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Health risk assessment due to environmental radioactivity and heavy metal contamination at the central solid waste dumpsite in Ebonyi State, Nigeria

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Abstract

The study assessed the levels of radiation exposure due to environmental radioactivity and heavy metal contamination at the central solid waste dumpsite in Abakiliki, Ebonyi State and its health impact on surrounding communities. Soil samples collected from landfills/dumpsites, farms, and control sites were assessed to determine environmental radioactivity and heavy metal concentrations, and compared to the control site values. The radioactivity concentration was determined using a NaI(Ti) gamma spectrometer. The estimated radiological hazard indices from the dumpsite and farmland showed that the average values of Radium Equivalent (R_{eq}), and Excess lifetime cancer risk are 146 Bq kg^{-1} and 1.445 $\times$ 10^{-3} respectively. The average concentration of heavy metals in soil samples was evaluated using an atomic absorption spectrophotometer (AAS). The concentration of heavy metals in studied samples showed that Pb > Fe > Cu > Zn > Co > Ni > Cd > Cr > Hg > As. Soil contamination was based on the geo-accumulation index (Igeo), Potential ecological risk coefficient (RI), Chronic daily take (CDI), Total carcinogenic risk index (TCRI), Total hazard quotient (THQ) and pollution load index (PLI). The average values of Igeo, CDI, TCRI, THQ and PLI for dumpsites and surrounding farms were 2.01, 207.19, 6.1 $\times$ 10^{-2}, 2.66, 0.95 and 1.33 respectively. Generally, high concentrations of Pb and Fe were observed at the dumpsites and surrounding farmlands have potential negative health implications for the health of humans and plants around the dumpsite.

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1. Introduction

Humans, plants and animals are constantly exposed to natural and man-made environmental hazards. This could be from ionizing radiations or contamination by heavy metals caused by human activities within an environment [1]. For ionizing radiation, the primal series radionuclides of ^{226}Ra, ^{238}U, ^{232}Th, and the single radionuclides, ^{40}K, are major sources of environmental background radiations [2]. Other sources of ionizing radiations are ^{137}Cs, ^{133}Ba, ^{90}Sr and ^{222}Rn gas which are mostly produced and disposed of by industries. All these materials when carelessly handled or disposed of constitute the overall effective radiation dose on living organisms in a given

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environment (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [3]. The risk factors from radioactive decay of ^{238}U, ^{232}Th series and ^{40}K as well as other radioactive materials which is a source of external hazard to the surrounding and internal human organs via inhalation and ingestion of radon and its decay products [3]. Other environmental hazards emanating from heavy metals such as Lead (Pb), Copper (Cu), Zinc (Zn), Cadmium (Cd), Iron (Fe), cobalt (Co) Arsenic (As), Nickel (Ni), Chromium (Cr) and Mercury (Hg) from unprocessed waste materials which penetrate the underground soil and leached into the adjoining farmlands [4–6]. These non-degradable heavy metals accumulate in the environment due to their bioavailability easily deposited into the human body through the food chain [7–9]. Although some heavy metals, like Cu, Fe and Zn have proved to be helpful to the health of humans as essential mineral elements in the body, they play important roles in body metabolism. However, these heavy metals could be toxic to human systems when they are ingested in excess [10, 11].

Recently, the natural list of radionuclides and heavy metal contamination has increased due to high human and industrial activities in Ebonyi State, Nigeria. Waste generation, disposal, and recycling have greatly contributed to the increase in levels of heavy metal contamination and human radiation exposure [12]. These radiation exposures could be external, from concentrations of ^{40}K, ^{238}U and ^{232}Th in soil or internal, due to inhalation of radon and its progenies in dust and fumes from waste management and disposal sites. The average worldwide specific activity of ^{40}K, ^{226}Ra, and ^{232}Th in the earth's crust is estimated to be 412, 35 and 45 Bqkg^{-1} respectively [13]. The understanding of radiation exposure levels and toxic heavy metal contamination at waste management and disposal sites will enhance on-the-spot assessment of possible radiological and environmental hazards to human and animal health due to waste disposal and management activities. Ionizing radiation exposure may alter the DNA of a living cell thereby causing serious health hazards in humans, such as mutations, cancer, leukemia and other different kinds of health challenges in plants and animals [14–17].

Recent studies have shown that population growth, industrialization and mining activities in Ebonyi State Nigeria have greatly amplified health risks in humans through radiation exposure and heavy metal contamination. Therefore, this study is crucial for proper human health risk assessment of the dumpsite and the health effects on the surrounding community. According to the International Agency for Research on Cancer (IARC) and the Environmental Protection Agency (EPA), exposure to ionizing radiation and toxic heavy metals is of foremost concern for a healthy environment. This is due to the radiological, carcinogenic, and non-carcinogenic effects of ionizing radiation and toxic heavy metals on human health [18, 19].

The absence of data on heavy metal concentration and radiological status of waste management site and surrounding farmlands in Ebonyi State Nigeria, for routine and systematic monitoring of the health and environmental impact around this dumpsite has also necessitated this research. This research, will in no small measure, facilitate the constant monitoring of heavy metal concentration, and radiation exposure levels of the dumpsite under consideration, ignite meaningful conversation around municipal waste management, and forestall possible environmental hazards within this site. It will enable government / Environmental protection agencies to make appropriate legislation for efficient waste management and disposals bearing in mind the health implications of heavy metals and radionuclides in farmlands on individuals within the dumpsite.

Some researchers in Nigeria have assessed heavy metal concentration [20, 21] and radiation exposure levels at different dumpsites and strategic locations [22–25].

The results of most of these researches have shown that the concentration of heavy metal is usually greater at the upper soil layer than at the lower soil layer. This has increased the possibility of root crops' absorption of these metals and subsequent transfer to human systems through the food chain. It was also observed that radiation exposure levels and activity concentrations of ^{40}K, ^{226}Ra, ^{232}Th and ^{238}U at most dumpsites were within the permissible limit. Generally, there were substantial increases in heavy metal concentration and moderate increases in radiation exposure level and activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th at most dumpsites relative to control sites.

However, further assessment and constant monitoring of heavy metal concentration and radiation exposure levels at these waste management and dumpsites is necessary to predict future hazards due to the increase in industrial and human activities around these dumpsites.

