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Heavy metals concentrations and naturally occurring radionuclides in soils affected by and around a solid waste dumpsite in Osogbo metropolis, Nigeria

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Abstract The presence of heavy metals and naturally occurring radioactive materials (NORMs) in high concentrations in soils can be hazardous to exposed humans. This study is aimed at measuring the concentrations of heavy metals (Cu, Pb, Ni, Zn, Cd, Co, and Cr) and activity concentration of ^{232}Th, ^{238}U, and ^{40}K in soils affected by and around a solid waste dumpsite in Osogbo metropolis, Nigeria. Atomic absorption spectrometry and gamma-ray spectrometric techniques were used to determine the concentrations of metals and NORMs, respectively. Possible environmental impact of the heavy metal content and the probable radiological hazard by the NORMs to the general public were assessed. The calculated pollution indices reported in this work for Co, Cr, Pb, and Ni show low pollution status. Geoaccumulation indices for Cu, Zn, and Cd indicated that the area under study is strongly contaminated by these metals. Evaluated ecological risk index narrowed down Cd as the poisonous metal with high concentration. The measured radionuclides' mean activity concentrations and the evaluated mean of radium equivalent and absorbed dose rate values are higher than the recommended safe limit, an indication of possible radiological hazard. The principal factor analysis results explained 76% of the collection of data and described chips of galvanized/chrome metals, scrap metals, waste from electronics, Cr, and Cd-containing waste as sources of the heavy metals. The practice of land cultivation around the dumpsite should be deterred to prevent the transportation of these vicious heavy metals into the food chain.

Keywords Ecological effects · Pollution index · Potential ecological risk · Radium equivalent · Radiological hazard

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Introduction

Solid wastes contain untreated residential and business waste generated by a region inside a given territory (Nda-Umar et al., 2012). In recent times, population increase and the rapid pace of industrialization have adversely influenced the quality and amount of solid waste produced. The decay of aggregated waste over a significant stretch of time crumbles the nature of the soil. The ecological consequences of solid wastes are governed, to a reasonable extent, by their heavy metal susceptibility, which as a result of urbanization

and industrialization keep increasing day after day (Getachew and Habtamu, 2015; Turan et al., 2017). Significant quantities of harmful metals generated by humans have been established to be accumulated in the soil (Agirtas & Kilicel, 1999; Amusan et al., 2005; Cheng et al., 2007; Esakku et al., 2005; Ideriah et al., 2010; Turan, 2019a, b). Lack of proper strong waste administration frameworks is evident in many developing countries, while the current framework was constrained by improper administrative design, institutional system, and fiscal restriction (Peter et al., 2008). Open waste disposal and failure to appropriately manage waste pose several health challenges to the populace, especially those living close to or working nearby the dumpsite (Ogundele et al., 2020).

The presence of heavy metals in little amount in undisturbed soils is fundamental for plants to remain healthy (Esakku et al., 2005; Ideriah et al., 2010). However, the copious concentrations of heavy metals in the soil system have been proved to be a global problem for living organisms (Amini et al., 2012; Shahbaz et al., 2018a, b; Turan, 2021). In addition, heavy metals can influence the ecosystem of host soil to bring about huge losses of soil quality (Esmaeili 2014; Shahbaz et al., 2019; Zubair et al., 2021). Since heavy metals are non-biodegradable (Turan et al. 2018), they are not easily detoxicated and ousted from the soil by metabolic activities once present in the ecosystem and consequentially threaten human health via their entry into the food chain (Balkhair & Ashraf, 2016; Turan et al., 2018).

Heavy metals can accumulate in the body of human through dermal assimilation of polluted dust stick to uncovered skin, consumption of food uncovered from dust that is contaminated with heavy metal, and the inhalation of suspended particles (Du et al., 2013; Ogundele et al., 2019a; Ogunsola et al., 1993; Taiwo et al., 2016). In addition, the cultivation of plant on heavy metal–contaminated soil can adversely affect the plant quality which may cause critical health issues to humans and animals that feed on such plants (Turan et al., 2018; Turan, 2019a, b). The consumption of food derived from plants contaminated by heavy metals can directly impair human health by inhibiting the functionalities of cells in inter-linked human body organs and thereby cause cardiovascular and renal instability, poor development of organs, gastrointestinal disturbance, intellectual disabilities in children, mental retardation, and infertility (Naeem et al., 2021; Ogundele et al., 2017; Rasool et al., 2021; Sofuoglu & Sofuoglu, 2017; Turan et al., 2018; Turan, 2019a, b; Van der Kuijp et al., 2013; Zubair et al., 2021).

