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Measurement of Natural Radioactivity and Assessment of Radiological Hazard Indices of Soil Over the Lithologic Units in Ile-Ife Area, South-West Nigeria

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ABSTRACT: The distribution of natural radioactivity levels of ^{238}U, ^{232}Th, and ^{40}K in soils overlying the 3 lithologic units within Obafemi Awolowo University, Ile-Ife, Nigeria was investigated to characterize the gamma radiation dose distribution over the lithologies and to assess the radiation hazard due to the natural radionuclides. A thallium-doped cesium iodide detector was employed to determine the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in 21 soil samples. The respective average concentrations of the 3 radionuclides are 37.7, 3.2, and 245.6 Bq kg^{-1} for granite gneiss, 31.9, 2.8, and 241.1 Bq kg^{-1} for banded gneiss, and 21.1, 1.7, and 196.7 Bq kg^{-1} for mica schist. The average concentration of ^{238}U in granite gneiss lithology exceeds the world average value. The evaluated values of radiation hazard parameters including average absorbed dose rate, outdoor annual effective dose and external hazard index are below the recommended limits. The spatial distribution of the radiation hazard parameters evaluated over the lithologies has been delineated. The highest average cancer risk of 1.15 per 10 000 population was obtained for the study area within the soil overlying the banded gneiss lithology. Generally, the radiation hazard from the soils in study area poses no significant health hazard.

KEYWORDS: Radioactivity, detector, gamma spectrometry, lithology, natural radionuclide, environmental monitoring

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Introduction

Ionizing radiation from natural sources that man is exposed to is an inevitable aspect of life. Human beings everywhere on earth are exposed to ionizing radiation from natural sources.[1] These sources of natural radiation that man is exposed to could either be a cosmic source or primordial source. Cosmic radiations are those which emanate from outer space which release high energy particles into the planet earth.[1] Their interaction with atmospheric particles produces secondary particles that are referred to as cosmogenic radionuclides.[2] The commonest of the radionuclides are the ^{3}H and ^{14}C. Cosmogenic radionuclides contribute about 0.4 mSv of the total annual dose of 2.4 mSv which man is exposed to from natural sources.[3] Of greater significance on the other hand are the primordial sources of radiation that contribute most of man's total radiation from natural sources. The primordial radionuclides are long-lived radionuclides which are present on earth since its formation.[4] The radionuclides are present in the soil, water, building materials, air and also in living organisms.[5-7] The radionuclides are also present in trace levels in the human body.[8,9]

The primordial radionuclides comprise of radionuclides in the ^{238}U and ^{232}Th decay series and non-series ^{40}K. Their half-lives are comparable with the age of the earth contribute the most to the radiation received by humans from natural sources.[3] The activity concentrations of the primordial radionuclides in the environment play an important role in public health. Soil plays vital role in the transport of primordial radionuclides in the environment. It does not only act as the source, but also serves as a conduit to other environmental media such as air and water.[10] For instance, the atmospheric interface between soil and air enables primordial radionuclide suspension in air.[11,12] In addition, radionuclides can also be leached into both groundwater and surface water.[5] From the perspective of radiation protection, assessment of the level of primordial radionuclides in the environment and the consequent radiation exposure to human is mostly carried out in soil.[13-16] In soil, the distribution of these radionuclides is not uniform.[17,18] On one hand, this is due in part to the transfer of the radionuclides between earth materials such as air to the soil, soil to water, soil to plant, etc.[19,20] On the other hand, the distribution of radionuclides in soils overlying different geologies varies,[21,22] and hence the human exposure due to gamma radiation from the radionuclides in soil also varies from place to place. Soils overlying shales and phosphate rocks in some areas of the world have been reported to exhibit a relatively high level of radioactivity.[3,23] Anthropogenic activities in an area can alter the distribution of the radionuclides in such environment,[24,25] however, the lithological spatial distribution of the radionuclides are useful tools employed in determining gamma radiation distribution and estimation of radiation hazards indices.[10,26,27] The area of study is an academic environment

