International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Risk Assessment of Background Radionuclides Doses in a Nigerian Local Government's Soil with Statistical Analyses

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Abstract: ***The environment around humans has always included ionizing radiation including the cosmic radiation and naturally occurring radioactive materials found in the earth's crust. With technological advancement and man's discovery of atomic and nuclear energy, man-made nuclear applications, particularly in the generation of electricity, are continuously expanding, and there are chances of being exposed to ionizing radiation. In this study, soil samples from a local government in Nigeria were tested for background radionuclides (40K, 238U, 232Th), including artificial source, 137Cs, using a 76x76mm NaI (Tl) detector crystal. The results showed that the activity concentrations in the soil were higher than the safe limit for 40K and 238U but lower for 232Th when compared to the global average value and soil in other areas. Apart from two sample locations, all of the soil samples contained 137Cs. The calculated radiological parameters have higher values than the global recommended values. A correlation analysis shows a very high positive relationships among the radionucludes and the parameters while a cluster anaylsis confirmed that 40K and 238U are the two radionuclides which contaminate the soil in the study area the most. The soil is therefore determined to be radiologically unsafe for use as agricultural land and building materials. The region should be strictly controlled for ongoing public and environmental assessment monitoring, it is advised.***

Keywords: Risk, Radionuclides, Doses, Nigeria

1. Introduction

Due to the radioactivity of our planet, people are constantly exposed to radiation. Ionizing radiation exposure has two main origins: naturally occurring sources and man-made sources. The naturally occurring radioactivity found in the crust of the planet can be further divided into two groups: virgin natural sources and modified natural sources. Virgin sources of radiation have existed on the world since the beginning of time and are of cosmogenic (produced as a result of cosmic ray from the sun and outer space with their interactions with the earth's atmosphere) or primordial (from the formation of earth) origin. Natural resources that have undergone modification typically result from human actions such as mining, burning fossil fuels for energy, making fertilizer, or using natural materials in construction. Technologically Enhanced Natural Radiation (TENR) is the name given to the latter. Recent human activities such as the environmental release of industrial effluents, hospital radioactive waste, and nuclear waste have significantly expanded the sources of TENR in soil, water, and air. Hilal, Attallah, Gehan, and Fayez-Hassan (2014) found elevated amounts of natural radioactivity in wastes connected to diverse industrial activities. Therefore, exposure to radiation can occur either externally from a nearby source or internally from radioactive material that has already entered the body.

Additionally, more than 60 naturally occurring radioactive elements can be found in soil, water, and air, making natural radiation the biggest contributor to the overall global dose rate. Inhalation of radon and its offspring is the main cause of large doses of natural radiation in areas with a typical background radiation (UNSCEAR, 2000). The primary external source of irradiation to the human body is gamma radiation from radionuclides like the 40K and 232Th family and their decay products. At sea level, the absorbed dose rate from cosmic radiation in the air is around 30 nGyh-1 (UNSCEAR, 2000). Moreover, terrestrial radionuclides are present in all rock formations at trace levels, they cause external gamma radiation exposures outdoors. As a result, geological and geographic conditions are also key determinants of natural environmental radiation (Nagaraja and Sathish, 2010). As they directly affect the level of gamma-absorbed dose received at a locality by altering the soil composition and natural radioactivity concentration levels. Igneous rocks like granite have higher radiation levels, while sedimentary rocks have lower radiation levels. However, there are notable outliers, since some shale and phosphate rocks contain radionuclides in rather high concentrations (Ramachandra et al., 1995).

2. Literature Review

The distribution of radioactivity in soil is dependent on the geological formation of the rock from which it is formed (UNSCEAR, 2000). According to Mehra, Badhan, Sonkawade, Kansal, and Singh (2010) as well as Senthilkumar and Narayanaswamy (2016), soil not only exposes people to radiation continuously but also serves as a pathway for radionuclides to move from soil to biological systems. This makes soil the primary environmental indicator of radioactive contamination. Even though soil is a significant environmental resource that is used for a variety of tasks, including the manufacture of raw materials and finished goods, land filling in playgrounds, creating streets or roads, etc., it typically contains natural radionuclides that increase exposure both indoors and outdoors. Soil radioactivity assessment is crucial to estimating how much the natural background activity will vary over time as a result of any radioactive discharge. According to earlier research, man is

subject to background radiation in the range of 2.4 mSv, which makes up about 80% of the yearly radiation dose exposure per person (Korkmazet al. 2017; Orgun, et al., 2005). Given that man lives, works, attends school, and conducts most of his daily activities in a building of some kind, construction is a necessary aspect of man's life in the contemporary day (Adewoyin et al., 2017). Therefore, having a thorough understanding of the natural radioactivity in soil will aid in assessing the population's radiation exposure level and in choosing the best sites for residential and commercial buildings.

It is crucial because radiological effects from excessive exposure to these radionuclides in humans can have serious negative effects like cancer and irradiating lung tissue. It is therefore essential to evaluate the natural environmental radioactivity and its related gamma radiation in order to determine the safety of the local population in order to prevent the types of diseases mentioned above. For instance, Dizman et al. (2016) investigated the background radiation level in soil to evaluate the associated health risks and established the likelihood of the annual effective gamma doses and lifetime cancer risks being higher than the global recommended average. For radiation measurement and protection (IAEA, 1989; ICRP, 1990), Korkmaz et al. (2017) noted that having sufficient knowledge of the distribution of radionuclides in the environment is quite helpful. Additionally, Kumari et al. (2017) believe that measuring the levels of radioactive pollutants released into the environment (Swedjemark, 1986; Righi and Bruzzi, 2006) will allow them to quantify the consequences of radiation exposure on people. The health risks associated with background radioactivity in soil have been the subject of numerous research conducted around the globe in recent decades (Bolat, ner, & etin, 2017; Ismail, Abdullahi, Samat, & Yasir, 2018; Rajesh, Kerur, & Anilkumar, 2017; Shilpa, Anandaram, & Mohankumari, 2018). A more precise assessment of the worldwide average values of dosimetric quantities will be possible thanks to the addition of these data to the global data bank on radioactivity. Few soil radioactivity surveys have been conducted in Nigeria for various regions (Ekong et al., 2021; Isa et al., 2022; Isa and Abuh, 2023; Kolo et al., 2017).