The conceivable outcomes of a significant level of radiation in the dumpsite as a result of natural radionuclides present in the soil should not be underestimated. The possibility of exposure to a high level of radiation from radionuclide-contaminated soil through ingestion or inhalation has been confirmed (Ademola et al., 2015; Sayyed et al., 2018). These radionuclides can be conceivably harmful to humans' health, even at low concentrations. Results of some research works have linked the source of vestiges of radionuclides in some staple foods consumed in Nigeria to dumpsites (Akinloye & Olomo, 2005; Jibiri et al., 2007). The vacant land around the dumpsite is noted for farming, and this can aid conveyance of possible high level of naturally occurring radioactive materials domicile in the soil from the study area by root-uptake and then through ingestion to the populace.

There has been an appraisal of the impact of solid waste on the quality of surface and shoal water within Osogbo metropolis using reliable methods (Oyelami et al., 2013; Ugwu et al., 2016), but evaluations of heavy metals and naturally occurring radionuclides in soils contaminated by solid waste from the study area along with possible pollution and radiation hazards they may present are still essential. In this research, the concentrations of Cu, Pb, Ni, Zn, Cd, Co, and Cr accumulated in the soil from Onibu-Eja, solid waste dumpsite, Osogbo, will be determined along with activity concentration of ^{232}Th, ^{238}U, and ^{40}K in the soil from the same area. Associated health risks posed by the measured elements will also be assessed.

Methodology

Study area

This study was carried out in Onibu-Eja solid waste dumpsite, which is located in Egbedore Local Government area, Osogbo, Southwest Nigeria. The study area coordinates are 7°47′41″N and 4°29′23″E. Geologically, the research area lies within the Southwestern Nigeria Precambrian basement complex, which forms part of Nigeria's basement complex (Oyelami et al., 2013; Rahaman, 1988, 1989; Ugwu et al., 2016). Onibu-Eja dumpsite receives all sorts of wastes from different

sources, such as kitchens, animal farms, hospitals, workshops (electronics and mechanical), saw-mill, and different industries (small, medium, and large scales) using various chemical substances. In the vicinity of the dumpsite under consideration, farming is the common practice where different arable crops are cultivated and animals grazing. There are also residential buildings and some small-scale shops for retail purposes.

Sample collection

Thirty-four (34) grids of 1 by 1 m, with a minimum of 10 m apart, were made in the dumpsite. The surface of each sampling point was cleared of solid material using a shovel until the soil beneath is reached. Soil samples taken from the edges and randomly in-between each grid were thoroughly mixed for homogeneity before a representative sample is collected into a well-labeled polythene bag. Another ten samples were collected 10 km in different directions from the dumpsite as controls. The samples were all obtained the same day. Then, they were conveyed to the environmental research laboratory in the Physics Department, Osun State University, Osogbo, for further preparation. In the laboratory, extraneous earth materials were removed from the samples after which they were air-dried to consistent weight at ambient temperature.

Sample preparation for heavy metal analysis

The samples were then sifted using a 2-mm mesh, after which 2.0 g of each sample was measured and souse with 15 mL mixture of perchloric ($HClO_4$) and nitric acids in ratio 3:1 inside a Foss Tecator digestion vessel. The temperature of the content was raised to and maintained at 400 °C until the solution was clear and allowed to cool. After cooling, the impurities in the solution were filtered out and the filtrate was diluted with distilled water to 50 mL in a volumetric flask. Elemental concentrations of Co, Cr, Pb, Cu, Zn, Cd, and Ni were determined using the Atomic Absorption Spectrometer (Buck Scientific VGP 210 Model). The detection limits of the measured metals ranged from 0.001 to 0.005 μg/g (Ogundele et al., 2019a, b).

Pollution indices

Indices of pollution, like pollution and contamination load factors, have successfully been used to appraise comparatively the contamination levels in the soil (Chen et al., 2015; Ogundele et al., 2020). The contamination factor was determined in this study using Eq. (1).

$$C_f^i = \frac{C_i}{C_b} \tag{1}$$

c_i and c_b are the quantified concentrations of *i*th heavy metal and that of the background, respectively. Background concentration for soil used for agricultural purposes recommended by the Canadian Council of Ministers for the Environment (CCME) (2014) is utilized in this research. The classification for the range of contamination factor is presented in columns 1 and 5 of Table 1.

The degree of contamination ($\boldsymbol{C_{deg}}$) is an indication of the total and order of magnitude of metal contamination in the soil (Islam et al., 2015). In this study, $\boldsymbol{C_{deg}}$ is quantified using Eq. (2).

$$C_{deg} = \sum_{i=1}^{n} C_f^i \tag{2}$$

The pollution status of the degree of contamination is categorized based on the ordered series given in columns 2 and 5 of Table 1.

