020/4609164>.
- [10] F.O. Ogbemudia, E.D. Anwana, R.E. Ita, I.N. Bassey, Air quality assessment along a landfill site in Uyo, *NJB* 33 (2020) 227–239.
- [11] P.O. Njoku, J.N. Edokpayi, J.O. Odiyo, Health and environmental risks of residents living close to a landfill: a case study of Thohoyandou landfill, Limpopo Province, South Africa, *Int. J. Environ. Res. Public Health* 16 (2019) 2125, <https://doi.org/10.3390/ijerph16122125>.
- [12] B. Norsa'adah, O. Salinah, N.N. Naing, A. Sarimah, Community health survey of residents living near a solid waste open dumpsite in Sabak, Kelantan, Malaysia, *Int. J. Environ. Res. Public Health* 17 (2020) 311, <https://doi.org/10.3390/ijerph17010311>.
- [13] I.E. Arinze, O. Igwe, C.O. Una, Analysis of heavy metals' contamination in soils and water at automobile junk markets in Obosi and Nnewi, Anambra State, Southeastern Nigeria, *Arab. J. Geosci.* 8 (2015) 10961–10976, <https://doi.org/10.1007/s12517-015-2001-6>.
- [14] L.O. Afolagboye, A.A. Ojo, A.O. Talabi, Evaluation of soil contamination status around a municipal waste dumpsite using contamination indices, soil-quality guidelines, and multivariate statistical analysis, *SN Appl. Sci.* 2020 (1864) 2, <https://doi.org/10.1007/s42452-020-03678-y>.
- [15] D. Aja, C.C. Okolo, N.J. Nwite, C. Njoku, Environmental risk assessment in selected dumpsite in Abakaliki metropolis, Ebonyi state, Southeastern, Nigeria, *Environmen. Challeng.* 4 (2020), 100143 <https://doi.org/10.1016/j.enceco.2021.100143>.
- [16] R. Gonzalez-Valencia, F. Magana-Rodriguez, J. Cristóbal, F. Thalasso, Hotspot detection and spatial distribution of methane emissions from landfills by a surface probe method, *Waste Manag.* 55 (2015) 299–305, <https://doi.org/10.1016/j.wasman.2016.03.004>.
- [17] N.C. Ogbuehi, M.C. Orji, O.O. Afolabi, Health exposure and environmental challenges of households living nearby an open landfill system in Nigerian Urban Centre, *Int. Arch. Pub. Health Commun. Med.* 6 (2022) 087, <https://doi.org/10.23937/2643-4512/1710087>.
- [18] A. Cachada, A.C. Dias, P. Pato, C. Mieirol, T. Rocha-Santos, M.E. Pereira, E.F. da Silva, A.C. Duarte, Major inputs and mobility of potentially toxic elements contamination in urban areas, *Environ. Monit. Assess.* 185 (2013) 279–294.
- [19] H. Setälä, G. Francini, J.A. Allen, A. Jumpponen, N. Hui, D.J. Kotze, Urban parks provide ecosystem services by retaining metals and nutrients in soils, *Environ. Pollut.* 231 (2017) 451–461.
- [20] V. Pecina, M. Brtnický, M. Balkova, J. Hegrova, M. Buckova, T. Baltazar, R. Licbinsky, M. Radziemska, Assessment of soil contamination with potentially toxic elements and soil Ecotoxicity of botanical garden in Brno, Czech Republic: are urban botanical gardens more polluted than urban parks? *Int. J. Environ. Res. Public Health* 18 (2021) 7622, <https://doi.org/10.3390/ijerph18147622>.
- [21] T.E. Olagunju, A.O. Olagunju, I.H. Akawu, C.U. Ugokwe, Quantification and risk assessment of heavy metals in groundwater and soil of residential areas around Awotan landfill, Ibadan, Southwest-Nigeria, *J. Toxicol. Risk Assess.* 6 (2020) 033, <https://doi.org/10.23937/2572-4061.1510033>.
- [22] B.K. Mavakala, P. Sivalingam, A. Laffite, C.K. Mulaji, G. Giuliani, P.T. Mpiana, J. Potéa, Evaluation of heavy metal content and potential ecological risks in soil samples from wild solid waste dumpsites in developing country under tropical conditions, *Environ. Chall.* 7 (2022), 100461.
- [23] M.A. Hassaan, A. El Nemr, F.F. Madkour, Environmental assessment of heavy metal pollution and human health risk, *American J. Water Sci. Eng.* 2 (2016) 14–19, <https://doi.org/10.11648/j.ajwse.20160203.11>.
- [24] L. Huang, S. Rad, L. Xu, L. Gui, X. Song, Y. Li, Z. Wu, Z. Chen, Heavy metals distribution, sources, and ecological risk assessment in Huixian wetland, South China, *Water* 12 (2020) 431, <https://doi.org/10.3390/w12020431>.
- [25] F.O. Ohiagu, K.C. Lele, P.C. Chikezie, A.W. Verla, C.E. Enyoh, Pollution profile and ecological risk assessment of heavy metals from dumpsites in Onne, Rivers state, Nigeria, *Chem. Africa* (2020) <https://doi.org/10.1007/s42250-020-00198-5>.
- [26] M. Alsafran, K. Usman, H. Al Jabri, M. Rizwan, Ecological and health risks assessment of potentially toxic metals and metalloids contaminants: a case study of agricultural soils in Qatar, *Toxics* 9 (35) (2021) <https://doi.org/10.3390/toxics9020035>.