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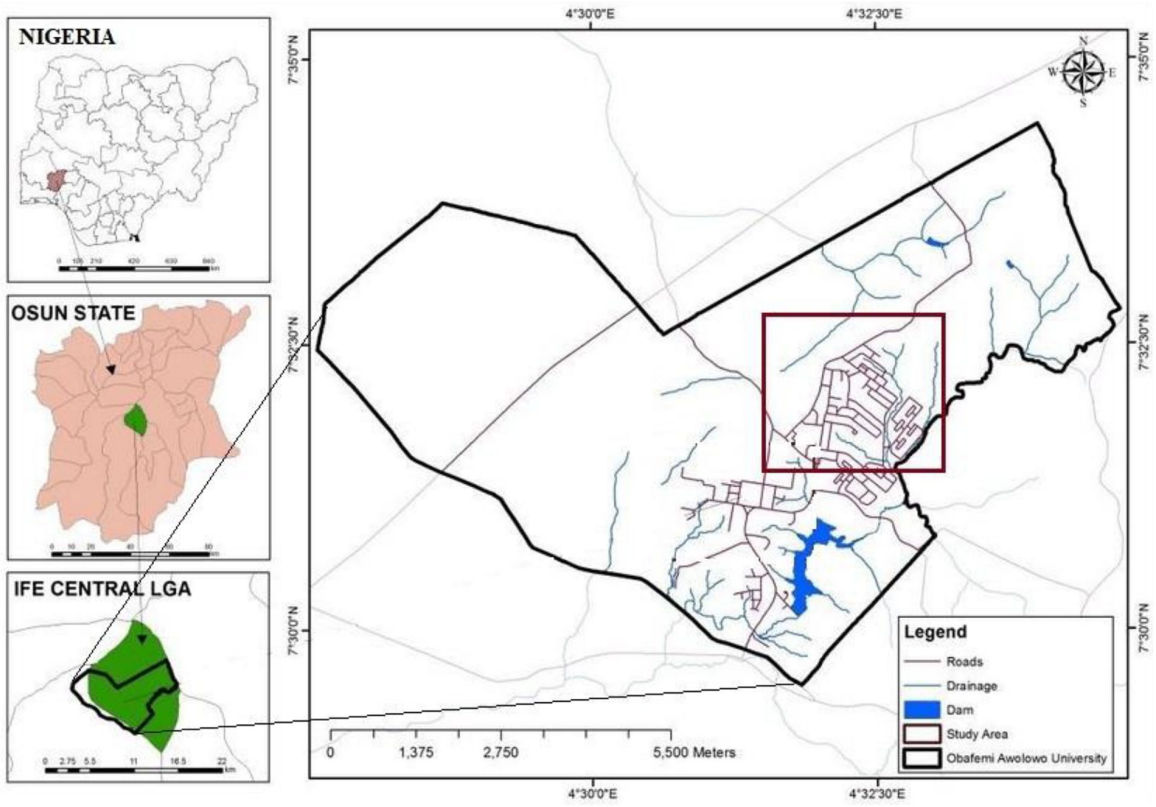


Figure 1. Study area map (Inset: maps of Nigeria, Osun State and Ife Central Local Government Area)—Digitized from.[35]

with a population of about 40 000 including staff and students. The buildings in the area are erected over 3 lithologies (banded gneiss, granite gneiss, and mica schist). The inhomogeneity of the geological setting of the area and high soil gas radon concentration (>230 kBq m^{-3}) has drawn the attention of previous researchers[28,29] to study the distribution of ^{222}Rn over the lithologies. Often, occurrences of high background radiation have been associated with high radon concentration.[30,31] However, a survey of literature revealed there has been no data regarding the radioactivity of the soil in the area and delineation of the activities across the lithologies.

This study is set out to achieve 2 main objectives. They are (i) to determine the activity concentrations of gamma-emitting radionuclides (^{238}U, ^{232}Th, and ^{40}K) across the different lithologies and (ii) to evaluate the associated radiation hazards. The data and information obtained from this study will serve as a useful tool for planning purposes for limiting the exposure of residents of the area.