The pollution load index (*PLI*) is used for the assessment of the total level of pollution of soil due to its heavy metal contents. It integrated the components of contamination in Eq. (1) for individual heavy metal

Table 1 Range and interpretations of pollution indices (Hakanson, 1980; Islam et al., 2015; Luo et al., 2007; Ogundele et al., 2020; Ogunkunle & Fatoba, 2013)

Contamination factor	Degree of contamination	Ecological risk factor	Ecological risk index	Pollution status
$C_f^i < 1$	$C_{deg} < 5$	$ERF < 150$	$E_r^i < 40$	low
$1 \le C_f^i < 3$	$5 \le C_{deg} < 10$	$150 \le ERF < 300$	$40 \le E_r^i < 80$	Moderate
$3 \le C_f^i < 6$	$10 \le C_{deg} < 20$	$300 \le ERF < 600$	$80 \le E_r^i < 160$	Considerate
$C_f^i \ge 6$	$C_{deg} \ge 20$	$ERF \ge 600$	$160 \le E_r^i < 320$	Very high

that is being considered (Chen et al., 2015; Islam et al., 2015). Equation (3) is used to evaluate *PLI*

$$PLI = \sqrt{C_f^1 \times C_f^2 \times C_f^3 \times \cdots \times C_f^n} \quad (3)$$

where n is the number of all the hazardous metals considered. The results of *PLI* can indicate the toxicity status of the soil from *free of pollution* to *highly polluted* in the range of zero to ten ($0 \rightarrow 10$) (Chen et al., 2015; Dung et al., 2013; Zhang et al., 2011).

Geoaccumulation index

Geoaccumulation index (I_{geo}) for the quantified concentrations of heavy metal n (C_n)in mg kg^{-1} and geochemical background concentration (B_n) was calculated using Eq. (4). I_{geo} is a geochemical tool that has proved useful in appraising the pollution status of heavy metals' elemental concentrations in the sediment, water, soil, and dust (Dung et al., 2013; Muller, 1969; Ogundele et al., 2020).

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \quad (4)$$

The constant 1.5 is added as suggested by Chen et al. (2015) as the correction factor for the background matrix to account for potential variation as a result of lithogenic effects in background values. In this study, the values suggested in the continental crust by Reimann and de Caritat (1998) for the background content of element n (B_n) are adopted. I_{geo} pollution status is rated as featured in Table 2.

Ecological risk factor

This study also uses the possible environmental risk factor *(ERF)*, which has been widely used to assess the nature of sediments and soils concerning heavy metal contamination, to assess heavy metal accumulation in soils, and to relate ecological effects to their toxicology (Hakanson, 1980; Qingjie et al., 2008).

$$ERF = \sum_{i=1}^{n} E_r^i \quad (5)$$

$$E_r^i = T_r^i \times C_f^i \quad (6)$$

ERF of the quantified heavy metals in the soil sample impacted by solid waste is calculated using Eq. (5), where the number of quantified heavy metals is n. The classification of ERF pollution status is featured in columns 3 and 5 of Table 1. Equation (6) is utilized to evaluate the possible ecological risk index ($\boldsymbol{E_r^i}$) for each quantified heavy metal i (Islam et al., 2015). The toxicity factor ($\boldsymbol{T_r^i}$) used in this study can be found in columns 1 and 11 of Table 3. The ranking systems for the pollution status of the ecological risk index are presented in columns 4 and 5 of Table 1.

Sample preparation for gamma-ray spectrometry analysis

Thoroughly washed and dried cylindrical high-strength thermoplastic materials were filled with 100 g of fine sample each, sealed hermetically, and held for a minimum of 28 days for the attainment of secular equilibrium between the parent and the daughter nuclides (Gbenu et al., 2020a). The sealed samples were then taken to Biological Trace Element Laboratory, Department of Physics and Engineering Physics, Obafemi Awolowo University, Ile-Ife, Nigeria. In this laboratory, the measurement of the activity concentrations of the naturally occurring radioactive materials (NORMs) was carried out using gamma-ray spectrometry technique. Each sample was counted for 36,000 s using a well-calibrated Cesium Iodide (CsI) scintillation detector, while Universal Radiation Spectrum Analyzer (URSA II) was used to process the spectra. Energy calibration is done through the measurement of the spectrum of a source which emits precisely known gamma ray energy, and the position of the measured peak was compared with the energy. Coverage of full spectrum of energies expected in

Table 2 Pollution range of the geoaccumulation index (Dung et al., 2013; Olujimi et al., 2014)

Pollution status	Clean	Clean to slightly polluted	Slightly polluted	Slightly to substantially polluted	Substantially polluted	Substantially to exceedingly polluted	Exceedingly polluted
I_{geo}	<0	$0 \rightarrow 1$	$1 \rightarrow 2$	$2 \rightarrow 3$	$3 \rightarrow 4$	$4 \rightarrow 5$	>5

Table 3 Descriptive statistics of the heavy metal concentrations results, the suggested background values, and the evaluated indices from the study area.

