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Assessment Of Radiological Hazards Of Soil Samples Around A Dumpsite In Igbudu Area Of Warri, Delta State

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ABSTRACT

The present study investigates the radiological impacts of the Igbudu dumpsite in Warri, Delta State, Nigeria, with a focus on the potential health and environmental risks associated with waste disposal. Eight (8) surface soil samples were collected from selected locations within and around the dumpsite and analysed using gamma-ray spectrometry with a sodium iodide thallium-activated [NaI(Tl)] detector for the determination of the activity concentrations of 238U, 232Th, and 40K. The results revealed that the mean activity concentrations of 238U, 232Th, and 40K in the soil samples were 5.60 ± 1.14 Bq/kg, 7.81 ± 0.62 Bq/kg, and 76.64 ± 5.03 Bq/kg, respectively. Radiological hazard parameters, including radium equivalent activity (Raeq), external hazard index (Hex), internal hazard index (Hin), absorbed dose rate (ADR), annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR), were evaluated. The mean values obtained were 21.29 Bq/kg, 0.06, 0.07, 10.59 nGy/h, 0.08 mSv/y and 0.04×10^{-3}, respectively. A correlation matrix was used to analyze the relationships between the radionuclide concentrations and hazard parameters, revealing strong positive correlations. From the radiation hazard indexes computed, all values obtained were found to be lower than the recommended values by regulatory authorities thus implying that the study area does not pose any immediate health risks to the public, as they remain below established safety thresholds.

Keywords:
Concentrations,
Risks,
Radioactivity,
Waste disposal.

INTRODUCTION

Naturally occurring radionuclides have been integral components of the Earth's environment since its formation and remain essential to various natural processes. They are found throughout different environmental media, such as soil, sediments, water, air, and plants. Their occurrence is largely the result of natural mechanisms, especially the radioactive decay of certain elements in the Earth's crust (Popoola et al., 2025). Recent studies have identified that the naturally occurring radioactive materials (NORMs) particularly 238U (uranium-238), 232Th (thorium-232), and 40K (potassium-40) contribute substantially to background radiation worldwide, including in Nigeria (Okoro et al., 2025). Because these radionuclides are present in soils, rocks, and groundwater globally, they contribute to continuous exposure (external and internal) for human populations (Munyao et al., 2025). The exponential increase in global waste generation due to urbanization and industrialization has led to the widespread use of landfills for waste disposal, posing challenges to urban inhabitants (Igwegbe et al., 2024). For example, recent soil and sediment analyses in peri-urban and industrial areas of Nigeria have documented elevated concentrations of 238U, 232Th, and 40K in soils and stream sediments beyond global averages (Popoola et al., 2025). Contaminated soils expose humans and other living organisms to high levels of radiation through gamma radiation absorption or inhalation of carcinogenic radon gas and its progeny. Prolonged exposure to elevated gamma radiation levels can result in acute diseases, including kidney, lung, and digestive system cancers (Oladejo et al., 2025). Waste generated close to industrial areas holds ecological significance as it can introduce pollution into various environmental components, such as water sources, food supplies, land, air, and vegetation (Daburum et al., 2023). Human radiation exposure can occur through two primary pathways: external exposure from 40K, 228Th, and 238U in soil and internal exposure from inhalation of radon and its by-products found in dust and waste disposal emissions (Echeweozo et al., 2025). In dumpsite environments, the decomposition of deposited wastes and the resulting chemical changes can alter the composition of the surrounding soil and affect the distribution and movement of potassium (^40K). In addition, leachate produced from decomposing wastes can seep into the soil and contaminate soil resources, surface water and groundwater. This contamination may also pose risks to nearby residential areas and ecological habitats (Kifwe et al., 2025; Gyabaah et al., 2024). These processes may contribute to spatial variations in 40K activity concentrations around dumpsites. Dumpsites comprise diverse wastes from multiple sources, including household, agricultural, industrial, and medical materials, as well as metal scraps. They contribute to environmental degradation and pose significant health risks to nearby populations (Ijabor et al., 2025). Evaluating radiation levels at waste dumpsites is essential for assessing potential radiological risks to human health and the environment associated with waste generation and disposal. Dumpsites inherently carry the potential for radiation emissions, stemming from radioactive waste in landfills and naturally occurring radionuclides in the soil. Radioactive contamination can be transmitted to humans through the soil via plant uptake (40K) or inhalation (222Rn and 220Rn), even at minimal concentrations, potentially affecting environmental integrity and human well-being and giving rise to long-term risks (Echeweozo et al., 2025; Turyahabwa et al., 2025). Recent investigations have reported measurable concentrations of 238U, 232Th and 40K in dumpsite soils, with variations in radiological hazard indices (Igwegbe et al., 2024; Kifwe et al., 2025; Gyabaah et al., 2024; Ijabor et al., 2025; Bassey & Udoh, 2022; Ojo, 2022; Egunjobi et al., 2020; Ogunremi et al., 2021; Gbadamosi et al., 2017; Ogungbemi et al., 2022; Onwuamaoke et al., 2021). These findings highlight the importance of site-specific radiological assessments, particularly in rapidly developing urban environments (Popoola et al., 2025; Echeweozo et al., 2025). Available studies have reported radiological characteristics of dumpsites in several Nigerian states, but site-specific information for the Igbudu dumpsite in Warri, Delta State, remains limited. The present study therefore determines activity concentrations of 40K, 232Th, and 238U in soil samples collected from various locations within and around the dump sites in the Igbudu area of Warri and evaluates the radiological hazards associated with it.