The goal of this work is to evaluate the various radiological danger indices (parameters) and debate them using statistical analysis. This is a follow-up to earlier research, which is summarized in Section 2 of this article. The findings of this study will provide crucial data for monitoring environmental contamination and suitable protective advice for the general people residing close to the study region. The results of this effort will also create a baseline data set that will help map the levels of radioactivity in Nigeria's surface soils and estimate population exposure.

2.1 Prior Study

We previously reported on the examination of background radiation and associated dose rates in soil samples from a Local Government in the state of north central Nigeria (Isa and Abuh, 2023). According to this investigation, the mean concentration of 238U and 40K activity was found to be 5.68 and 4.41 times greater than the global average value, respectively, whereas the concentration of 232Th was found to be lower. The mean values found in the study were contrasted with those from comparable soil research conducted in other countries. The comparison shows that the soil readings were greater than other stated global average values by UNSCEAR in 2000. The numerous radiological hazard indices, including increased lifetime cancer risk, are reported in this paper as a follow-up to the prior study. Additionally, using multivariate statistical methods, an effort has been made to determine the relationships between various radiological data or parameters.

3. Methods / Approach

For background mapping in this study, a Rados meter (RDS 120) was employed. The Rados is a flexible gamma radiation detector made for a variety of uses that need the detection of unusual or increased radiation levels and it could also be used to estimate a location's background radiation. Its functionality and user-friendly interface make it an ideal tool for monitoring and radioactive hazard detection on the ground. To safeguard the environment from ionizing radiation, it is crucial to monitor any radioactive discharge into the environment. It is crucial to use quick and precise measurement techniques. Numerous significant isotopes in naturally occurring radioactive materials (NORM) and technologically enhanced naturally occurring radioactive materials (TENORM) have appropriate gamma rays, enabling qualitative and quantitative analysis of the radionuclides by high-resolution gamma spectrometry. Utilizing the proper nuclear instruments, radiation levels and radionuclide concentrations in the environment are measured. Using a 76 mm x 76 mm NaI (TI) detector crystal optically connected to a photomultiplier tube (PMT), radioactivity levels were then detected and analyzed. To calculate each radioactivity level of the radionuclides, a spectral energy window and energy calibration were used, as shown in Table 1.

3.1 Soil Sample Preparation and Analysis of Gamma Spectrometry

Each of the soil samples that were collected was dried and pulverized into a fine powder. To stop 222Ra from escaping, the samples were triple sealed and packaged into radon-impermeable cylindrical plastic containers that were chosen based on the space allocation of the detector vessel and measure 76 mm in dimension (geometry). Each container lid's inside rim was coated with Vaseline jelly as part of the sealing procedure, and gaps between the lid assembly and the container were filled with candle wax to close them. Finally, masking adhesive tape was used to tightly seal each lid to its container counterpart. As soon as the samples were ready, the empty containers were weighed to determine their weight. Once the sample was sealed inside the container, the empty container and soil sample were weighed again to determine their combined weight. To determine the sample's weight, one must deduct the empty container's weight from the container's weight plus soil sample. The samples were kept at room temperature for 30 days before gamma spectroscopy tests to allow radon and its short-lived offspring to attain secular radioactive equilibrium.

The assessment of the activity of various radionuclides in environmental samples can be done easily, directly, and

without causing any damage using gamma spectrometry. Techniques for detecting semiconductors with high efficiency (NaI (Tl) detectors) and high resolution are available using gamma spectrometry. The method allows for the use of numerous samples for counting. Only when the detectors are being used do they need liquid nitrogen cooling. In order to ascertain the activity concentration of radionuclides in environmental soil samples, a gamma ray spectrometer was used in the current study. This gamma ray spectrometer is a 76mm x 76mm NaI (TI) detector crystal that was optically connected to a PMT for the analysis. Preamble and a 1 kilovolt external supply are both built within the assembly. A 6 cm lead shield with copper and cadmium sheets surrounds the detector. The purpose of this setup is to lessen the impacts of background radiation and dispersed radiation.Maestro software from Canberra Nuclear Products is used for data collecting. For each sample, the measurements were made for a total of 36000 seconds (10 hours). Equation (1) was applied to the peak areas of each energy level in the spectrum to calculate the activity concentrations for the natural radionuclide in each sample (Ibeanu, 1999).

$$C(Bq.Kg^{-1}) = \frac{c_n}{c_{fk}} \quad (1)$$

Where C is the radionuclide sample's activity concentration, expressed in $Bq.Kg^{-1}$;
C_{fk} is the detecting system's calibration factor.
C_n stands for count rate (counts/second) and it is expressed as:

$$\text{Count per second (cps)} = \frac{netcount}{livetime} \quad (2)$$

For the artificial radionuclide and using the photo peak as stated in Table 1, the activity content of 137Cs in the soil samples were methodically calculated and expressed relative to dry weight using the equation below (Uosif, 2007):

$$\text{Activity concentration} = \frac{c}{e \times i \times m} \quad (3)$$

In which, C is the net count per second . e represents the detector's measured counting efficiency,
i is the radionuclide's gamma line's strength or intensity, and M is the soil sample's mass, expressed in kilograms.

The analysis's spectral energy window is shown in Table 1 and the background count rate was conducted for 36000 seconds (10 hours).