Metals	Range (mg kg^{-1})	Mean ± SD (mg kg^{-1})	Skewness	Kurtosis	Control mean ± SD (mg kg^{-1})	CCME (2014)	C_f^i	Reimann and De Caritat (1998)	I_{geo}	T_r^i (Zhengqi et al. 2008)	E_r^i
Cu	2.13–5074.85	342.60 ± 891.95	5.02	26.99	53.00 ± 4.26	63.00	5.44	14.3	4.00	5	27.19
Zn	6.85–4834.24	893.67 ± 980.73	2.19	6.82	121.34 ± 7.41	250.00	3.57	52	3.52	1	3.57
Co	1.50–34.75	9.36 ± 8.27	1.78	2.57	6.22 ± 2.61	40.00	0.23	11.6	−0.89	5	1.17
Cr	0.66–16.42	7.10 ± 3.35	0.63	1.28	4.78 ± 1.11	64.00	0.11	35	−2.89	2	0.22
Pb	1.88–46.90	20.29 ± 9.57	0.62	1.27	16.77 ± 2.59	70.00	0.29	17	−0.33	5	1.45
Cd	0.09–22.50	2.70 ± 4.52	3.23	11.96	0.65 ± 0.18	1.40	1.93	0.1	4.17	30	57.87
Ni	1.90–23.41	6.91 ± 4.09	2.06	7.00	3.82 ± 0.65	45.00	0.15	18.6	−2.01	5	0.77

this study was assured in the detector energy calibration, which was done using 3 point sources of gamma emitter samples (Ba-133, Cs-137, and Co-60) of known energies that permitted the determination of a linear equation relating gamma energy to channel number. Evaluation of activity in the samples was done using Rocketdyne reference soil sample (ENV 94,084) as comparator standard for efficiency calibration of the detector. The peaks corresponding to 352 keV (Pb-214) for U-238, 1460 keV for K-40, and 240 keV (Ra-224) for Th-232 were employed for the estimation of natural radionuclides in all the samples. The integrated counts recorded under the energy peaks 1460, 352, and 240 keV were noted for each spectrum (Inuyomi et al., 2019).

Estimation of radiation hazard of soil samples

Radium equivalent activities (Ra_{eq}) were calculated using Eq. (7). This was done to appraise the gamma radiation exposure from the study area (Ademola et al., 2015; Gbenu et al., 2015, 2016; Oladejo et al., 2020).

$$Ra_{eq} = 1.43A_{Th} + A_{Ra} + 0.077A_K \quad (7)$$

$\boldsymbol{A_{Th}}$, $\boldsymbol{A_{Ra}}$, and $\boldsymbol{A_K}$ are the activity concentrations of ^{232}Th, ^{238}U, and ^{40}K in Bq kg^{-1} respectively. ^{226}Ra being one of the decay products in ^{238}U decay series (Awwad et al., 2012), ^{238}U is substituted for ^{226}Ra in this work.

Also evaluated based on accepted data and recommended formulas was the absorbed dose rate (D_R) of gamma radiation from the key primordial radioactive elements in the sampled soil from the study area using Eq. (8) (European Commission (EC), 1999); Gbenu et al., 2015; Oladejo et al., 2020; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1993).

$$D_R\left(\text{nGyh}^{-1}\right) = 0.446A_{Ra} + 0.662\text{A}_{Th} + 0.048\text{A}_{Ra} \quad (8)$$

Statistical analysis

Multivariate statistical tools that utilize the approach of data dimensionality reduction were deployed to locate a couple of elements that gives explicit variance within the data set of the quantified concentrations of the element (Gbenu et al., 2020b; Hair

et al., 2014; Ogundele et al., 2020). Correlation analysis between the measured concentrations of the element in the sampled soil was carried out to ascertain the connectivity between the elements. To identify basic factors that reflect what the variables (measured concentrations of the elements) have in common, principal component factor analysis was carried out (Ogundele et al., 2020). The target for using multivariate statistical analyses was to determine the meaning of the specific new calculated dimensions and to detect possible variable associations with a certain signification. The detection of possible key variances in the data collection through the statistical analysis performed was also an objective.