MATERIALS AND METHODS

Study Area

This research was carried out in Igbudu, a community situated in the Warri South Local Government Area of Delta State, Nigeria. Igbudu is located within the oil-producing region of the Niger Delta. The geographical coordinates of the study area are approximately 5°31' 33''N latitude and 5°45' 4''E longitude. The region experiences an annual rainfall of approximately 100mm. Igbudu has a population of over 6,000 residents. The soil in this area is characterized by a medium texture, and the salinity of the soil is observed to vary within the first meter of the soil profile. Igbudu experiences a tropical climate, typical of the Niger Delta region. It is characterized by high temperatures and high humidity throughout the year. The region's proximity to the equator contributes to its warm and humid climate. The climate in the Niger Delta, including Igbudu, follows a distinct wet and dry season pattern. The wet season, with heavy rainfall, typically occurs from April to October. The dry season, with less rainfall, is observed from November to March. The region generally has warm to hot temperatures, with average temperatures ranging from 25°C to 32°C (77°F to 89.6°F) throughout the year. High humidity is a notable feature of the Niger Delta's climate, especially during the wet season, contributing to the tropical feel of the region. During the wet season, expect frequent rain and thunderstorms, with the heaviest rainfall occurring between June and August. Flooding can be a concern in low-lying areas. The dry season is characterized by more stable weather conditions, with less rainfall and more sunshine.