Materials and Method

The physical setting of the study area

The study area is a first-generation University in Nigeria located Ile-Ife town of Osun State. The area lies on the Precambrian basement complex of Southwest Nigeria with geographical coordinates between 7°30″ and 7°32″ on the north of the equator and between 4°30″ and 4°33″ on the east of the Greenwich meridian (Figure 1). The elevation is between 220 and 380 m above sea level. It lies within the tropical rain forest region of Nigeria. The area is characterized by 2 distinct seasons—the rainy season usually from April to October, and the dry season from November to March. The annual rainfall ranges between 150 and 3000 mm with varying relative humidity between 40%and 98%.[32] The diurnal temperature varies from 23°C to 39°C with abundant sunshine. The geology of the study area has been extensively studied by Adepelumi et al.[33] The area is underlain with granite gneiss, banded gneiss, and mica schist rock types (Figure 2). The banded gneiss is the oldest recognizable rock. Nearly half of the outcrops in the area are banded gneiss rock types which is the oldest rock and it generally occurs as a low-lying outcrop. It exhibits medium grain and is grayish in color with typical band lines of few millimeters to centimeters in width. There are occurrences of inselbergs forming gentle slope with the surrounding planes which are of granite gneiss rocks with strata of mineral bands. The granite gneiss occupies the northwestern part of the study area while the mica schist runs from the northeast through to the south. Banded gneiss is sandwiched between the granite gneiss and mica schist. The landscape is characterized by a steep slope gradient ranging from about 6% to 12%. The bedrock weathered into thick regolith overburden materials that vary from lateritic clay, clayey sand to sand.[34]

Samples collection and preparation

Seven soil samples were spatially collected from each of the 3 lithologies in the study area making a total of 21 soil samples.

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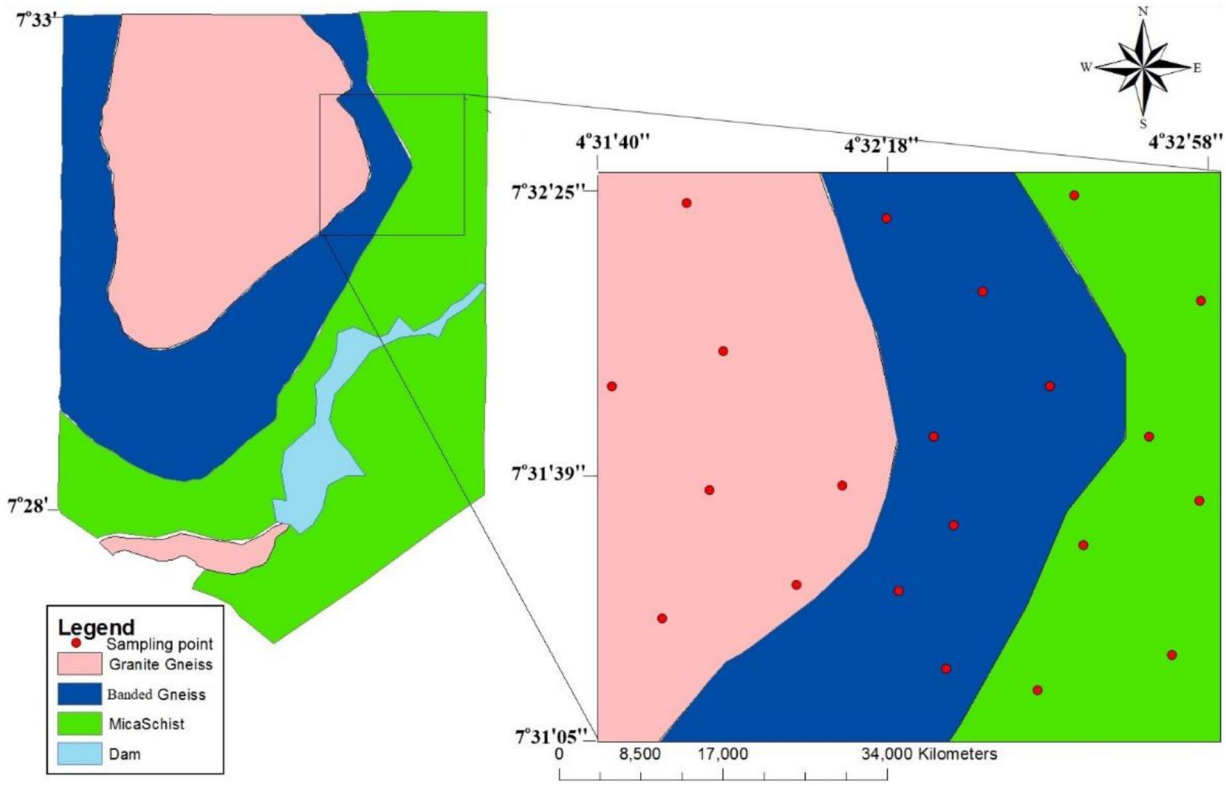