The main objective of this research is to monitor and evaluate the level of ionizing radiation exposure by measuring the activity concentrations of ^{40}K, ^{232}Th and ^{238}U in soil samples at the Ebonyi State central dumpsite for solid waste and the surrounding farmlands as well as to evaluate heavy metal concentration in soil samples in that location. The result obtained shall be analyzed to determine the nexus between environmental contamination by radionuclides and heavy metals with intermittent health challenges like leukemia, stillbirth and body rashes observed in the community where the dumpsite is located. This will be achieved by evaluating the radiological hazards on people living around the dumpsite and the inherent risk connected with the consumption of crops and food polluted by heavy metals within that location. Findings from this study shall also assist the Ebonyi State government, through the Ministry of Health and Environment, National Council on Radiation Protection and Management (NCRM) and other environmental protection agencies to produce baseline data on environmental radioactivity and heavy metal monitoring initiatives for Ebonyi state, Nigeria. The results shall also provide a reference guideline for future radiation exposure assessment and heavy metal concentration analysis within and around the Ebonyi State solid waste management and recycling plant.

2. Theoretical background

2.1. Radiological hazard assessment

Radiation hazards on individuals and workers within the waste recycling plant and the surrounding dumpsites due to

the concentration of radionuclides observed in soil samples were assessed and evaluated based on important radiation hazard indices/parameters. These radiation hazard indices include;

2.1.1. Radium equivalent activity

The ^{40}K, ^{232}Th, and ^{238}U distribution in soil is not generally uniform for a particular location. Hence, the measurement of radium equivalent activity (Ra_{eq}). it brings uniformity to radiation exposures from naturally occurring radionuclide materials usually referred to as NORMs [3]. Radium equivalent provides the weighted amount of ^{40}K, ^{232}Th and ^{238}U activity concentrations in Bqkg^{-1}. That is where 4810 Bqkg^{-1} of ^{40}K, 259 Bqkg^{-1} of ^{232}Th and ^{370} Bqkg^{-1} of ^{238}U yield the same gamma radiation dose based on equation (1) [26].

$$Ra_{eq} = 0.077C_k + 1.43C_{Th} + C_U, \quad (1)$$

where C_k, C_{Th} and C_U are individual activity concentrations of ^{40}K, ^{232}Th and ^{238}U.

2.1.2. Assessment of internal and external hazard index

Internal hazard index (H_{ex}) and External hazard index (H_{in}) were calculated to assess the internal and external exposure of the several radiations emanating from ^{40}K, ^{232}Th and ^{238}U in soil samples using equations (2) and (3) respectively [14, 27].

$$H_{in} = \frac{C_K}{4810} + \frac{C_{Th}}{259} + \frac{C_U}{185}, \quad (2)$$

$$H_{ex} = \frac{C_K}{4810} + \frac{C_{Th}}{259} + \frac{C_U}{370}, \quad (3)$$

where C_k, C_{Th} and C_U represent respective activity concentrations of ^{40}K, ^{232}Th and ^{238}U from investigated soil samples. The individual values of H_{in} and H_{ex} must be less than 1 for the hazard level to be negligible.

2.1.3. Estimation of Absorbed Dose Rate (ADR)

The estimation of ADR in nGyh^{-1} for air at 1meter beyond ground level was evaluated with Equation (4);

$$ADR = 0.0417C_k + 0.604C_{Th} + 0.462C_U. \quad (4)$$

Radium and its progenies resulting from the disintegration of uranium produce most of the radiations, hence ^{226}Ra from ^{238}U was utilized in the estimation of the absorbed gamma dose rate. The estimated absorbed gamma dose rates in air (usually 1m above the ground level) are associated with human absorbed dose.

2.1.4. Estimation of Annual Effective Dose (AED)

The sum of indoor and outdoor annual effective doses is usually referred to Annual effective dose measured in (mSvy^{-1}). It was calculated using equations (5), (6) and (7).

$$AED_{in}\ (mS\,vy^{-1}) = ADR(nGyh^{-1}) \times 0.7(S\,vGy^{-1}) \times 0.8 \times 8760(hy^{-1}) \times 10^{-6}, \quad (5)$$

$$AED_{out}\ (mS\,vy^{-1}) = ADR(nGyh^{-1}) \times 0.7(S\,vGy^{-1}) \times 0.2 \times 8760(hy^{-1}) \times 10^{-6}, \quad (6)$$

$$AED_{TOTAL} = AED_{in} + AED_{out}, \quad (7)$$

where ADR represents the rate of dose absorption in the air, 8760 is the total number of hours in a year; 0.7 is used to convert absorption dose to effective dose while 0.2 and 0.8 provide occupancy factors of indoor and outdoor exposures, respectively [3].

2.1.5. Estimation of Excess Lifetime Cancer Risk (ELCR)

The growth of cancerous cells as a result of ionizing radiation exposure is not instantaneous. It takes quite a lot of years to develop if it develops at all. Therefore, the possibility of cancer sickness in the lifetime of an individual as a result of low radiation exposure is referred to as Excess lifetime cancer risk [15]. The ELCR was estimated with equation (8).

$$ELCR = AED_{TOTAL} \times LE \times RF \quad (8)$$

where AED_{Total} gives the total annual effective dose, LE is the average life expectancy which is presumed to be 70 years for Nigerians and RF with the value of 0.05 Sv^{-1} [2] implies fatal cancer risk factor per sievert

2.1.6. Estimation of gamma representative index

(Iγ) The gamma representative index evaluated with Equation 9 is a parameter used to measure radiation hazard caused by the total activity of respective NORM in a particular location [26, 28].

$$(I\gamma) = \frac{C_K}{1500} + \frac{C_{Th}}{100} + \frac{C_u}{150}. \quad (9)$$

When the gamma representative index is less than or equal to 1, it implies that the annual effective dose is ≤ 1 mSv

2.2. Heavy metals concentration assessment

2.2.1. Geo-accumulation Index (I_{geo})

Geo-accumulation index is the evaluation of heavy metals concentration in soil [29, 30, 35]. It is evaluated with equation (10).

$$I_{geo} = + + \log_2\left[\frac{C_n}{1.5B_n}\right], \quad (10)$$

where C_n represent concentration in mg/kg of n heavy metal; B_n represents geochemical background value concentration of average continental shale. While 1.5 is a constant factor that corrects background matrix variation from lithogenic effects according to Agca and Ozdel [31] . The geo-accumulation index is categorized into seven (7) [30] as shown in Table 1.

Table 1. Geo-accumulation index categorization.