For optimization of valuating in the vicinage of either 0 or 1 in the loading factor without tampering with the variability in totality or as an individual element, varimax rotation was employed (Ogundele et al., 2020). With the approach of varimax rotation, high loadings (i.e., > 50% association) indicate an association between the variable and the factor, while loadings near zero indicate a clear lack of association (Ogundele et al., 2020). Subsequent upon rotation, elements emerging from similar sources are factored together (Hair et al., 2014). Statistical analysis in this study was performed using computer software Statistical Package for Social Sciences (SPSS Statistics 26).

Results and discussion

Concentrations of heavy metals

The results of Cu, Zn, Co, Cr, Pb, Cd, and Ni quantified from soil samples collected from Onibu-Eja dumpsite are presented in the descriptive statistical format in Table 3. The results show a great variance of dispersion of the appraised heavy metals in the area under study. This may be consequent upon the composition of different solid waste materials that are disposed in the dumpsite and had decomposed over time. The measured mean concentrations of Zn and Cu are 893.67 and 342.60 mg kg^{-1}, respectively, much more prominent than the background values suggested by Reimann and de Caritat (1998), Radojevic and Bashkin (2006), and Canadian Council of Ministers of the Environment (CCME), (2014). Although Zn and Cu are essential elements for plants, their elevated concentrations are phytotoxic and directly affect crop yield and soil fertility (Balkhair & Ashraf, 2016; Caussy et al., 2003; Turan et al., 2018). The mean concentration of Pb is 20.29 mg kg^{-1}. This mean concentration is within the stipulated background concentration for Pb (Canadian Council of Ministers of the Environment 2014; Radojevic & Bashkin, 2006; Reimann & de Caritat, 1998), but higher than the threshold range of 5 mg kg^{-1} set by World Health Organization. Food and Agriculture Organization WHO/FAO (2007), a clear indication that the examined soil poses toxic effects on plants, humans, and animals (Naeem et al., 2021). Furthermore, the mean concentration of Pb in soil affected by solid waste is higher than its concentration in other samples from the control area, a denotation of possible enhanced concentration as a result of dumping activity. The mean values for Co, Cr, Ni, and Cd concentrations are 9.36, 7.10, 6.91, and 2.70 mg kg^{-1}, respectively. Co, Cr, and Ni mean concentrations in the dumpsite are lower than the stipulated background reported by Radojevic and Bashkin (2006) and Reimann and de Caritat (1998), but their transcendence of the mean values for the samples from the control area connotes an aggregation of these heavy metals in the dumpsite. The values of Cd concentration in the dumpsite are notably higher than those from the suggested background and the control samples. Elevated concentration of Cd has been implicated in causing metabolic irregularities and oxidative stress in plant which distort their respective physiological and morphological attributes (Bagheri et al., 2014; Jali et al., 2016; Kim et al., 2020; Yang et al., 2016; Zubair et al., 2021).

Descriptive statistics of elemental concentrations of heavy metals

The pattern and concentration variation of the appraised heavy metals is presented in column 3 of Table 3. The evaluated values for the standard deviation of Cu, Zn, and Cd are observed to be very high, which may be due to the large variation in the distribution of the elements in the area (Islam et al., 2015; Ogundele et al., 2020). Skewness in statistics connotes a lopsidedness and asymmetry from the mean of data distribution (Ogundele et al., 2020; Raghu et al., 2017). Column 4 of Table 3 features skewness calculated for the heavy metal distribution in the area. Cr and Pb concentrations were slightly skewed

positively (< 1), a connotation of moderate distortion in distribution. While Zn, Cu, Co, Ni, and Cd concentrations with skewness greater than 1 (> 1) indicate that their distributions are highly distorted. Likewise, kurtosis of the distribution was evaluated to determine the peakness or flatness of the data collection. Results of evaluated kurtosis are presented in column 5 of Table 3. A subzero kurtosis is an indication of the flattened distribution of data and is called a platykurtic distribution. If the kurtosis is greater than zero, then the distribution is peaked and is called a leptokurtic distribution. In this work, all the distributions have kurtosis greater than 0, suggesting peaked distributions (Ogundele et al., 2020; Raghu et al., 2017).