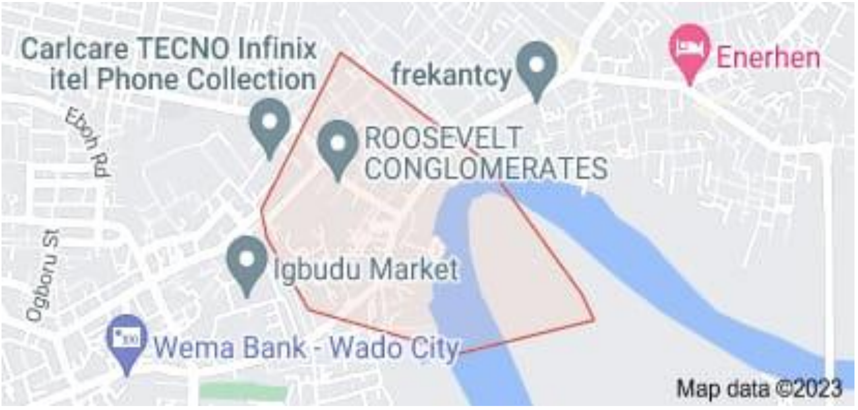

Figure 1: Map of the study area

Sample Collection and Preparation

Eight soil samples were randomly collected from different locations within the Igbudu dumpsite in the Warri South Local Government Area of Delta State. The samples were obtained at a depth of 0-5cm using a cleaned and dried coring tool. Each soil sample was individually packed in black polythene bags, labeled, and transported to the Radiation and Health Physics Laboratory of the Physics Department at the University of Ibadan. In the laboratory, they were sun-dried until reaching a constant weight, pulverized, and passed through a 2 mm mesh sieve. Two hundred grams (200 g) of each sample were then measured using an electronic balance and placed in 6.6 cm diameter plastic containers suitable for precise alignment with the NaI(Tl) detector used for measurements. These containers were hermetically sealed with adhesive tape and stored for 30 days to achieve secular equilibrium between radium and its gaseous decay progenies. However, this study did not investigate the vertical distribution of radionuclides at greater depths, which is a limitation of the sampling design.

Sample Measurements

Radionuclide concentrations were determined through gamma-ray spectrometry utilizing a sodium iodide detector. The detection setup consisted of a scintillation detector coupled to a Canberra multi-channel analyzer. The detector, a 7.6 cm × 7.6 cm NaI(Tl) manufactured by Bicron, was shielded from the environment by a cylindrical lead shield of approximately 5 cm in thickness, featuring a fixed bottom and a movable lid. Prior to measurements, the spectrometer was tested for linearity and energy calibration using gamma sources sourced from the International Atomic Energy Agency (IAEA), Vienna, Austria (Ademola et al., 2008). The system's detection efficiency calibration was performed using a reference soil sample provided by Rocket dyne Laboratories, Canoga Park, CA, USA, which is traceable to a mixed gamma source (No. 48722-356) by Analytics Inc., Atlanta, Georgia. The detector exhibited a resolution of approximately 8% at 0.662 MeV, the gamma-ray energy of 137Cs, which is capable of distinguishing the gamma ray energies of interest in this study. Each sample underwent a 10-hour measurement for statistical accuracy. Background measurements with an empty plastic container of similar geometry to the sample container were conducted to determine the laboratory's ambient background (Gbadamosi et al., 2017). The background spectrum was subtracted from the measured spectra to derive the net radionuclide activities. The background, reference sample, and soil samples were measured under identical conditions. Additionally, measurements were periodically repeated for quality assurance and to confirm the stability of the measurement system. The activity concentrations of 238U, 232Th, and 40K were calculated based on detected photo peaks in the spectra. Radium content of the samples was estimated from the 1.760 MeV gamma-ray energy of 214Bi, while the 2.614 MeV gamma-ray energy of 208Tl was used to determine thorium content, and the 1.460 MeV gamma-ray energy for the concentration of 40K in the samples (Al-Thobaiti et al., 2023). The activity concentrations () of 238U, 232Th, and 40K in Bq/kg were calculated using the following formula:A_c

$$A_c = \frac{C_{net}}{\gamma_d \times E_{ff}(E_\gamma) \times T \times M} \qquad (1)$$

Where C_{net} represents the net peak counts, γ_d is absolute gamma decay intensity for the specific energy photo peak (including the decay branching ratio information), $E_{ff}(E_\gamma)$ is the absolute efficiency of the detector at energy E, T is the counting time in sec and M is the mass of the sample in kilograms.

Evaluation of Radiation Hazards Using Activity Concentration

Radionuclides can pose health risks both externally and internally. To evaluate the radiation hazards associated with the soil samples, some parameters listed below have been employed.

Radium Equivalent Activity

The concentrations of radionuclides have been expressed in terms of radium equivalent activity (Raeq) in Bq/kg. This allows for the comparison of the specific activity of materials with varying quantities of 238U, 232Th and 40K, and is calculated using equation 2 (Ugbede & Akpolile, 2019):

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \quad (2)$$

Where A_U, A_{Th} and A_K represent the activity concentrations of ^{238}U, ^{232}Th and ^{40}K, measured in becquerels per kilogram, respectively. The radium equivalent activity (Raeq) for the collected soil samples ranges from 20.35 to 30.59 Bq/kg, with an average value of 24.12 Bq/kg. The average value is below the recommended permissible limit of 370 Bq/kg for materials to be used in construction.