Table 1: Analysis's Spectral Energy Window.

Radionuclides	Source	Isotopes	Gamma Energy, E□ (keV)	Energy window (kev)	Gamma Intensity I□ (%)
214Pb	238U decay	238U	351.87	1120-1820	38.9
214Bi	238U decay		609.31		43.3
208Bi	238U decay		1764.49		15.7
238Ac	232Th decay	232Th	911.21	1680-2820	27.7
208Tl	232Th decay		2614.51		85.8
40K	primordial	40K	1460.8	1380-1540	10.7
137Cs	Nuclear weapons tests in 60s, 70s and Chernobyl	137Cs	661.6	661.6	85.2

3.2 Mutivariate Statistical Analysis

To identify the privity of various parameters obtained from natural radionuclides, multivariate statistical analyses (Pearson's correlation analysis, and cluster analysis) have been carried out using the python programming language.

4. Results / Discussion

4.1 Activity concentrations of 238U, 232Th, 40K and 137Cs

Table 2 includes the concentration of man-made radionuclide and naturally radioactive components found in soil samples. 40K, 238U, 232Th, and 137Cs have activity concentrations that vary from 382.71±18.41 to 3385±164.43Bqkg-1, 17.22±1.30 to 388.22±28.94Bqkg-1, 14.3±0.80 to 57.30±3.19, and 1.49±0.9 to 4.46±0.26Bqkg-1, respectively. According to the study, the average activity concentrations for 40K, 238U, 232Th, and 137Cs are 1853.58±90.45, 181.85±14.24, 34.91±2.04, and 2.69±0.22 correspondingly. According to UNSCEAR (2000), the average global concentrations of 40K, 238U, and 232Th are 420, 33, and 45Bq kg-1, respectively. Thorium follows Uranium in the magmatic series, increasing Uranium's mobility in the soil and causing it to withdraw from the mineral crystal lattice, whereas Thorium has a higher ionic radius and thus maintains its mineral form (Gbenuet al., 2016; Moura et al., 2011). As a result, Thorium has a lower activity concentration than Uranium. The fact that 40K has a greater activity concentration than 238U and 232Th may be related to the soils' higher average silica content (Navarrete, Zuniga, Espinosa, & Golzarri, 2014). The sampling locations and activity concentrations for 238U, 232Th, 40K, and 137Cs are depicted in Fig. 1.

Table 2: Activity Concentration of Radionuclides of the Soil Samples

S/N	Sample Code	Activities in Bq/kg			
		^{40}K	^{238}U	^{232}Th	^{137}Cs
1	YE 01	598.82 ±28.82	43.54 ±3.23	27.10 ±1.51	1.71 ±0.10
2	YE02	1094.75 ±54.15	63.56 ±6.37	15.21 ±1.51	1.49 ±0.09

3	YE03	3385 ±164.43	288.73 ±22.04	36.68 ±2.11	4.22 ±0.24
4	YE04	466.93 ±23.41	149.27 ±12.77	28.77 ±1.65	2.01 ±0.12
5	YE05	382.71 ±18.41	17.22 ±1.30	14.34 ±0.80	ND
6	YE06	3131.94 ±152.82	388.22 ±28.94	32.79 ±1.89	4.46 ±0.26
7	YE07	2997.82 ±145.84	282.80 ±21.24	42.17 ±2.42	4.02 ±0.23
8	YE08	2750.54 ±134.15	360.76 ±26.67	45.42 ±2.61	4.16 ±0.24
9	YE09	2515.55 ±123.60	203.42 ±17.76	39.51 ±2.28	3.39 ±0.20
10	YE10	443.95 ±21.38	30.23 ±2.29	57.30 ±3.19	1.50 ±0.86
11	YE11	1147.70 ±57.19	206.64 ±16.14	42.99 ±2.46	2.80 ±0.17
12	YE12	3327.29 ±161.18	147.77 ±12.12	36.60 ±2.10	2.52 ±0.15
13	Min	382.71 ±18.41	17.22 ±1.30	14.34 ±0.80	1.49 ±0.09
14	Max	3385 ±164.43	388.22 ±28.94	57.30 ±3.19	4.46 ±0.26
15	Mean	1853.58 ±90.45	181.85 ±14.24	34.91 ±2.04	2.69 ±0.22

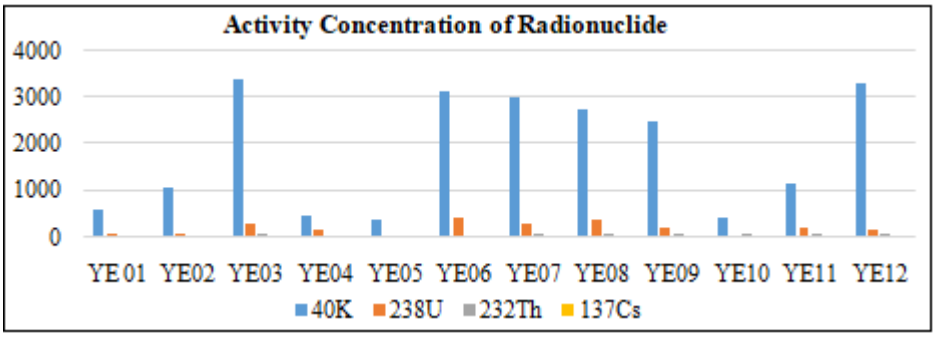

Figure 1: Activity Concentration of the selected Radionulides in the Soil Samples