Figure 2. Geological map of the study area showing the 3 lithological units and sampling points.

The samples were collected at approximate depths of 15 cm. The sample from each location was collected at the edges of a 1 m^2 land area and also at the center to obtain a representative sample. The samples from all the locations were collected in different polythene bags to avoid sample contamination and labeled appropriately for ease of identification. The samples were thereafter transported to the laboratory for further preparation before spectrometric measurement. At the Laboratory, organic materials were removed from the soil samples and then oven-dried at a temperature of 110°C until a uniform weight was achieved. The dried soil samples were thereafter pulverized and sieved using a 0.2 mm mesh and 200 g of each soil sample was weighted into 7 cm × 9 cm plastic containers. The containers were sealed hermetically with adhesive tapes to prevent the escape of radiogenic gases and then kept for 28 days for the parent radionuclides present in the samples to achieve secular equilibrium with their respective progenies.

Activity concentrations measurement using CsI(Tl) detector

Spectrometric analysis of the soil samples was carried out using a Thallium-doped Cesium Iodide detector at the Department of Physics and Engineering Physics, Obafemi Awolowo University, Ile-Ife. The spectrometric system comprises of the detector, a URSA II Multichannel Analyser, and a custom-made Pb-shield array. The schematic diagram showing the experimental set-up is shown in Figure 3. A reference soil standard (IAEA S-375) with known activity from the International Atomic Energy Agency, Vienna, Austria, counted at the same geometry as the samples, was used for the efficiency and energy calibrations of the detector. The efficiency of the detector across the energy spectrum is presented in Figure 4. The IAEA 375 is a homogenized top soil (<20 cm) of 0.3 mm grain size.[30,31] The reference material contains the following radionuclides: ^{40}K, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{129}I, ^{134}Cs, ^{137}Cs, ^{226}Ra, ^{232}Th, ^{228}Th, ^{234}U, ^{238}U, ^{238}Pu, $^{239+240}Pu$, and ^{241}Am.[36,37] Typically, spectral resolution of about 7.3% full width at half maximum, FWHM at 662 keV of ^{137}Cs is specified by detector manufacturers.[38] To minimize statistical uncertainty, the soil samples were counted for 36 000 seconds. The ambient background count was carried out by counting the empty sample container with the same geometry as the sample container used in the actual measurement. The obtained count was subtracted from the sample count to determine the net count due to the radionuclide content of the soil samples. The activity concentrations of ^{238}U and ^{232}Th were determined from 352 KeV gamma energy of ^{214}Pb and 583 KeV gamma energy of ^{208}Tl respectively since radioactive equilibrium has been achieved between the parent radionuclides and their daughters. The activity of non-series ^{40}K was determined from the photopeak corresponding to 1460 KeV. The specific activity concentration of each radionuclide in the samples was obtained using the comparative method of analysis. In this method, the activity concentration of the samples is determined by comparing the relevant peak area in the sample