I_{geo}	Pollution load index	Degree of contamination
$I_{geo} < 0$	0	Background concentration
$0 \leq I_{geo} \leq 1$	1	Uncontaminated
$1 \leq I_{geo} \leq 2$	2	Moderately contaminated to uncontaminated
$2 \leq I_{geo} \leq 3$	3	Moderately contaminated
$3 \leq I_{geo} \leq 4$	4	Moderately to highly contaminated
$4 \leq I_{geo} \leq 5$	5	Highly contaminated
$I_{geo} \leq 5$	6	Very highly polluted

2.2.2. *Potential Ecological Risk Assessment (PER) / Contamination Factor (CF)*

PER gives the contamination factor (CF) which expresses the impact of heavy metal contamination in soils due to the sediment nature of heavy metals and its environmental characteristics. The potential ecological risk coefficient gives the toxicological effect of heavy metal concentration in any ecological environment [32]. It's evaluated with equations (11), (12) and (13).

$$PC = \frac{C_n}{B_n}, \tag{11}$$

$$PER = PC\ x\ T_r, \tag{12}$$

$$RI = \sum_{i=1}^{n} PER, \tag{13}$$

where C_n and B_n maintain their early ascribed meaning. PER gives the potential ecological risk coefficient for a specific heavy metal in an environment under consideration; T_r is the parameter that gives the toxic response factor of a heavy metal. According to the Hakanson standard [33]. It recognized T_r of Hg as 40, Cr as 2, Cd as 30, As 10, Pb as 5, Cu as 5, Zn as 1, and Ni as 5. RI is the potential ecological risk coefficient which gives the impact of considered heavy metal contamination in soils of a particular environment. The potential ecological risk coefficient is classified as shown in Table 2.

2.2.3. *Pollution Load Index (PLI)*

A PLI greater than 1 implies heavy metal pollution exists while a value less than 1 implies no heavy metal pollution. PLI of the investigated area was determined by calculating the n root of products of the n CFs using equation (14) [34].

$$PLI = (\ CF_1\ \times\ CF_2\ \times\ CF_3\ \times \cdots \times\ CF_n)^{\frac{1}{n}}, \tag{14}$$

where n represents the number of heavy metals under consideration investigated (n = 10) this index offers a simple and elegant means for evaluating the extent of heavy metal contamination. This contamination or pollution levels are categorized on a scale of 1 to 6, based on pollution intensity (0 = none, 1 = none to medium, 2 = moderate, 3 = moderately to strong, 4 = strongly polluted, 5 = strong to very strong, 6 = very strong) [35].

2.3. *Human health hazard assessment due to the presence of heavy metal*

Human health risk assessment techniques considered in this research were for Non-carcinogenic and carcinogenic hazards as explained by Muhammad *et al.* [36].

2.3.1. *Non-carcinogenic assessment*

Health risk assessment based on heavy metals present in an environment provides noncarcinogenic and carcinogenic hazards on the human body due to constant ingestion, inhalation, or body contact (epidermal) with heavy metals [37, 38]. Based on relevant standards recognized by the United States Environmental Protection Agency (USEPA) [39–41] the total potential non-carcinogenic health risk due to heavy metals exposure in soil is obtained by evaluating the THQ.

THQ is the summation of ratios between the reference dose (RfD) and Chronic Daily Intake (CDI) of each element. In this study, the RfD of each element was adopted from USEPA screening levels [42]. The exposed population is assumed to be safe when HQ is lower than 1 [18].

The hazard index or Total hazard quotient (THQ) is calculated with equations (15) and (16) [40, 41].

$$HQ = \frac{CDI}{RFD}, \tag{15}$$

$$THQ = \sum_{k=1}^{n} HQ = HQ_{\mathrm{Cr}} + HQ_{\mathrm{Cd}} + HQ_{\mathrm{Co}} + HQ_{\mathrm{Pb}} + HQ_{\mathrm{Ni}} + HQ_{\mathrm{Zn}} + HQ_{\mathrm{cu}} + HQ_{\mathrm{As}} + HQ_{\mathrm{Fe}} + HQ_{Hg}, \tag{16}$$

THQ value ≤ 1, implies the absence of noncarcinogenic health risk. THQ value > 1 implies potential noncarcinogenic health risk, which means a higher likelihood of causing harmful health impacts to the human body. The higher the THQ value, the greater the health risk.

2.3.2. *Carcinogenic risk index (CRI) assessment*

The CRI and Total carcinogenic risk index (TCRI) give the possibility of displaying any form or symptom of cancer by an individual in a lifetime usually 70 years on average due to constant contact or exposure to carcinogenic heavy metals [43, 44]. Equation (17) was applied in the computation of TCRI.

$$TCRI = \sum CRI = CDI \times CSF, \tag{17}$$

Table 2. PER coefficient classification.

Ecological risk level	Low	Moderate	Considerable	High	Significantly high
PER	< 40	41 – 79	80 – 159	160 – 319	320
RI	< 150	151 -300	301- 599	≥ 600	-

where CSF provides the cancer slope factor. The CSF is the generated risk due to lifetime exposure to carcinogenic chemicals at the average rate of one mg/kg per day.

The CDI of heavy metals is the mass of heavy metal that is in contact with a body weight, per unit time. It is expressed and evaluated with equation (18) [45, 46].

$$CDI = \frac{C_n \times IR \times EF \times ED}{B_w \times A_T}, \tag{18}$$

where C_n in mg/kg is the concentration of heavy metals in the location, IR is the Ingestion rate, EF is the Exposure frequency, ED is the Exposure duration, B_W is the Body weight, A_T is the Averaging Time.

If the TCRI value is less than 10^{-6}, this implies there is no carcinogenic risk. However, if the TCRI value is greater than 10^{-4}, this implies a high probability that heavy metals may cause cancer risk to the human body. Single carcinogenic metals and multi-carcinogenic metals have permissible limits of 10^{-6} and less than 10^{-4} respectively [47, 48]. Table 3 shows the Input parameters applied in calculating CDI values *USEPA* [49, 50].

The values of parameters applied in the computation of the values of CSF and RfD through ingestion are displayed in Table 4 [49].

3. Materials and methods

3.1. Study area

The study was carried out in a dumpsite and the surrounding farmlands located around the Ebonyi State solid waste recycling plant in the Enyim community of Ezza North Local government of Ebonyi State, Nigeria. As displayed in Figure 1. The waste recycling dumpsite was cited on a land area of 2.5 sq. Km. which lies between 6.353536N and 8.044732E and is surrounded by farmlands and housing estates. Sampling sites/ locations were geographically identified using the Global Positioning System (GPS) The dumpsite was established in 2015 to receive solid waste from the Abakiliki metropolis and its environs before moving to the recycling plant as shown in Figure 2 The dumpsite receives waste materials estimated at 10 tons per month. The high level of human activities, the quantity of waste dumped as well and the proximity of the dumpsite to the surrounding farmlands and a housing estate make the dumpsite and the surrounding farmlands an important site for radiological and environmental hazards assessment studies because of the suspected presence of radioactive materials and the risk of heavy metals contamination in the farmland.