Additionally, it can be seen from the results that activity concentration values in all sampling locations are in the order 40K > 238U > 232Th, with the exception of the soil sample location at YE10, which was in the order 40K > 232Th > 238U. This finding differs from that which Inigo Valan, Mathiyarasu, Sridhar, Narayanan, and Stephen (2015) presented as an observation. Boxplots (Fig.2) were used to display the concentration of activity. The little cube inside the box represents the average value. The lower quartile, also known as the 25th percentile, is represented by the bottom portion of the boxplot, while the upper quartile, also known as the 75th percentile, is shown by the upper part of the box. The median, also known as the 50th percentile, is the line that splits the box into two parts. The range is shown as a vertical line connecting the box's minimum and maximum values. There are no data points that fall outside the box plot's whiskers, or outliers. According to UNSCEAR (2000), the average global concentrations of 40K, 238U, and 232Th are 420, 33, and 45Bq kg-1, respectively. The outcome of this investigation demonstrates that the mean values of 40K (1853.5890.45) and 238U (181.8514.24) are higher than the internationally advised values, exposing locals to background ionizing radiation. Despite being less than the global average (UNSCEAR, 2000), the 232nd's mean value of 34.912.04 is nevertheless significant. When compared to the global average, the activity concentration of radionuclides is greater for both 40K and 238U by factors of 4.41 and 5.68, respectively, and lower for 232Th by 0.78. For 137Cs, a man-made radionuclide, the computed value in every region should be zero, and values above zero indicate contamination in the area, which can occur for a variety of reasons and lead to radiological health issues among study area residents.

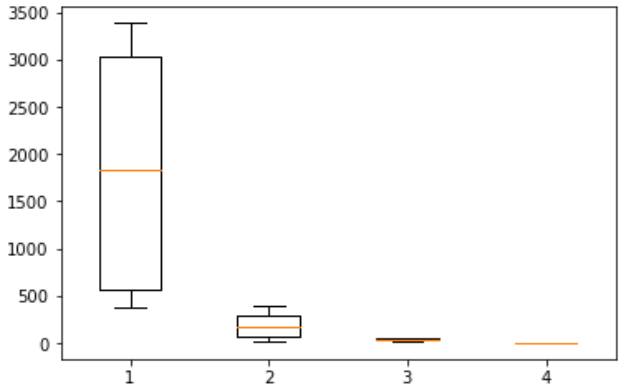

Figure 2: Boxplots of the Radionulides
Where 1 =40K, 2 =238U, 3=232Th and 4=137Cs

Table 3 compares the analysis of naturally occurring radionuclides from the research area's soil with selected other soil types from the literature. The values reported in the chosen studies on soil on radiation are less than the mean activity concentrations of 40K and 238U in this study in all the study locations. In contrast, the activity concentration of 232Th is higher in the remaining selected studies than it is in the two studies that were chosen, Chandrasekaran et al. (2014) and Korkmaz et al. (2017) (see Table 3). The variances in radioactive concentrations in the research locations' geological formations are the cause of the discrepancy in radioactivity levels. The estimated amount of the elements in the soil from Yagba East is currently beyond the safe limit and can represent a radiological health hazard to the general people, according to a comparison of average activity concentrations of radionuclides with other locations and UNSCEAR (2000) guidelines.

Table 3: Comparison with other Studies

Case study	40K	238U	232Th	Country	References

Soil	1146.88	19.16	48.56	India	Chandrasekaran et al. 2014
Surface soil	451.1	71.6	83.9	Turkey (Karada˘g)	Korkmaz et al. 2017
Granite (soil)	441.06	11.51	15.42]	Nigeria (Asa)	Orosun et al. 2020
Surface soil	923	26	29	China (Bayanwula)	Bai et al. 2017
Mining soil	270.14	12.14	23.23	Nigeria (Fashina)	Oluyide et al. 2019
Sand (soil)	337	78	33	Egypt	El-Afifi et al. 2006
Surface soil	57.8	2.07	6.89	Nigeria (Ogwa)	Popoola et al. 2019
Surface soil	1.41	4.85	30.19	Nigeria (Igueben)	Popoola et al. 2019
Soil	1853.58	181.85	34.91	Nigeria (Yagba East)	Present study
Soil and rock	420	33	45	Global limit	UNSCEAR2000

5. Effects of Radiological Hazard Evaluation

Different radiological dangers transmitted to the nearby living biota might be evaluated depending on the activity concentration of primordial radioactive elements. Table 4 lists the values of all radiation risks that were measured.

5.1 Radium Equivalent (Ra_{eq})

The recognized index for analyzing the radiation exposure caused by the primordial radionuclides is the radium equivalent activity index in Bq/kg. The formula used to determine the radium equivalent (Orgun et al., 2007) enables us to explain the gamma output from various mixes of uranium, thorium, and potassium in soil samples from the study area.

$$Ra_{eq}(BqKg^{-1}) = C_U + 1.43C_{Th} + 0.077C_K \quad (4)$$

where the specific activity concentrations of 238U, 232Th, and 40K in Bqkg-1 are CU, CTh, and CK, respectively. Radium equivalent was estimated with the results shown in Table 4 and ranged from 67.20Bqkg-1 to 676.27Bqkg-1 with a mean value of 373.10Bqkg-1. This is due to the concentration of the three naturally occurring radionuclides. According to all indications, the radium equivalent values from sites YE01, YE02, YE04, YE05, YE10, and YE11 were less than the advised threshold limit of 370 Bq/kg, however the values from sites YE03, YE06, YE07, YE08, YE09, and YE12 were more than the advised value (UNSCEAR, 2000). The average value of radium equivalent in this investigation was 373 Bq/kg, which is somewhat higher than the 370 Bqkg-1 recommended maximum allowable level by UNSCEAR (2000). Based on the radioactive level of the soil samples, a value over the suggested value denotes a higher dosage limit of 1.0 mSv for public exposure to 238U, 232Th, and 40K activities (Ugbede et al., 2021). Therefore, if the soils are being used for building construction and or agricultural activities, there may be a greater risk of radioactive hazard exposure. In a similar vein, if youngsters (children) with developing bodies and weak/moderate immune systems are exposed to enough of them, bad things could happen.