Results of pollution indices

The evaluated average contamination factor values are presented in Table 3, column 8. The average contamination factors for Co, Cr, Pb, and Ni have values less than 1 (C_f^i<1), indicating that these heavy metals contribute trifling or no pollution to the study area. Cd contamination factor is between 1 and 3 ($1 \leq C_f^i < 3$,), which implies moderate contamination status. Cu and Zn contamination factors ranged between 3 and 6 ($3 \leq C_f^i < 6$), signifying considerate pollution status. The value of C_{deg} evaluated in this study is 11.73, denoting a considerate level of pollution. The index of pollution load (*PLI*) evaluated in this study is 0.64, signaling an unpolluted status.

The results of the geoaccumulation index (I_{geo}) are presented in column 10 of Table 3. Geoaccumulation indices of Co, Cr, Pb, and Ni have values below 1 ($I_{geo} < 1$), thereby classified as unpolluted. Cu, Zn, and Cd have geoaccumulation index values ranging between 3 and 4 ($3 < I_{geo} \leq 4$), stipulating a strongly polluted status. This could be ascribed to the accumulation and decay of solid wastes that are rich in these heavy metals. This proffers that the sampled soil could be mainly contaminated by accretion of Cd, Zn, and Cu amidst the appraised heavy metals.

Potential ecological risk index (E_r^i) results are presented in Table 3, column 11. All heavy metals quantified, Cd exempted, have E_r^i values below forty (< 40), suggesting a low-risk classification. Cd has an ecological risk index value of 57.87, which suggests moderate risk. Regulation of Cd-prone wastes is very important to mitigate the possible health risks it posed to the populace (Ogundele et al., 2020; Zubair et al., 2021). Farming around the dumpsite is unhealthy, as a plausible channel of heavy metals into humans' food chain, and consuming farm product from this region is hazardous (Ogundele et al., 2020). The average possible environmental risk factor (ERF) is 92.24, an indicator of a low degree of ecological pollution.

Radionuclide concentration results

The distribution of natural radionuclides in the sampled soil from the study area and the evaluated absorbed dose rate and radium equivalent are described statistically in Table 4. Negative skewness observed for the distributions of ^{232}Th and ^{238}U in Table 4 denotes a dispersion with asymmetric tail broadening toward more negative values. The negative kurtosis values for all the NORM distributions in Table 4 indicate a flattened distribution.

The presence of radionuclides ^{238}U, ^{40}K, and ^{232}Th is evident in all the samples. The computed mean activity levels of ^{40}K, ^{238}U, and ^{232}Th are 718.16 ± 67.05, 264.28 ± 27.54, and 53.65 ± 5.96 Bq kg^{-1}, respectively. The mean values of the three natural radionuclide concentrations from the dumpsite's soil are observed to be comparable with values from the control environment, suggesting that dumping activity does not influence the appraised concentrations of these radionuclides. Activity levels of ^{232}Th, ^{40}K, and ^{238}U in the sampled soils are observed to have values greater than the worldwide

Table 4 Statistical presentation of concentrations (Bq kg^{-1}) of NORMs and the evaluated absorbed dose rate (nGyh^{-1}) and radium equivalent (Bq kg^{-1}) of the sampled soil from the study area

	Range	Mean ± SD	Control (mean ± SD)	Skewness	Kurtosis
^{232}Th	43.42–63.05	53.65 ± 5.96	51.35 ± 3.54	−0.37	−0.85
^{238}U	216.45–318.74	264.28 ± 27.54	259.36 ± 17.75	−0.05	−0.58
^{40}K	617.91–893.26	718.16 ± 67.05	706.48 ± 42.38	0.62	−0.03
Ra_{eq}	326.13–473.26	396.30 ± 40.45	387.19 ± 29.18	−0.06	−0.61
D_R	154.94–223.97	187.86 ± 19.01	183.58 ± 16.27	−0.04	−0.60

average activity concentration of 30, 400, and 35 Bq kg^{-1}, respectively (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 2000).

Radium equivalent (Ra_{eq}) activity mean values in the dumpsite and the control area are 396.30 and 387.19 Bq kg^{-1}, respectively. These mean values compare well with the suggested allowable limit of 370 Bq kg^{-1}(Organization for Economic Cooperation and Development (OECD), 1979). Absorbed dose rate (D_R) evaluated mean values are 187.86 and 183.58 $nGyh^{-1}$ in soil samples from the dumpsite and control areas, respectively. The evaluated absorbed dose rate (D_R) values are of the order of 2.23 and 2.18 greater than the worldwide population-weighted average of 84 $nGyh^{-1}$ suggesting an enhanced ionizing radiation doses than what is acceptable internationally (OECD, Organization for Economic Cooperation and Development, 1979).