3.2. Sample collection and preparation

400 grams of soil samples were randomly collected from five (5) different points on the dumpsite and five (5) different points on the surrounding farmland on 6^{th} November 2023. Soil samples were collected with a metal trowel and after each collection, the metal trowel was thoroughly cleaned several times with deionized water to prevent interference and cross-contamination. Soil samples were collected at a distance of 15 m within the upper soil layer of 0 – 5 cm [31]. This soil layer was selected because most biogenic and anthropogenic contaminants settle down within this depth [51, 52]. Two control samples were collected from a nearby forest reserve 500 m from the center of the dumpsite, free from waste disposal and other human activities. All collected samples were divided into two parts, one part for activity concentration test and the other part for heavy metals concentration analysis. Number of samples collected was based on the size of the dumpsite and the adjoining farmland. The sampling points were carefully selected to include areas with high human activities.

All samples were separately packed, labeled, and immediately conveyed to the laboratory. At the laboratory, all samples were sun-dried for seven (7) days to reduce moisture. Thereafter, samples for the activity concentration test were pulverized by grinding and sieved through a mesh sieve 2 mm to accomplish homogeneity. The homogenized soil samples were then oven-dried at 120 °C for 10 hours until they reached constant weight and later measured using an electronic weighing balance. Three hundred grams (300 g) of each sample were hermetically kept in branded cylindrical containers with 6.5 cm (diameter) and 3.5 cm (height). Additional information listed on each of the containers are sample name, sample acquisition date, and net weight. Samples were kept for 30 days to reach secular equilibrium between parent and daughter radionuclides and their gaseous decay progenies before gamma spectroscopy counting using a 3" x 3" NaI(Ti) gamma radiation spectrometer.

3.3. Measurement of toxic heavy metal concentration

Soil samples collected for heavy metals concentration analysis were further pulverized and sieved with 0.2 mm mesh, packaged, and taken to the Aluminum smelting company of Nigeria (ALSCON) Ikot Abasi, Akwa Ibom State, for the evaluation of heavy metals (Fe, Cu, Pb, Zn, As, Co, Cd, Cr, Hg, and Ni) concentration using Unicam 939 model of Atomic absorption spectrometer (AAS). In the laboratory, each sample was subjected to microwave-assisted processing at 175^{o}C. 0.5g of each sample was digested in an 8 ml mix of concentrated, HCl, and HNO_3 in the ratio of (2:7). A Very small quantity of hydrogen peroxide (H_2O_2) was slowly added to each of the sample solutions to reduce the volatile behavior of the acidic reaction in the test tube. Thereafter, each of the sample solutions was

Table 3. Input parameters for computation of CDI value.

Parameter	Symbol	Unit	Adult
Ingestion rate	IR	mg/dose	3.0
Exposure frequency	EF	Dose/year	350
Exposure duration	ED	Years	30
Body weight	Bw	Kg	70
Averaging time	A_T(ED x 365)	Days	10950

Table 4. Soil heavy metals CSF and RFD values for ingestion exposure pathways.

Heavy metals	CSF(mg/kg/day) Ingestion	RfD (mg/kg/day) Ingestion
Cr	0.5	3×10^{-3}
Cd	6.1	1×10^{-3}
Co	-	2×10^{-3}
Pb	8.5×10^{-3}	3.5 x 10^{-3}
Ni	0.91	2×10^{-2}
Zn	-	3×10^{-1}
Cu	-	4×10^{-2}
As	1.5	3×10^{-4}
Fe	-	3×10^{-3}
Hg	-	1.6×10^{-4}

Figure 1. Google map of the study area.

diluted with distilled water, chilled and filtered using Whatman filter (No.41) paper, and stored in acid-sterilized tubes at 5 °C before the evaluation of heavy metals concentration.

These measurements were carried out in duplicate. The relative standard deviation between similar analyses was less than 4% which is within an acceptable level of accuracy [31]. International Certified reference materials (Loam Soil C, Lot No. 707904) obtained from the National Institute of Standards and Technology (NIST) were applied as standard samples for quality assurance and control. Recovery rates for heavy metals in the standard reference material were between 80 % and 115 %. The minimum detection limit (MDL) for each evaluated sample

Figure 2. Ebonyi state solid waste dumpsite.

Cr, Cd, Co Pb, Ni, Zn, Cu, As, Fe, were obtained at 1.3 mg/kg, 0.4 mg/kg, 0.6 mg/kg, 2.1 mg/kg, 1.5 mg/kg, 0.07 mg/kg, 0.6 mg/kg, 0.04 mg/kg, 1.8 mg/kg and respectively. The sequence of the atomic absorption spectrometer comprised of a quality-controlled sample and a blank sample which was introduced after 8 samples analysis. An atomic fluorescence spectrometer (AFS-9760) was applied in mercury concentration evaluation using Hydride generation/ cold vapor fitment [52]. The MDL for Hg was observed at 0.03 mg/kg.

3.4. Measurements of radionuclide concentration

Radionuclide concentrations measurement was done by gamma-ray spectrometry 3" x 3" inches sodium iodide [NaI(TI)] detector) bounded in a 10 cm thick lead wall. Before the main gamma spectroscopy, efficiency and energy calibrations of the gamma-counting systems were carried out. These calibrations were carried out in two stages, efficiency calibration and energy calibration.

The efficiency calibration of the gamma-counting systems was achieved by converting the count per second under the photopeaks to activity concentration in Bq/kg of certified standard samples. The certified standard samples have activity concentrations of 7.24 Bq/kg for ^{137}Cs at energy 0.662 MeV, 510.00 Bq/kg for ^{40}K at energy 1.460 MeV, and 11.00 Bq/kg for ^{232}Th at energy 2.615 MeV. The detector resolution at 0.662 MeV of ^{137}Cs was 8%. This resolution was enough to differentiate gamma energies of interest.

Energy calibrations were carried out for different energies of interest in the selected sample geometry using certified reference samples from the International Atomic Energy Agency, Vienna, Austria. The calibration procedures described in the IAEA/AL/314 technical report for measurement of radiation in Food and Environment were strictly adhered to. Furthermore, duplicate samples were added to ensure the consistency of the measurements. Blank samples were correspondingly added to eradicate the occurrence of cross-contamination in these samples. Energy calibrations convert all channel numbers to energy in MeV. This was achieved by inserting various gamma radiation sources of known energies at 5cm from the detector. After a preset counting time of 100s, channels of various photopeaks corresponding to the gamma energies were recognized and recorded.