5.2 Representative level index (RLI) or Gamma index (GI)

To calculate the gamma radiation risk associated with the natural radionuclide in particular samples under study, the representative level index or gamma index is used. A lower radiological danger to soil and plants is implied by values of $I_y \leq 1$ which correspond to an annual effective dose less than or equal to the upper limit of 1mSv]. The following formula (Alam et al., 1999; Avwiri et al., 2013; Turhan et al., 2008) is used to compute or quantify it:

$$\text{RLI} = \frac{1}{150}Cu + \frac{1}{100}Cth + \frac{1}{1500}\text{Ck} \quad (5)$$

where the activity concentrations of 238U, 232Th, and 40K in Bq kg1, respectively, are Cu; CTh; and Ck. Table 4 lists the RLI measurements made for each soil sample, with values ranging from 0.513 to 5.004 and an average of 2.794. In the sample locations YE06 and YE05, the lowest and highest values were obtained. When compared to the current study, the average of 2.794 exceeds unity, the representative level index's upper limit (Alam et al., 1999) and therefore, the soilsamples have radiation contamination. In the sample sites of YE02, YE03, YE04, YE06, YE07, YE08, YE09, YE10, YE11 and YE12, it is noticed that the RLI values of soil samples in those locations are higher than the maximum limit and lower than the maximum limit in sample locations of YE01 and YE05. These demonstrate that the soil under investigation has extremely high gamma radiation levels and may impair radiological systems when employed in the construction of buildings or in agricultural activities.

5.3 Activity utilization index (AUI)

Activity Utilization Index (AUI) is determined using the following relation together with the dose rates in air from various combinations of 238U, 232Th, and 40K (Bqkg-1) in soil samples and by using the appropriate conversion factors (El-Gamal, et al., 2007).

$$\text{AUI} = \frac{C_U}{50}Fu + \frac{C_{Th}}{50}Fth + \frac{C_K}{500}\text{Fk} \quad (6)$$

where Cu, CTh, and Ck are the activity concentrations of 238U, 232Th, and 40K in Bqkg-1 in soil samples, respectively. While according to (Chandrasekaran et al., 2014), Fu (0.462), Fth (0.604), and Fk (0.042) are the respective fractional contributions from the actual activities of 238U, 232Th, and 40K to the total dose rate in air. The AUI values estimated in this investigation are listed in Table 4, with a range from 0.364 to 4.246 and an average of 2.257. According to El-Gamal et al. (2007), this figure indicates that AUI >2, which represents an annual effective dosage 0.3 mSv/y and which is over the recommended dose rate.

Table 4: Some Radiological Parameters in the Soil Samples

S/N	Sample Code	RLI	AUI	Ra_eqin Bq/kg
1	YE 01	0.960	0.779	128.4
2	YE02	1.306	0.863	169.61
3	YE03	4.549	3.395	601.83
4	YE04	1.554	1.766	226.36
5	YE05	0.513	0.364	67.20
6	YE06	5.004	4.246	676.27

7	YE07	4.306	3.374	557.23
8	YE08	4.693	4.113	637.50
9	YE09	3.428	2.568	453.62
10	YE10	1.070	1.008	146.35
11	YE11	2.573	2.524	356.49
12	YE12	3.569	2.086	456.31
13	Min	0.513	0.364	67.20
14	Max	5.004	4.246	676.27
15	Mean	2.794	2.257	373.10

6. Dose Rate Estimation Analysis

6.1 Absorbed dose rate (D)

The amount of radiation absorbed or received determines whether tissue and/or organs will sustain radiation damage. The amount of energy delivered per mass of the radioactive substance is known as the absorbed dose. The conversion factors 0.462, 0.604, and 0.0417 for Uranium, Thorium, and Potassium, respectively, are used to convert the observed activity concentrations of 238U, 232Th, and 40K into doses (UNSCEAR, 2000). The formula below is used to compute the total absorbed dose rate (D) in nGy/h (Beretka and Mathew, 1985; UNSCEAR, 2000):

$$D_R(\text{ŋGyh}^{-1}) = 0.462C_U + 0.604C_{Th} + 0.0417C_K \quad _{nGy/h} \quad (7)$$

where the activity concentrations of 238U, 232Th, and 40K in Bqkg-1 are denoted by Cu, CTh, and CK. The total dose rate values are shown in Table 5 and range from 32.69 to 330.71 nGy/h, with an average of 182.94 nGy/h. It is evident from the current investigation that the average absorbed dose rate values in the study area are significantly higher than the maximum allowable level of 55 nGy/h (UNSCEAR, 2000).

6.2 Alpha Index

This index is one of the radiological indicators created to evaluate the environmental safety owing to excessive radiation exposure from soils used in construction. The estimation according to Joel et al., 2019 and Joel et al., 2020 definition was performed using equation:

$$I_\alpha = \frac{Cu}{200} \quad (8)$$

Where;
Cu is concentration of 238U.

The determined, lowest, maximum and mean values of I alpha for the natural radionuclides are 0.086, 1.941, and 0.909, respectively, according to Table 5. The soil samples' computed mean Ialpha value is just slightly within the usual limit of 1 (Joel., et al., 2020) The study area's somewhat value of the alpha index indicates a little higher radiological risk since the numerous activities conducted there have a propensity to raise background radiation levels, which puts the population at risk for radiation exposure. Even while the study area is currently somewhat safe, if the activities there are not curbed, it won't be for very long. This is the case because using the soil resources to site constructions in urban communities will soon no longer be safe for residents and will offer health risks to people or government organizations.