External Hazards Index

The external hazard index (Hex) is calculated using the following formula (UNSCEAR, 2000):

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3)$$

Where A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Becquerels per kilogram, respectively. The external hazard index must be less than one for the external gamma dose rate to remain under 1.5 mSv/yr, which is the upper limit for gamma dose rates in construction materials. The results range from 0.04 to 0.80, with a mean value of 0.22 Bq/kg.

Internal Hazards Index

The internal hazard index (Hin) is calculated by using Equation 4 (Ugbede et al., 2023):

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

Absorbed Gamma Dose Rates

The conversion factors used to calculate the absorbed dose rates in air (D) (in nGy/h) are provided by Equation 5 (UNSCEAR, 2000):

$$D = 0.0417A_K + 0.604A_{Th} + 0.463A_U \quad (5)$$

Where A_U, A_{Th} and A_K are the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the soil samples, measured in Becquerels per kilogram, respectively. The obtained values of absorbed dose rates in air range from 0.05 to 0.08 nGy/h, with an average of 0.06 nGy/h. This value is considerably lower than the world average of 59 nGy/h. The absorbed dose rate represents the radiation received in the open air from the radionuclide concentration in environmental materials and is expressed in grays (Gy).

Annual Effective Dose Rate

To estimate the annual effective dose rate (mSv/yr) resulting from natural radionuclides in the soil samples, several factors are considered: the conversion factor of 0.7 Sv/Gy is used to convert absorbed dose in air to effective dose; Indoor and outdoor occupancy factors of 0.8 and 0.2 are used, respectively (UNSCEAR, 2000). These factors represent the proportion of total time an individual is exposed to a radiation field indoors and outdoors; Eight thousand seven hundred and sixty hours per year and the factor for converting nanos to millis (10-6). The indoor and outdoor annual effective doses (mSv/yr) are determined by the equations (6):

$$AEDR(mSvyr^{-1}) = ADR \times 8760 \times 0.2 \times 0.7SvGy^{-1} \times 10^{-6} \quad (6)$$

Where AEDR is the outdoor annual effective dose rate (Jibiri & Okeyode, 2012; Popoola et al., 2025).

Representative Gamma Index (Iγ)

The gamma radiation hazard associated with the concentrations of natural radionuclides in the investigated soil samples is assessed using the representative gamma index (Iγr). This index, as described by (Jibiri & Okeyode, 2012) is a screening parameter for materials with potential radiation health implications. It is calculated using the following equation (UNSCEAR, 2000):

$$I_\gamma = \frac{A_U}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (7)$$

Where AU, ATh and AK are the specific activities of 238U, 232Th, and 40K in Bq/kg, respectively. The condition for achieving the specified dose criteria, where Iγ must be less than or equal to 1, corresponds to an annual effective dose below 1 mSv (Kolo et al., 2019).

Excess Lifetime Cancer Risk (ELCR)

It deals with the estimated cancer risk individuals are likely to encounter over a lifetime due to exposures from radiation sources with low penetrating abilities. The Excess Lifetime Cancer Risk (ELCR) with a recommended limit of 0.29×10^{-3} is given by;

$$ELCR = AEDE \times DL \times RF \quad (8)$$

where AEDE is the Annual Effective Dose Equivalent; DL is the Duration of Life; estimated to be 70 years by UNSCEAR, 2000 and modified by WHO (2023) to be 55.75 years for an average Nigerian and RF is the Risk Factor (sv−1), that is fatal cancer risk per Sievert for stochastic effects, ICRP uses RF as 0.05 sv−1 for the public (Akpolile, 2024). A duration of life (DL) of 55.75 years was used in the calculation.

RESULTS AND DISCUSSION

The activity concentrations of K-40, U-238, and Th-232 are displayed in Table 1.