Measurements with empty plastic vessels with comparable geometry as sample containers were carried out to evaluate the ambient background count in the laboratory. Each sample was placed in the detector and counted individually for 10 hours, to achieve good statistics.

Due to the low-intensity photon emission and slow decay rates, the activity concentrations of ^{238}U and ^{232}Th were difficult to measure directly from the detector, so, under radioactive secular equilibrium conditions, the photopeaks of their short-lived progenies were applied for the assessment of activity concentration of ^{238}U and ^{232}Th [53].

Since secular equilibrium was attained between ^{238}U and ^{232}Th and their decay products, The gamma lines of ^{228}Ac, ^{212}Bi, ^{212}Pb, and ^{208}Tl were used to determine ^{232}Th while ^{214}Bi and ^{214}Pb were used for ^{238}U and 1460.8 keV for ^{40}K. Hence, the activity concentrations of ^{40}K, ^{232}Th, and ^{238}U were computed using detected photopeaks in the obtained spectra.

Measurements were repeated twice for accuracy to determine the constancy of the measuring system. Experimental error of all results from statistical counting, calibration, etc, was

Table 5. Activity concentration in soil samples from the central solid waste dumpsite, surrounding farmland and the control site.

Sample location	Area	Sample point coordinate	Radionuclide Activity ($Bqkg^{--1}$)		
			^{40}K	^{232}Th	^{238}U
Location 1 (0 – 5cm)	Dumpsite	6.355386N 8.044508E	510.1 ± 5.2	58.6 ± 3.4	46.6 ± 3.0
Location 2 (0 – 5cm)	Dumpsite	6.355326N 8.044046E	460.6 ± 4.5	60.7± 2.5	51.6 ± 3.1
Location 3 (0 – 5cm)	Dumpsite	6.354445N 8.043958E	512.4 ± 4.0	48.6± 3.8	60.6 ± 4.0
Location 4 (0 – 5cm)	Dumpsite	6.354567N 8.043947E	494.2 ± 4.5	40.5 ± 3.2	50.4 ± 3.5
Location 5 (0 – 5cm)	Dumpsite	6.3544561N 8.043832E	485.9 ± 5.5	70.7± 3.5	65.6 ± 3.6
AVERAGE VALUE (Dumpsite)			492.64 ± 4.7	55.82 ± 3.3	54.96 ± 3.4
Location 6 (0 – 5cm)	Farmland	6.354110N 8.046777E	402.4 ± 4.0	40.3 ± 3.8	30.5± 2.8
Location 7(0 – 5cm)	Farmland	6.354472N 8.046704E	361.6 ± 3.8	44.5 ± 4.0	25.7± 2.6
Location 8(0 – 5cm)	Farmland	6.354435N 8.046704E	400.8± 4.2	45.6 ± 4.5	33.6 ± 2.0
Location 9 (0 -5cm)	Farmland	6.354687N 8.046641E	422.5± 5.5	40.1± 3.8	36.2 ± 1.8
Location10 (0 – 5cm)	Farmland	6.355463N 8.043457E	396.1 ± 3.3	35.5 ± 3.2	29.4 ± 2.0
AVERAGE VALUE (Farmland)			396.68 ± 4.2	41.2 ± 3.9	31.08 ± 2.2
Dumpsite & Farmland Average Value			444.66 ± 4.5	48.51 ± 3.6	43.02 ± 2.8
CONTROL SAMPLE 1		6.355952N 8.038763E	198.5 ± 2.8	30.6 ± 2.0	18.8 ± 2.0
CONTROL SAMPLE II		6.354962N 8.038960E	214.8 ±2.6	25.6 ± 1.8	20.4 ± 2 2
AVERAGE CONTROL SAMPLE			206.65 ± 2.7	28.1 ± 1.9	19.6 ± 2.1
World average (UNSCEAR, 2000)			412.00 ± 0.00	45.00 ± 0.00	32.00 ± 0.00

normally less than 10%.

Specific activity concentrations of various radionuclides in each sample were evaluated from net counts of peak emission after removing background counts and divided the value with photopeak efficiency, gamma intensity of the radionuclide, the mass of the sample, and counting time [14]. Activity Concentration of ^{40}K, ^{232}Th, and ^{238}U in soil within Ebonyi state solid waste recycling plant and surrounding dumpsites were obtained using equation (19).

$$C(Bq/kg) = \frac{C_{net}}{r_d x E_{ff}(E_r)_{xTXM}}, \tag{19}$$

where C_{net} gives net peak counts, Υ_d represent absolute gamma decay intensity for specific energy photopeak and the decay branching ratio information, E_{ff} (E_γ) gives the absolute efficiency of the detector at energy E, T implies the counting time (sec) and M represents the mass of the investigated sample in kilograms.

To find the lowest activity concentration that can be measured by a detector system without a sample, usually referred to as minimum limit of detection (MLD), equation 20 was applied.

$$MLD = 4.65\frac{\sqrt{C_b}}{t_b}k, \tag{20}$$

where C_b represents background count, t_b represents background counting time (s) while k gives the conversion factor from counts per second (cps) to activity concentration in Bq/kg. k is expressed as; $\frac{1}{\Upsilon_d x(E_r)_M}$ where Υ_d, E_γ and M maintains already established definitions. The MDL for ^{40}K, ^{232}Th and ^{238}U were established at 0.1940, 0.0047, and 0.0182 Bq/kg respectively.