6.3 Annual effective dose equivalent (AEDE)

Primordial radionuclides are naturally occurring substances that are present to varying degrees in all environmental media, including the human body. Gamma radiation from radionuclides in the 238U and 232Th family as well as from 40K, which is present in all soils, are the principal sources of external radiation that are absorbed by the human body. Similar to outdoor exposure, indoor exposure to gamma rays is fundamentally higher than outdoor exposure if earth elements were utilized in construction. Indoor exposure is much more important when the length of tenancy is taken into consideration (UNSCEAR, 2000). Thus, in air, the absorbed dose conversion coefficient to effective dose and the outdoor including indoor occupancy factors must be taken into consideration when estimating annual effective doses. The UNSCEAR (2000) report stated that the occupancy factor for indoor and outdoor spaces is 0.8 and 0.2, respectively, and that the conversion coefficient from the absorbed radiation in air to the effective dose received by humans is 0.7 Sv/Gy. This indicates that 0.8 and 0.2 of the time is spent indoors and outside, respectively. Using the equations 9 and 10, the annual effective dose equivalent (AEDE) in indoor and outdoor air were calculated as thus (Hazou and Patchali, 2021; UNSCEAR, 2000):

$$\text{AEDRoutdoor (mSvy-1)} = \text{D (nGyh-1)} \times 0.7\ \text{(SvGy-1)} \times 0.2 \times 8760\ \text{(hy-1)} \times 10^{-6} \quad (9)$$

$$\text{AEDRindoor (mSvy-1)} = \text{D (nGyh-1)} \times 0.7\ \text{(SvGy-1)} \times 0.8 \times 8760\ \text{(hy-1)} \times 10^{-6} \quad (10)$$

Table 5 lists the computed AEDE values for both indoor and outdoor environments. The AEDE values range from 0.160 to 1.628 mSv/y (indoor) and 0.040 to 0.407 mSv/y (outdoor) respectively. The respective AEDE mean values for indoor and outdoor are 0.900 and 0.225. The permissible and standard values for an absorbed effective dose rate indoors and outdoors are 0.42 mSvy-1 and 0.08 mSvy-1, respectively (UNSCEAR, 2008). For this study, the AEDE for both indoor and outdoor exceeds the maximum permitted level, which might cause radiological hazard to study area people.

6.4 Annual gonadal dose equivalent (AGDE)

According to UNSCEAR (1988), the active bone marrow and bone surface cells are the organs of interest. As a result, the following formula is used to compute the annual gonadal dose equivalent (AGDE) resulting from the particular activities of 238U, 232Th, and 40K (Mamont-Ciesla, Gwiazdowski, Biernacka, & Zak, 1982):

$$\text{AGDE(Svy}{-}1) = 3.09C_U + 4.18C_{Th} + 0.314C_K \quad (11)$$

The calculated AGDE values are shown in Table 5 and range from 233.32 to 2320.09 mSvy1 with an average value of 1268.11 mSvy-1. This clearly shows that the AGDE values of all soil samples in the current study are significantly higher than the global average value of 300 mSvy-1 (Xinwei, et al., 2006).

6.5 Hazard indices (Hex and Hin)

By calculating the following two hazard indices using the relations presented below, the gamma ray radiation dangers caused by the specified radioactive elements in soil samples are evaluated (Xinwei et al., 2006):

$$H_{ex} = \frac{C_U}{370\,Bq\,Kg^{-1}} + \frac{C_{Th}}{259\,Bq\,Kg^{-1}} + \frac{C_K}{4810\,Bq\,Kg^{-1}} \quad (12)$$

$$H_{in} = \frac{C_U}{185\,Bq\,Kg^{-1}} + \frac{C_{Th}}{259\,Bq\,Kg^{-1}} + \frac{C_K}{4810\,Bq\,Kg^{-1}} \quad (13)$$

where the activity concentrations of 238U, 232Th, and 40K in Bq kg1 are Cu, CTh, and CK. According to Al-Trabulsy, Khater, and Habbani (2011), the internal hazard index (Hin) is used to limit internal exposure to radon and its transient byproducts, which are also harmful to the respiratory system. Table 5 includes a list of the calculated hazard indices. Between 0.288 and 2.876 and 0.182 and 1.827, respectively, are the HIn and Hex values. For Hin and Hex, the average values are 1.503 and 1.012, respectively. The UNSCEAR (2000) study suggests that the hazard indices' recommended value be less than unity. Table 5 makes it evident that the danger indices determined in this investigation are higher than the suggested level. This is due to the fact that there are more than the maximum value of 1. Therefore, it may be claimed that the surface and deep soil interactions with the research area's population may cause diseases of the external and respiratory systems (Ademila and Ugo, 2018). Additionally, there are considerable radiation dangers and soil samples should not be used for construction.

6.6 Excess lifetime cancer risk (ELCR)

An excess lifetime cancer risk is defined as the propensity for study region residents to develop cancer over a prolonged period of time by exposure to a particular radiation dose. The majority of experts concur that ionizing radiation, even at modest doses, can raise the risk of cancer. A very modest amount above 100 mSv is where this risk becomes apparent. As the radiation exposure rises, so does the risk of developing cancer. An average adult's lifetime risk of developing deadly cancer is predicted to increase by about 4% after exposure to one Sievert of radiation over time, and there is a 0.8% chance that any future offspring may inherit a genetic abnormality. The formula for calculating excess lifetime cancer risk (ELCR) is given below (Chandrasekaran et al., 2014; Sb, et al., 2018). The results are shown in Table 5.

$$ELCR = AEDRout \times DL \times RF \times 10^{-3} \quad (14)$$

Where AEDRout, DL, and RF are, respectively, the outdoor annual effective dose rate, the lifespan (70 years), and the risk factor (0.05 Sv-1).