Correlation analysis result

The results of correlation analysis between all the measured elements are presented as correlation matrix in Table 5. The results show a considerable degree of interrelationship. For example, Cr and Pb are observed to be perfectly and directly correlated (correlation coefficient, $R = 1.000$), indicating the existence of a perfect relationship between the metals and suggesting a common source. Cu and Ni are also seen to be positively correlated with each other ($R > 0.798$), a reflection of good association as well. Zn is moderately correlated with Co, Cr, and Pb, and Ni with Cr and Pb with R slightly greater than 0.5. Cd lacks correlation with all other metals ($R \approx 0$) except for Co that it is negatively and weakly correlated with, suggesting an independent source. Cu is weakly correlated with Zn, Cr, and Pb $3 < R < 5$. These correlation coefficient results between the heavy metals suggest 2 different possible sources. Natural radionuclides are observed to be strongly and positively correlated ($R > 0.840$) with one another, predicting a common source.

Factor analysis results

The results of factor analysis for measured heavy metals and natural radionuclides are presented in Table 6. Premises on the initial eigenvalue's results (total > 1), three factors with total cumulative variance > 76% were carefully considered. Factor loading is the statistical relationship of the variable (measured concentrations of the elements) and the factor (likely sources), while the squared loading is the amount of the variable's total variance accounted for by the factor (Hair et al., 2014). Factor loadings greater than ±0.5 are considered practically significant and are used for interpretation of the factor analysis. An intersection is noticed for Co in the component matrix for principal component 1 (PC 1) and PC 3, but after varimax rotation, it was reduced to PC 3. PC 1, which is responsible for 36.054% of the total variance, is loaded with Cr (0.88), Pb (0.88), Ni (0.83), Zn (0.65), and Cu (0.761). Indiscriminate disposal of waste from printing processes, construction materials, metals (iron, steel, and brass coated with Zn), a large quantity of used dry cells, used Ni–Cd and Pb-acid batteries, plumbing material, glassware, petrol, gasoline, Zn-containing pesticides (e.g., Zineb, Mancozeb, and Ziram), and large proportions of product packaging, waste metal cans, and containers are the main sources that could contribute to this factor (Mousavi & Seyedi, 2011; Naeem et al.,

Table 5 Correlation matrix of total elemental contents

	Cu	Zn	Co	Cr	Pb	Cd	Ni	40K	238U	232Th
Cu	1.000									
Zn	0.300	1.000								
Co	0.112	0.524	1.000							
Cr	0.484	0.539	0.43	1.000						
Pb	0.483	0.539	0.43	1.000	1.000					
Cd	0.059	−0.026	−0.225	0.002	0.001	1.000				
Ni	0.798	0.458	0.409	0.545	0.545	0.01	1.000			
40 K	−0.191	0.005	0.142	0.106	0.106	−0.189	−0.077	1.000		
238U	−0.171	0.088	0.093	0.045	0.046	−0.204	0.003	0.878	1.000	
232Th	−0.207	0.123	0.137	0.056	0.057	−0.183	0.006	0.844	0.969	1.000

Table 6 Preliminary eigenvalues (PE), extraction sums of squared loadings (ESSL), rotation sums of squared loadings (RSSL), component matrix (CM), and rotated component matrix (RCM) analysis results for all the measured elements

Component	PE			ESSL			RSSL		
	Sum	VP	PA	Sum	VP	PA	Sum	VP	PA
1	3.605	36.054	36.054	3.605	36.054	36.054	3.493	34.927	34.927
2	2.947	29.474	65.528	2.947	29.474	65.528	2.842	28.417	63.344
3	1.083	10.831	76.359	1.083	10.831	76.359	1.301	13.015	76.359
4	0.898	8.977	85.336						
5	0.709	7.088	92.423						
6	0.455	4.552	96.975						
7	0.181	1.815	98.790						
8	0.096	0.962	99.752						
9	0.025	0.248	100.000						
10	8.397E-6	8.397E-5	100.000						
Metals	CM			RCM					
	1	2	3	1	2	3			
Cr	0.890			0.883					
Pb	0.890			0.882					
Ni	0.790			0.833					
Zn	0.720			0.654		0.370			
Cu	0.646		0.338	0.761					
Co	0.619		-0.553	0.471		0.691			
^{238}U		0.951			0.978				
^{232}Th		0.944			0.966				
^{40}K		0.916			0.936				
Cd		-0.303	0.705			0.752			

VP variation percentage, *PA* percentage accumulation.