Table 1: Activity Concentrations of ^{40}K, ^{238}U and ^{232}Th in the Soil Samples from Igbudu Dumpsite

Sample code	K-40 (Bq/Kg)	U-238 (Bq/Kg)	Th-232 (Bq/Kg)
S1	127.68±8.01	4.83±1.11	9.55±0.39
S2	68.14±4.67	12.44±2.08	8.98±0.81
S3	20.71±1.64	6.24±1.39	14.55±1.21
S4	83.84±5.29	6.13±1.26	3.84±0.36
S5	87.21±5.80	3.74±0.91	4.35±0.38
S6	71.32±4.60	4.83±0.99	6.73±0.58
S7	64.10±4.30	0.98±0.27	5.51±0.49
S8	90.10±5.96	BDL	8.94±0.74
Mean value	76.64 ± 5.03	5.60 ± 1.14	7.81 ± 0.62

BDL: Below Detection Limit

The average activity concentration of 40K was 76.64 ± 5.03 Bq/kg, with the highest sample having a value of 127.68±8.01 Bq/kg and the lowest sample having 20.71±1.64 Bq/kg; U-238 had an average value of 5.60±1.14 Bq/kg with values ranging between 0.98±0.27 Bq/kg and 12.44±2.08 Bq/kg; Th-232 had a mean value of 7.81±0.62 Bq/kg with values ranging between 3.84±0.36 Bq/kg and 14.55±1.21 Bq/kg. In all of the samples examined, the values for the three radionuclides follow the same pattern, with K-40 having the highest activity. It is expected, given that it is a naturally occurring radionuclide that is abundant in the earth's crust. The low concentrations observed are likely due to the age of the dumpsite and the nature of wastes dumped on the site which were majorly domestic municipal wastes as also reported by Ojo in 2022. Also, from Table 1, it was observed that the values of the radionuclides measured varied from place to place which could be an indication of the chemical changes resulting from the decomposition of the constituent elements in the soil particles (Ogunremi et al., 2021). The activity concentrations in the soil samples analyzed compared reasonably well to the worldwide average amounts of 400, 30, and 35 Bq/kg for K-40, U-238, and Th-232, as reported by (Jibiri & Okeyode, 2012) as seen in Figure 1 below.

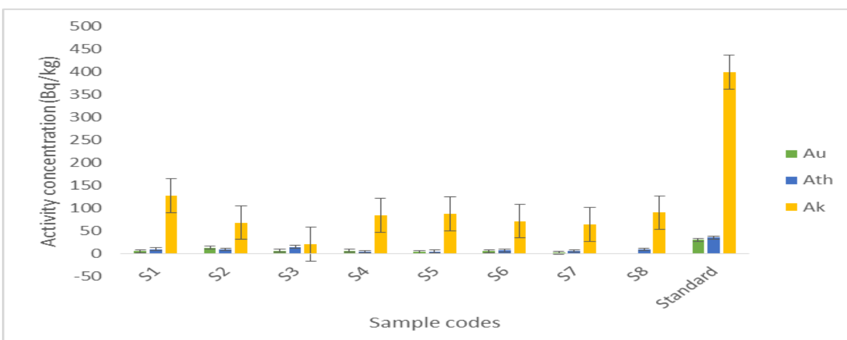

Figure 2: Comparison of activity concentration of soil samples with standard

Table 2: Radiological Parameters of Soil Samples from Igbudu Dumpsite

Sample Codes	Ra_{eq} (Bq/kg)	ADR (nGy/h)	H_{ex}	H_{in}	AEDE (mSv/y)		ELCR ($\times10^{-3}$)
S1	28.32	14.02	0.08	0.09	0.02	0.11	0.05
S2	30.53	14.39	0.08	0.12	0.02	0.11	0.05
S3	28.64	12.65	0.08	0.09	0.02	0.10	0.04
S4	18.08	9.11	0.05	0.07	0.01	0.07	0.03
S5	16.68	8.47	0.05	0.06	0.01	0.06	0.03
S6	19.95	9.66	0.05	0.07	0.01	0.07	0.03
S7	13.80	6.80	0.04	0.04	0.01	0.05	0.02
S8	19.72	9.64	0.05	0.05	0.01	0.07	0.03