From above equation, ELCR has been calculated to have a value that ranges from 0.140 to 1.423, with a mean of 0.788. The ELCR average around the world is 0.29 x 10^{-3}, and in the current study, only two of the soil sample locations—YE01 and YE05—had ELCR values that were lower than the average. The other locations had higher ELCR values.

Table 5: Radiological Parameters of the Soil Samples

S/N	Sample Code	Dose rate (D) (nGy/h)	AGDE (mSv/y)	AEDE (mSv/y-1)		Hazard indices		Ia	ELCR mSv
				Out	In	H_{in}	H_{ex}		
1	YE 01	61.64	435.85	0.076	0.304	0.464	0.347	0.218	0.266
2	YE02	84.53	603.73	0.104	0.416	0.631	0.459	0.318	0.364
3	YE03	297.71	2108.30	0.366	1.464	2.407	1.626	1.444	1.281
4	YE04	105.95	728.12	0.130	0.520	1.015	0.611	0.746	0.455
5	YE05	32.69	233.32	0.040	0.160	0.228	0.182	0.086	0.140
6	YE06	330.71	2320.09	0.407	1.628	2.876	1.827	1.941	1.423
7	YE07	281.99	1991.44	0.347	1.388	2.315	1.550	1.414	1.214
8	YE08	309.62	1682.10	0.381	1.524	2.697	1.722	1.804	1.334
9	YE09	223.49	1583.60	0.275	1.100	1.776	1.226	1.017	0.963
10	YE10	67.23	472.32	0.083	0.332	0.476	0.395	0.151	0.291
11	YE11	169.61	1403.84	0.209	0.836	1.522	0.963	1.033	0.732
12	YE12	230.13	1654.60	0.283	1.132	1.632	1.232	0.739	0.991
13	Min	32.69	233.32	0.040	0.160	0.228	0.182	0.086	0.140
14	Max	330.71	2320.09	0.407	1.628	2.876	1.827	1.941	1.423
15	Mean	182.94	1268.11	0.225	0.900	1.503	1.012	0.909	0.788

6.7 Evaluation of Radiological Characteristics in Relation to other Global Contexts

Table 6 displays the comparative data from the literature. The average values of the radiological parameters reported in this study are higher than that of Industrial dumpsites soils (Ademola et al., 2014), soils around Olode mining site (Nwankwoa et al., 2015), cement factory (Usikalu, Akinyemi, & Achuka, 2014), Komu mining (Nwankwoa et al., 2015), soils around petroleum industry (Hajer Hrichia, Baccoucheb, & Belgaied, 2015) and world average values (UNSCEAR, 2000). This suggests that the study area is extremely radioactively contaminated, and additional research is required to confirm or disprove this result (for example, using data from local blood samples and plant species, notably vegetables).

Table 6: A Comparison of Radiological Characteristics in Several Global Contexts

Sampling Sites	Raeq	RLI	AUI	Dose rate (D) (nGy/h)	AGDE (mSv/y)	AEDE (mSv/y-1)		Hazard indices		Ia	ELCR mSv	References
						Out	In	**H_{in}**	**H_{ex}**			
Soil of industrial dumpsites,	61.02			29.790		0.037		0.180				Ademola, et al., 2014

Nigeria												
Olode mining site, Nigeria	45.70			21.640		0.032		0.120	0.170			Nwankwoa et al., 2015
Soils around cement factory, Nigeria				40.880		0.050						Usikalu et al., 2014
Soil from petroleum Industry, Tunisia	38.60			18.500		0.022		0.104	0.129			Hajer Hrichia et al., 2015
Soil around phosphate fertilizer, Mumbai, India	211.00								0.570			Sahu et al., 2014
Soil, phosphate fertilizer, Egypt	126.20			67.300								Ahmed &El-Arabi, 2005
Petroleum waste, Saudi Arabia	116.46			59.380				0.405	0.315			Al-Saleh &Al-Harshan, 2008
Worldwide	370	1	0.07	55.00	300	0.080		<1	<1		0.29	UNSECAR, 2000
Present study	373.10	2.794	2.257	182.94	1268.11	0.225	0.900	1.503	1.012	0.909	0.788	

7. Data analysis with statistics

7.1 Descriptive Statistics

The results produced by utilizing the Python programming language and the radionuclide activity concentrations are given in Table 7 after the descriptive statistical analysis was completed. The radionuclides were found to have the following skewness values: 40K (-0.001239), 238U (-0.227751), 232Th (-0.212407), and 137Cs (-0.366120). Due to the risk of left tail occurrences, the distributions for 40K, 232Th, and 137Cs are negatively skewed (i.e. left skewed). This indicates that the locals in the research region should exercise caution when using the soil, particularly for construction. The distribution of 238U is, however, right-skewed and positively skewed. The distribution of all the radionuclide activity concentrations was asymmetrical or significantly skewed (to the left or right) and not normally distributed. The radionuclides' kurtosis values were determined to be as follows: 137Cs (-0.680265), 232Th (0.101640), 238U (-1.234905), and 40K (-2.097631). When compared to a normal distribution, the positive kurtosis value for the 232Th radionuclide indicates a high or peaked distribution, or a distribution with a laptokurtic shape. The fact that 40K, 238U, and 137Cs have negative kurtosis values compared to their normal distributions, or a platykurtic shape, denotes flattened peaks.

7.2 Analysis of Pearson's correlation coefficient

Using Pearson's correlation coefficient analysis, the potential mutual relationships and degree of association between the observed radiological parameters are evaluated. The results are shown in Table 7 as a linear correlation matrix and heat map as in Figure 3. The correlation coefficient between 40K, U238 and radiological measures is strongly positive. Consequently, these connections demonstrate that radionuclides 40K and 238U contribute to the emission of gamma radiation at each location. The radiological variables do, however, correlate well with 232Th Senthilkumar & Narayanaswamy, (2016) and Ravisankar et al. (2014) both reported a different trend. Additionally, a very weak association between 238U and 232Th and a substantial positive correlation between 40K and 238U are discovered.