2021; Radojevic & Bashkin, 2006; Shahbaz et al., 2018a, b, 2019; Turan, 2019a). Besides, Pb concentrations can be traced to waste from day-to-day life products containing Pb (i.e., glazed ceramic, solder, and paints), metal plating, and leather tanning coupled with exhausts from automobiles along the main road (Kushwaha et al., 2018; Turan, 2019b).

Potential sources of Cu include components of electronic waste: laptops, toys, transistors, television, computers, wires, and cable (Ogundele et al., 2020). Consequently, the discovered sources are as follows: waste of chrome metals, chips of galvanized iron, used dry and wet cells, and electronics waste. PC 2 is populated with naturally occurring radioactive materials, ^{238}U (0.98), ^{232}Th (0.97), and ^{40}K (0.94), which explained 29.474% of the sum of variation. The presence of these radionuclides can be traced to the geological formation of the study area. PC 3 is loaded with Co (0.69) and Cd (0.75). These metals explained 10.831% of the sum of variation. Probable sources leading to this constituent include wastes from electroplating processes, scrabs of alloys of the metals, Co-containing wastes, spent Ni–Cd batteries, used kitchen utensils, and soldering components. Figure 1 presents graphically the components that describe the relationship among the appraised metals.

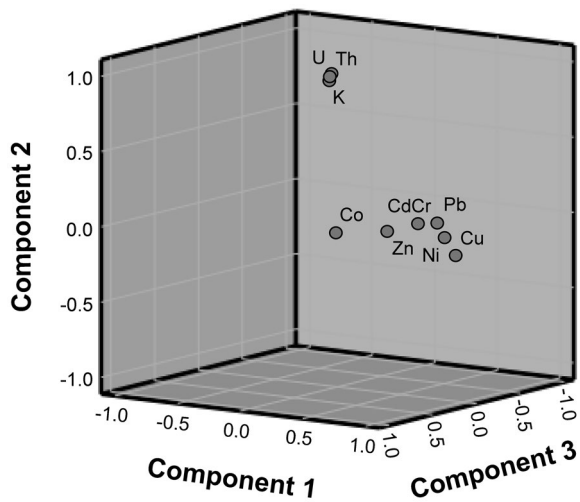

Fig. 1 Analysis of principal component plot

Conclusion

Concentrations of selected heavy metals in soils affected by solid waste from Onibu-Eja dumpsite were appraised using Atomic Absorption Spectrophotometer. Indices of pollution were evaluated to adequately appraise the degree to which the appraised heavy metals pollute the study area. The results stipulate that the values of mean concentrations of Zn, Cu, Co, Cr, Cd, and Ni are greater than the stipulated background values in the soil. The calculated pollution indices reported in this work for Co, Cr, Pb, and Ni $C_f^i < 1, I_{geo} < 0$) reflect low pollution status. Geoaccumulation index of the metals Cu, Zn, and Cd, with $3 < I_{geo} \leq 4$ suggests a strong pollution status. Evaluated ecological risk index singles Cd out as the only heavy metal with poisonous concentration ($E_r^i > 40$). Activity levels of ^{232}Th, ^{40} K, and ^{238}U in the sampled soils were measured using the gamma-ray spectroscopy technique. Possible radiological risk and level of radiation exposure in the soil from the area were also evaluated. The calculated radium equivalent (Ra_{eq}) mean value is 387.19 Bq kg^{-1}, and the absorbed dose rate (D_R) is evaluated to be 187.86 nGyh^{-1}. These are substantial values compared with the recommended safety ones. Hence, populace living, farming, and selling in the vicinity may be endangered by nocent radiation arising from this area. Factor analysis results explained 76% of the data collection and identified heavy metals sources as metals chips, liquidated electronic components, Cr and Cd-containing wastes. It is thereby recommended that governments discourage human activity in the dumpsite area. The practice of land cultivation around the dumpsite should be deterred to prevent the transportation of these vicious heavy metals into the food chain. Waste management agencies should be trained and equipped to identify and quantify the potentials of solid waste and to sensitize the general public of the appropriate means of recycling or disposal, as the case may be of solid waste.

Author contribution All authors contributed to the conception and design of the study. The preparation of materials, processing, and storage of samples were executed by Olubusayo F. Oladejo, Lasun T. Ogundele, and Mutiu A. Fakunle; gamma spectroscopic analysis was performed by Samuel O. Inuyomi and Stephen F. Olukotun. SPSS analysis was performed by Olubusayo F. Oladejo. The manuscript was first drafted by Olubusayo F. Oladejo, edited and reviewed by all the authors with constructive contributions. The final manuscript was read and approved by all authors.

Availability of data and material Substantial data are embedded in the manuscript.

Declarations

Conflict of interest The authors declare no competing interests.

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