4. Results and discussion

4.1. Activity concentration

Measured activity concentrations of ^{40}K, ^{232}Th, and ^{238}U in soil samples obtained from the dumpsite, surrounding farmland, and the control site are shown in Table 5 and Figure 6. It was observed that the activity concentrations of the investigated radionuclide were higher at the dumpsite than the world average values. The farmland and the control site displayed activity concentrations that were below the world average values From the radiological hazard assessment displayed in Table 6, average Ra_{eq} values at the dumpsite, surrounding farmlands and the control site were 169.86 Bq/kg, 120.54 Bq/kg and 75.69 Bq/kg respectively. These values are below the permissible limit of 370 Bq/kg [3]. This implies the studied area is radiological safe. The average H_{ex} and H_{in} values for dumpsite and farmland were 0.395 and 0.511. Luckily, these values are < 1, which is the standard limit [3]. From Table 6, ADR at the dumpsite, surrounding farmlands, and the control site were found to be 79.64 Gyh^{-1}, 55.78 Gyh^{-1}, and 45.65 Gyh^{-1} respectively. These values are above the estimated world average of 57 nGy/h [3] except for the control site. This suggests a higher concentration of radionuclides at the dumpsite and surrounding farmlands (see Table 5). The estimated ADE at the dumpsite, surrounding farmlands and the control site were 0.487 $mSvy^{-1}$, 0.338 $mSvy^{-1}$ *and* 0.275 $mSvy^{-1}$ respectively. These values are below the allowable limit of 1.00 $mSvy^{-1}$ for persons in public places and 20.00 $mSvy^{-1}$ for industrial workers as recommended by [3, 14]. The value from the dumpsite is slightly higher than that measured from farmlands and the control site (see Table 5). The difference in value was attributed to high radionuclide

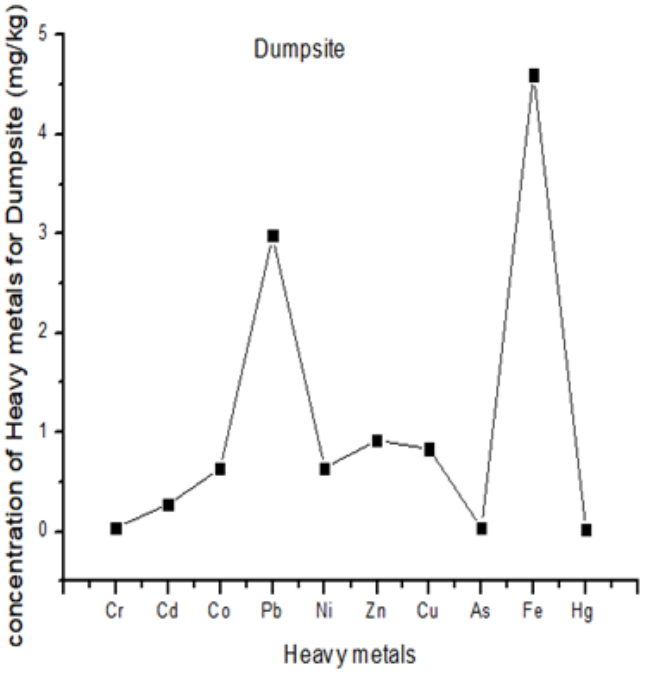

Figure 3. The 3D interactions of DNEAA and its complexes with SARS-CoV-2 protein.

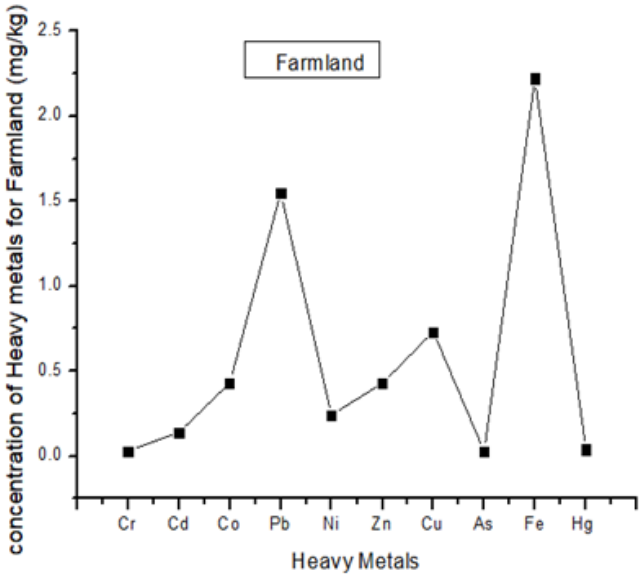

Figure 4. The 3D interactions of DNEAA and its complexes with SARS-CoV-2 protein.

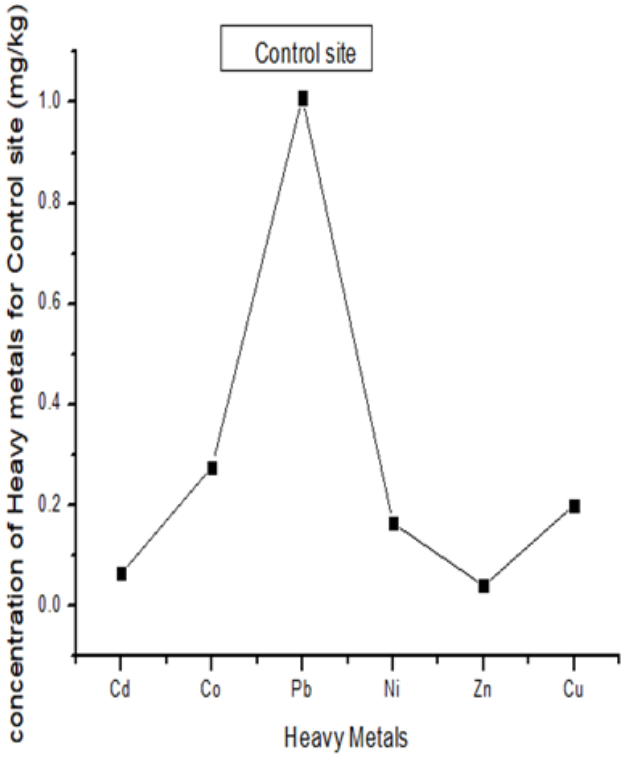

Figure 5. The 3D interactions of DNEAA and its complexes with SARS-CoV-2 protein.

concentrations of 40K, 232Th, and 238U and their decay products which are more on the dumpsite. This is obvious when Figure 3 is compared to Figures 4 and 5. When municipal or industrial waste materials are dumped radionuclides associated with these waste materials are redistributed in the soil and this can increase the radiation level of the dumpsite and the surrounding farmlands. Generally, the measured absorbed dose rates are above the 0.274 μSv/hr global average natural dose of background ionizing radiation [3, 16].

Table 7 shows elevated levels of heavy metals, particularly lead and cadmium, in soil samples from the dumpsite compared to farmland and control sites. These high levels in the dumpsite indicate contamination from waste disposal activities. Some farmland areas also exhibit elevated levels, suggesting potential contamination from nearby dumpsites. These findings raise concerns about environmental and human health risks due to contamination of groundwater, surface water, and the food chain. Parameters examined in Table 8 show a higher risk of heavy metal contamination at the dumpsite compared to farmland and a control site. This suggests significant ecological and potential human health risks at the dump site. Farmland also shows elevated contamination levels, indicating the possible migration of metals from the dump site. These findings suggest a need for further investigation and potential remediation measures to mitigate environmental and human health risks.