Table 7: Pearson Correlation Coefficient between Natural Radionuclides and Radiological Parameters

	40K	238U	232Th	RLI	AUI	Raeq	D	AGDE	AEDEout	**AEDEin**	Hin	Hex	Ia	ECLR
40K	1													
238U	0.79	1												
232Th	0.29	0.36	1											
RLI	0.94	0.95	0.41	1										
AUI	0.82	0.99	0.45	0.96	1									
Raeq	0.92	0.96	0.41	0.99	0.98	1								
D	0.94	0.95	0.40	0.99	0.97	0.99	1							
AGDE	0.93	0.92	0.39	0.98	0.93	0.98	0.98	1						
AEDE out	0.94	0.95	0.40	0.99	0.97	0.99	0.99	0.98	1					
AEDE in	0.94	0.95	0.40	0.99	0.97	0.99	0.99	0.98	0.98	1				
Hin	0.88	0.98	0.40	0.99	0.99	0.99	0.99	0.96	0.98	0.99	1			
Hex	0.93	0.96	0.41	0.99	0.98	0.99	0.99	0.98	0.98	0.99	0.99	1		
Ia	0.79	1.00	0.36	0.95	0.99	0.96	0.95	0.92	0.98	0.95	0.98	0.96	1	
ELCR	0.94	0.95	0.40	0.99	0.97	0.99	0.99	0.98	0.92	0.99	0.99	0.99	0.95	1

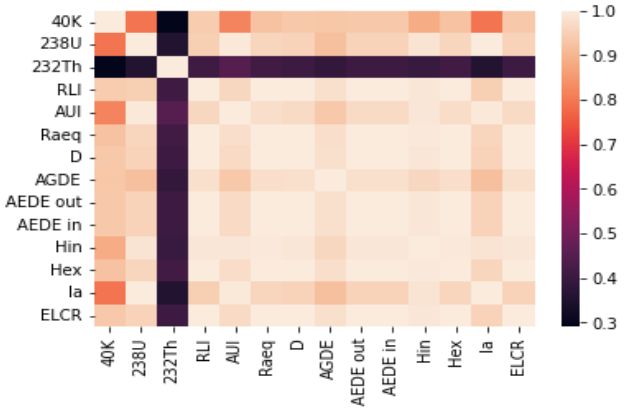

Figure 3: Correlation heat map of the relationship among the radiological parameters

7.3 Cluster Analysis

In order to group the system's objects into optimal groups for which the observations or objects within each group are similar but the groups are dissimilar from one another, hierarchical cluster analysis (HCA), a multivariate statistical analysis, is used. The HCA with average linkage approach is additionally used in this work to investigate the relationships between radioactivity and radiological indicators. In Figure 4, three distinct clusters are shown. The first cluster is mostly made up of the particles AGDE and AEDE out, the second cluster is made up of the particles 232Th, Ra_eq, D, and ELCR, and the third cluster is made up of the particles 40K, 238U, RLI, AUI, AEDEin, and Hin. This cluster analysis shows that the quantities of 40K, 238U, and 232Th in the study area are the cause of all the radiological parameters (apart from AGDE and AEDEout). The concentration of 232Th is what determines the dose that humans take in. This outcome slightly differs from the findings of the study by Senthilkumar & Narayanaswamy, (2016).

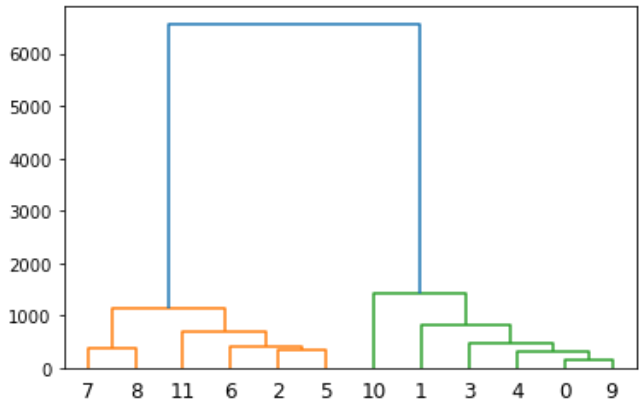

Figure 4: Dendogram showing the groups of the radiological parameters
Where 0=40K, 1=238U, 2=232Th,3=RLI, 4=AUI, 5=Ra, 6=D, 7=AGDE, 8=AEDEout, 9=AEDEin, 10=Hin, 11=ECLR

8. Conclusion

Gamma ray emissions from human activity and natural radionuclides on earth can easily diffuse within the environment and travel great distances, having significant effects on the soil and inhabitants over time. Through soil use and contact, this technique has had negative health impacts. In tisstudy, the activity concentration of radionuclides with the global average value is higher for both 40K and 238U and lower for 232Th by a factor of 4.41 and 5.68, respectively. All but two of the soil samples tested were contaminated with 137Cs, which can lead to a variety of health-related problems through exposure overtimes. A positive association between the radiological parameters and both 40K and 238U, as well as a marginally positive link with 232Th, is revealed by Pearson correlation analysis. This shows that the principal sources of gamma radiation emission across the whole research area are radionuclides 40K and 238U. The hierarchical cluster analysis, which shows that several radiological parameters cluster with the radionuclides of 40K and 238U, further supports this. Moreover, in tis study, RLI, AUI, absorbed dose, AGDE, yearly effective dose, internal hazard index, and external hazard index are just a few of the radioactive hazard metrics that are far over UNSECEAR's recommended norms. Raeq, Hin, Hout, and ECLR, however, are recorded at a somewhat greater level than the limits set forth by UNSECEAR.

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