Sample Codes	Ra_{eq} (Bq/kg)	ADR (nGy/h)	H_{ex}	H_{in}	AEDE (mSv/y)		ELCR ($\times 10^{-3}$)
Min	13.80	6.80	0.04	0.04	0.01	0.05	0.02
Max	30.53	14.39	0.08	0.12	0.01	0.11	0.05
Mean	21.29	10.59	0.06	0.07	0.01	0.08	0.04
Standard (UNSCEAR, 2000)	370	59	1	1	1	1	0.29

The absorbed dose rate calculated from observed activity concentrations in the soil sample is less than the global average of 59 nGy/h. Other computed radiation hazard indexes as shown in Table 2. Figure 2 and Table 2 revealed that the hazard parameters were lower than the standard recommendations given by UNSCEAR thus indicating that the environment poses no health risk to the residents of the studied area. The correlation matrix presents the relationship between the different radionuclides (K-40, U-238, Th-232) and various radiological hazard indices (Raeq, Hex, Hin, ADR, AEDE, ELCR) in the soil samples. Figure 4 indicates that the strong correlation between Th-232 and U-238 with Raeq with value 0.77 and 0.70 respectively align with findings in environmental radioactivity studies. For instance, a study on radionuclide contamination in soil highlighted that thorium and uranium isotopes significantly contribute to radiological hazards due to their long half-lives and radiotoxicity (Abd Bahar & Fandi, 2024). Additionally, the observed strong interrelationships among hazard indices are consistent with methodologies used in radiological assessments, where indices like Hex and Hin are derived from activity concentrations of radionuclides to evaluate potential health risks (Singh et al., 2025). The overall finding shows that ambient radiation poses no considerable health risk to the residents of the research area and that the environment is safe for human habitation.

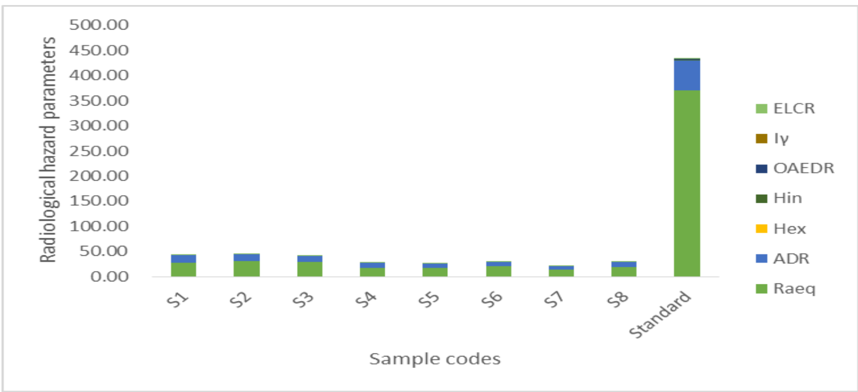

Figure 3: Variation of radiological hazard parameters with standard

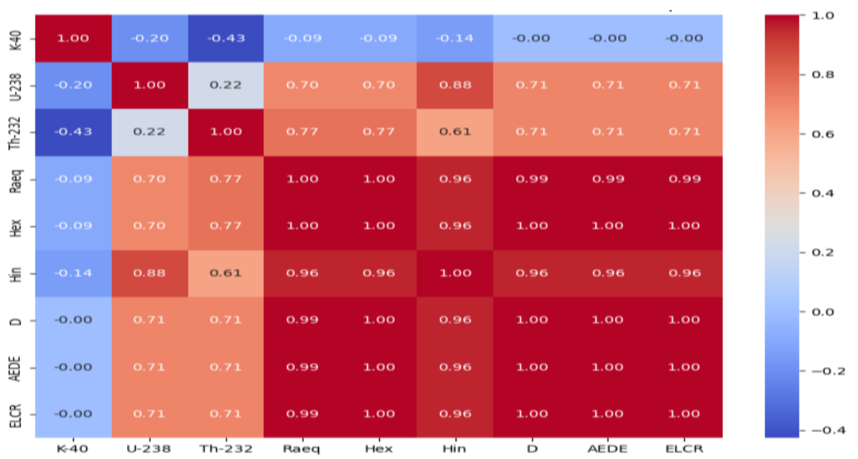

Figure 4: Correlation Matrix of Radionuclides and Hazard Indices in the Soil Samples

From Table 4, the obtained results when compared with other studies on radionuclide assessment in dumpsites available in literature shows a good correlation.