The general average value for this study was compared to average values of activity concentration of radionuclides in other dumpsites around Nigeria is displayed in Table 9.

From Table 6 and Figure 7, the calculated average ELCR for the dumpsite, surrounding farmlands and the control site were found to be 1.705×10^{-3}, 1.183×10^{-3} and 0.963 x 10^{-3} respectively. These values are above the standard average value of 0.29×10^{-3} [50]. This infers that the likelihood of people living or working around the dumpsite developing cancer over a lifetime is very high, especially at the dumpsite

Table 6. Radiological hazard and indoor exposure risk assessment of dumpsite and farmland.

Site	Ra_{eq} ($Bqkg^{--1}$)	H_{ex}	H_{in}	ADR (Gyh^{-1})	AED_{in} ($mSvy^{-1}$)	AED_{out} ($mSvy^{-1}$)	AED_{total} ($mSvy^{-1}$)	ELCR x 10^{-3}	Iγ
Dumpsite (Ave)	169.86	0.465	0.614	79.64	0.39	0.097	0.487	1.705	1.252
Farmland (Ave)	120.54	0.325	0.409	55.78	0.27	0.068	0.338	1.183	0.884
Average Value for Dumpsite and Farmland	146.63	0.395	0.511	67.71	0.33	0.083	0.413	1.445	1.068
Control site (Ave)	75.69	0.247	0.300	45.65	0.22	0.055	0.275	0.963	0.549

Table 7. Heavy metal concentration in soil samples from the central solid waste dumpsite, surrounding farmland and the control site.

Site	AREA	Heavy metal concentration (mg/kg)									
		Cr	Cd	Co	Pb	Ni	Zn	Cu	As	Fe	*Hg
Location 1 (0 – 5cm)	Dumpsite	0.06	0.18	0.56	3.05	0.21	0.94	1.01	0.04	5.92	0.02
Location 2 (0 – 5cm)	Dumpsite	ND	0.24	0.72	3.20	0.62	1.04	0.96	ND	4.54	ND
Location 3 (0 – 5cm)	Dumpsite	0.04	0.36	0.84	2.36	0.84	0.80	0.74	ND	4.35	0.04
Location 4 (0 – 5cm)	Dumpsite	0.03	0.21	0.41	2.49	0.80	1.08	0.61	0.02	3.89	ND
Location 5 (0 – 5cm)	Dumpsite	ND	0.41	0.61	3.77	0.72	0.72	0.81	0.06	4.29	0.02
AVERAGE VALUE(Dumpsite)		0.04	0.28	0.63	2.98	0.64	0.92	0.83	0.04	4.60	0.02
Location 6 (0 – 5cm)	Farmland	ND	0.10	0.31	2.11	0.40	0.82	0.92	0.03	2.45	ND
Location 7(0 – 5cm)	Farmland	0.02	0.20	0.41	1.20	0.11	0.41	0.81	ND	2.34	ND
Location 8(0 – 5cm)	Farmland	ND	0.15	0.51	1.44	0.16	0.32	0.62	ND	1.94	0.04
Location 9 (0 -5cm)	Farmland	ND	0.09	0.42	1.32	0.32	0.50	0.91	0.02	2.06	ND
Location10 (0 – 5cm)	Farmland	0.04	0.14	0.50	1.68	0.22	0.12	0.40	ND	2.31	ND
AVERAGE VALUE(Farmland)		0.03	0.14	0.43	1.55	0.24	0.43	0.73	0.03	2.22	0.04
Dumpsite & Farmland Average Value		0.035	0.21	0.53	2.265	0.44	0.675	0.78	0.035	3.41	0.03
CONTROL SAMPLE 1		ND	0.08	0.30	0.98	0.20	0.04	0.20	ND	1.06	ND
CONTROL SAMPLE II		ND	0.05	0.25	1.04	0.13	ND	0.20	ND	1.00	ND
AVERAGE CONTROL SAMPLE		ND	0.065	0.275	1.01	0.165	0.04	0.2	ND	1.03	ND
WHO acceptable range of heavy metal in soil (mg/kg). [38]		0.002 - 0.2	0.02 - 0.5	0.04-0.2	0.3 - 10	0.1 - 5	12 - 60	1 - 12	0.09 – 1.5	-	0.001 - 0.04

ND – not detected. * - (μ/Hg)

Table 8. Summary of heavy metal contamination assessment for dumpsite and farmland.

Location	I_{geo}	RI	CDI	TCRI	THQ	PLI
Dumpsite (Ave)	2.63	272.76	0.45	9.81×10^{-2}	1.07	1.37
Farmland (Ave)	1.40	142.22	0.24	2.3×10^{-2}	0.84	1.30
Average Value for Dumpsite and Farmland	2.01	207.19	0.35	6.1×10^{-2}	0.95	1.33
Control site (Ave)	0.66	125	0.11	2.3×10^{-2}	0.46	1.11

Table 9. Comparison of activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in Abakaliki dumpsites with other locations in Nigeria.

Location	Activity concentration (Bq/kg)			References
	^{40}K	^{226}Ra/ ^{238}U	^{232}Th	
Owerri	BDL-686.17	BDL-103.51	BDL-65.28	Emelue *et al.* [24]
Lagos	409±86.08	69.69±19.10	14.49±3.33	Oladapo *et al.* [25]
Akure	180±6	51±6	34±4	Faweya & Babalola [23]
Port Harcourt	643.10 ± 5.94	41.96 ± 5.53	62.61 ± 18.97	Avwiri & Olatubosun [26]
Abakaliki	444.66 ± 4.5	43.02 ± 2.8	48.51 ± 3.6	Present study
0K26Ra a				

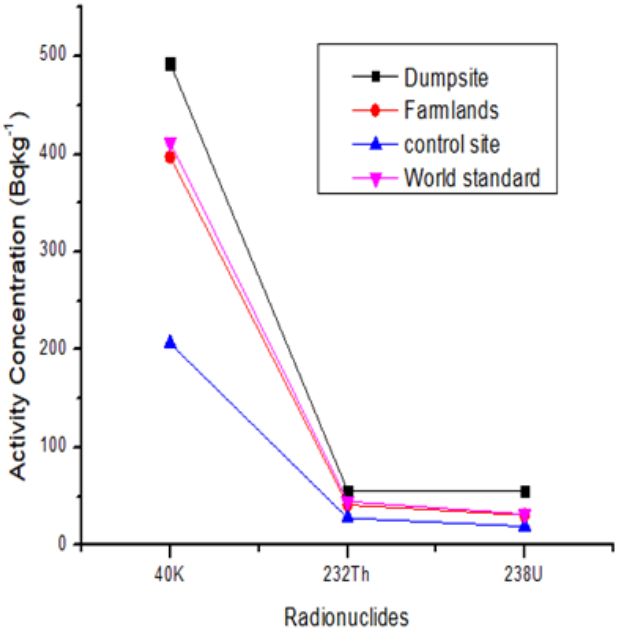

Figure 6. The 3D interactions of DNEAA and its complexes with SARS-CoV-2 protein.