- [27] W. Ahmad, R.D. Alharthy, Zubair M. Ahmed, M. Hameed A Rafique S., Toxic and heavy metals contamination assessment in soil and water to evaluate human health risk, *Sci. Report.* 11 (2021) 17006, <https://doi.org/10.1038/s41598-021-94616-4>.
- [28] P.C. Agyeman, K. John, N.M. Kebonye, L. Borůvka, R. Vašat, O. Drabek, K. Němeček, Human health risk exposure and ecological risk assessment of potentially toxic element pollution in agricultural soils in the district of Frydek Mistek, Czech Republic: a sample location approach, *Environ. Sci. Eur.* 33 (2021) 137, <https://doi.org/10.1186/s12302-021-00577-w>.
- [29] F.B.G. Taneel, M.T.N. Eshalomi, Heavy metal contents in plants and soils in abandoned solid waste dumpsites in Port Harcourt, Nigeria, *Res. J. Environ. Toxicol.* 9 (2015) 342–349, <https://doi.org/10.3923/rjet.2015.342.349>.
- [30] O.O. Afolabi, O.M. Adesope, Ecotoxicological risk assessment of heavy metals from remediated oil spill site in Niger Delta region, Nigeria, *Environmen. Chem. Ecotoxicol.* 4 (2022) 186–193, <https://doi.org/10.1016/j.enceco.2022.10.001>.
- [31] S.S. Babu, T. Chakrabarti, J.K. Bhattacharyya, Studies on environmental quality in and around municipal solid waste dumpsite, *Resour. Conserv. Recycl.* 55 (2010) 129–134, <https://doi.org/10.1016/j.rescon.2010.08.003>.
- [32] S. Wu, S. Peng, X. Zhang, D. Wu, W. Luo, T. Zhang, S. Zhou, G. Yang, H. Wan, L. Wu, Levels and health risk assessments of heavy metals in urban soils in Dongguan, China, *J. Geochem. Explor.* 148 (2015) 71–78.
- [33] J. Wang, Q. Shan, X. Liang, F. Guan, Z. Zhang, H. Huang, H. Fang, Levels and human health risk assessments of heavy metals in fish tissue obtained from the agricultural heritage rice-fish-farming system in China, *J. Hazard. Mater.* 386 (2020), 121627.
- [34] A. Souri, S. Niyogi, A. Naji, Distribution, source apportionment, bioavailability and ecological risks of metals in reef sediments and corals of the Persian Gulf (Iran): Khark Island, Chirouyeh, and Hendorabi Island, *Mar. Pollut. Bull.* 149 (2019), 110654.
- [35] L. Hakanson, Ecological risk index for aquatic pollution control A sedimentological approach, *Water Res.* 14 (1980) 975–1001.
- [36] C. Muzerengi, Enrichment and Geoaccumulation of Pb, Zn, As, Cd, and Cr in soils near new union gold mine, Limpopo Province of South Africa, *IMWA 2017-13th International Mine Water Association Congress, Lappeenranta*, 25–30 June 2017, pp. 720–727.

- [37] K. Loska, I.D. Wiechu, I. Korus, Metal contamination of farming soils affected by industry, *Environ. Int.* 30 (2004) 159–165.
- [38] V. Kumar, S. Anket, R.B. Minakshi, K.T. Ashwani, Temporal distribution, source apportionment, and pollution assessment of metals in the sediments of Beas river, India, *Hum. Ecol. Risk Assess.* 24 (2018) 2162–2181, <https://doi.org/10.1080/10807039.2018.1440529>.
- [39] C. Kamunda, M. Mathuthu, M. Madhuku, Health risk assessment of heavy metals in soils from Witwatersrand gold mining basin, South Africa, *Int. J. Environ. Res. Public Health* 13 (2016) 663, <https://doi.org/10.3390/ijerph13070663>.
- [40] T.K. Boateng, F. Opoku, O. Akoto, Heavy metal contamination assessment of groundwater quality: a case study of Oti landfill site, Kumasi, *Appl Water Sci* 9 (2019) 33, <https://doi.org/10.1007/s13201-019-0915-y>.
- [41] J.N. Edokpayi, A.M. Enitan, N. Mutileni, J.O. Odiyo, Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa, *Chem. Central J.* 12 (2018) 2, <https://doi.org/10.1186/s13065-017-0369-y>.
- [42] United States Environmental Protection Agency (USEPA), Risk Assessment Guidance for Superfund, vol. 1, Human Health Evaluation Manual (Part A), Report EPA/540/1-89/002, 1989 Washington, DC.
- [43] N.K. Asare-Donkor, T.A. Boadu, A.A. Adimado, Evaluation of Groundwater and Surface Water Quality and Human Risk Assessment for Trace Metals in Human Settlements Around the Bosomtwe Crater Lake in Ghana, 2016, SpringerPlus, 1812 5, <https://doi.org/10.1186/s40064-016-3462-0>.
- [44] A.A. Mohammadi, Assessment of heavy metal pollution and human health risks assessment in soils around an industrial zone in Neyshabur, Iran, *Biol. Trace Elem. Res.* 630 (2019) 1–10, <https://doi.org/10.1007/s12011-019-01816-1>.
- [45] F. Ustaoglu, Y. Tepe, Water quality and sediment contamination assessment of Pazarsuyu stream, Turkey using multivariate statistical methods and pollution indicators, *Int. Soil and Water Conserv. Res.* 7 (2019) 47–56.