Table 3: Comparison of Present Studies with Similar Studies Found In Literature

Location	U-238	Th-232	K-40	References
Igbudu, Warri, Delta State	5.60 ± 1.14	7.81 ± 0.62	76.64 ± 5.03	Present study
Kaduna, Kaduna State	78.80 ± 13.91	21.89 ± 1.67	330.43±22.04	(Onwuamaoke et al., 2021)
Agbara, Ogun State	40.30 ± 7.20	26.00 ± 2.20	103.00 ± 7.50	(Echeweozo et al., 2025)
Olusosun,Lagos State	19.10 ± 0.62	29.10 ± 4.40	171.50 ± 6.10	(Ogungbemi et al., 2022)
Mowe, Ogun State	67.28 ± 11.77	11.21 ± 1.07	1071.85±58.10	(Egunjobi et al., 2020)
Gbagada, Illupeju, Olusosun, Lagos State	11.58	11.68	337.22	(Ogunremi et al., 2021)
Chikun LGA, Kaduna North	84.96 – 115.96	126.79 – 171.32	317.11 – 521.77	(Sombo et al., 2024)
Igabi LGA, Kaduna North	97.35 – 180.57	166.04 – 387.00	541.72 – 801.08	(Sombo et al., 2024)
Kaduna South	70.57 – 132.02	139.43 – 182.96	526.19 – 707.42	(Sombo et al., 2024)

The activity concentrations obtained in this study were compared with those reported for selected dumpsites and waste-disposal areas in Nigeria, as presented in Table 3. The mean radionuclide concentrations recorded at Igbudu were generally lower than those reported for Kaduna, Agbara, Olusosun and Mowe. In particular, the concentrations of 238-U and 40-K at Igbudu were considerably lower than those reported for Kaduna and Mowe, while the 232-Th concentration was also lower than the values reported for Kaduna, Agbara and Olusosun. These differences may be related to variations in the geological characteristics of the areas, soil composition, types of waste deposited and waste-management practices. The observed differences highlight the site-specific nature of radionuclide distribution and the need for localized radiological assessments of waste-disposal sites.

CONCLUSION

The radiological analysis of soil samples from the Igbudu dumpsite has revealed elevated concentrations of U-238, Th-232, and K-40 with mean values of 5.60 Bq/kg, 7.81 Bq/kg, and 76.64 Bq/kg, respectively. The activity concentrations have been used to estimate the radiation hazard indexes for the people living in the study area. The correlation matrix have been used to show the relationship between the radionuclides and the radiological hazard indices. The findings revealed that the soil samples had low levels of radiological hazard, based on the measured radionuclide concentrations and the calculated radiological risk parameters were found to be below the recommended limits. The wastes dumped in the area do not contain any radioactive element but subsequent evaluation of the radiological assessment of the area is needed for continued safety. However, the relatively small number of samples limits the spatial representativeness of the assessment. Therefore, the findings should be understood within the limitations of the sampling approach and the period during which the measurements were taken.

Based on the findings of this study, regular radiological monitoring of the Igbudu dumpsite and its surrounding environment is recommended to detect any future changes in natural radionuclide levels. Future studies should involve a larger number of soil samples and include different soil depths to provide a better understanding of how radionuclides are distributed within the area. It is also recommended that samples be collected during both wet and dry seasons to determine whether seasonal changes affect radionuclide distribution. In addition, future research could examine the types and composition of wastes deposited at the site and how they may influence the movement and distribution of radionuclides in the soil.

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