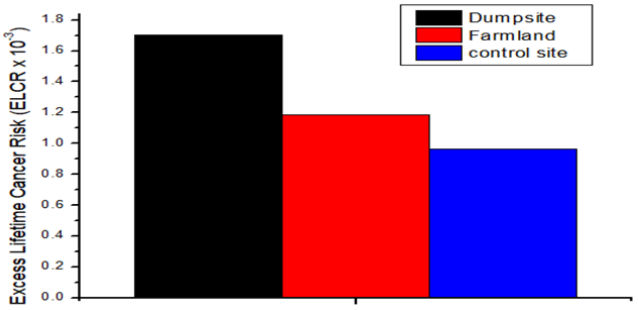

Figure 7. The 3D interactions of DNEAA and its complexes with SARS-CoV-2 protein.

The gamma active index (Iγ) for the dumpsite, surrounding farmlands, and the control site were 1.252, 0.884, and 0.549 respectively. The high gamma active index beyond one indicates a higher level of gamma radiation at the dump site. Radiological, this calls for caution for workers at the dump site.

The average value of I_{geo} for soil samples obtained from the dumpsite, surrounding farmlands and the control site were found to be 2.63, 1.40, and 0.66 respectively as shown in Table 8. This showed that the I_{geo} was highest at the dump site. Considering that the I_{geo} of the dumpsite was $2 \leq I_{geo} \leq 3$ (this implies, Moderately contaminated) farmland gave $1 \leq I_{geo} \leq 2$ (this implies, Moderately contaminated to uncontaminated) while the control site gave $0 \leq I_{geo} \leq 1$(this implies, Uncontaminated). The results obtained for Potential ecological risk coefficient (RI) / Ecological risk index (RI) showed that the dumpsite, surrounding farmlands and the control site gave RI values of 272.76, 142.22, and 125.00 respectively, from Table 2, Therefore, the dumpsite gave Moderate Ecological risk level while the farmland and the control site gave low Ecological risk level. The Chronic daily intake (CDI) of heavy metals for adults obtained for the dumpsite, surrounding farmlands, and the control site gave 0.45 mg/kg/day, 0.25 mg/kg/day, and 0.11 mg/kg/day respectively.

The total carcinogenic risk index (TCRI) gives a more detailed estimate of the potential toxicity of individual heavy metals in an ecosystem. This study revealed that the dumpsite, surrounding farmlands and the control site have average TCRI values of 9.8×10^{-2}, 2.3×10^{-2}, and 2.3×10^{-2}, respectively. Considering that TCRI values were below 5 [46, 54]. This suggests there is no extreme risk.

Pollution load index (PLI) measures heavy metal pollution or contamination of a site or a location. This study revealed the PLI for the dumpsite, surrounding farmlands and the control site were 1.37, 1.30, and 1.11 respectively which indicated low-level pollution in the study area at that moment. Contamination

level is categorized based on intensities from a scale ranging from 1 to 6 (0 = none, 1 = none to medium, 2 = moderate, 3 = moderately to strong, 4 = strongly polluted, 5 = strong to very strong, 6 = very strong) [35]. In this study, the PLI greater than 1 implies heavy metal pollution exists in the medium scale while a value less than 1 implies no heavy metal pollution. The control site has a PLI of 1.11 this may be due to residual heavy metals associated with the geological formation of the location.

5. Conclusion

The average concentration values of ^{40}K, ^{232}Th and ^{238}U obtained from all investigated sites are lower than the world average values. The calculated radiological hazard indices from the measured parameters indicated that the mean concentrations of Radium Equivalent (Ra_{eq}), Internal and External Hazards, Absorbed dose rate, Annual Effective Dose, Excess lifetime cancer risk, and Gamma Representative Level index are 146 Bq kg^{-1}, 0.511, 0.395, 0.771 mSvyr^{-1}, 0.413 nGyh^{-1}, 1.445×10^{-3}, and 1.06 respectively. The Average heavy metals concentration in soil samples from the dumpsites, surrounding farms and control sites was evaluated with an atomic absorption spectrophotometer (AAS). The heavy metal contamination analysis revealed that the average heavy metal concentration of the dumpsites and surrounding farms for Cr, Cd, Co Pb, Ni, Zn, Cu, As, Fe, and Hg were found to be 0.035, 0.21, 0.53, 2.265, 0.44, 0.675, 0.78, 0.035, 3.41, 0.03 mg/kg (dry wt) respectively. The concentration of heavy metals in the studied samples slopes from Pb > Fe > Cu > Zn > Co > Ni > Cd > Cr > Hg > As. Soil contamination was assessed based on the geo-accumulation index (I_{geo}), Potential ecological risk coefficient (RI), Chronic daily take (CDI), Total carcinogenic risk index (TCRI), Total hazard quotient (THQ) and pollution load index (PLI). The average values of I_{geo}, CDI, TCRI, THQ and PLI for dumpsites and surrounding farms were found to be 2.01, 207.19, 6.1×10^{-2}, 2.66, 0.95 and 1.33 respectively. Generally, elevated concentrations of heavy metals especially Pb and Fe were observed in the dumpsites and surrounding farmlands. By comparing the mean values of the activity concentrations, and their radiological risks with other waste recycling dumpsites in Nigeria, the Ebonyi state solid waste management and recycling plant and the surrounding dumpsites do not pose any immediate radiological. However, heavy metal concentration assessment showed a slightly elevated but moderate concentration which may pose a carcinogenic risk to workers and residents in the surrounding communities. The study suggests regular monitoring of radiological risks and heavy metal contamination of the dumpsite and surrounding farmlands to forestall environmental hazards and some health challenges like leukemia, stillbirth, and body rashes observed in surrounding communities.

Data Availabbility

The data supporting this study's findings are available from the corresponding author upon request.

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