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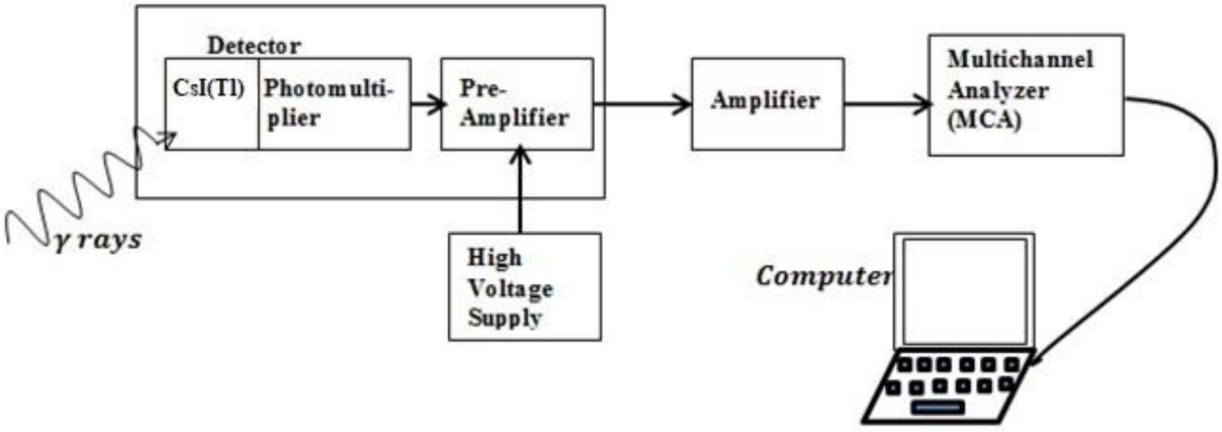


Figure 3. Schematic diagram showing the experimental set-up.

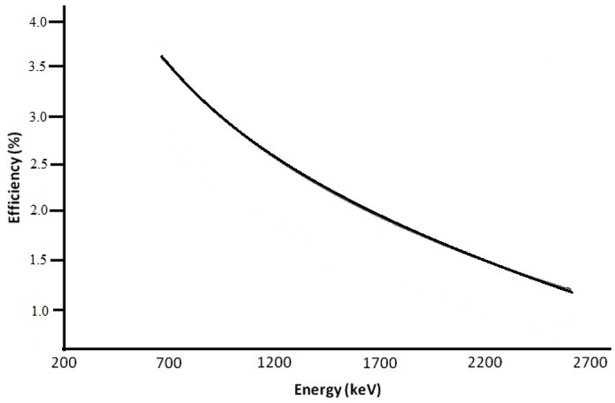


Figure 4. Efficiency of the CsI (Tl) detector across different energies using the IAEA 375 soil standard.

with area of similar photopeak in a reference standard with already known activity concentration. The activity concentrations of the radionuclides in a sample counted on a detector with a given efficiency for the gamma line of interest were evaluated using equation (1):

$$A(Bq\,kg^{-1}) = kn_s \quad (1)$$

where

$$k = \left(\gamma.\varepsilon.t.M_s\right)^{-1} \quad (2)$$

where n_s is the net count rate under the corresponding photopeak, γ is the gamma energy, ε is the detector efficiency at that energy, t is the total counting time (36 000 seconds), and M_s is the mass of sample in kg. In comparing the unknown activity of the sample A_s with the known activity of the reference soil standard A_{st}, equation (3) below was employed.

$$A_s = n\frac{A_{st}.M_{st}}{n_{st}.M_s} \quad (3)$$

Since the counting geometry and detector efficiency, gamma fractional abundance and the counting time are the same for both the standard and the sample. The subscripts st and s represents standard and sample respectively.

The minimum detectable activity concentration of the soil samples which is defined as lower limit of detection (LLD) was estimated using equation (4).[39]

$$LLD = 4.65\left(\frac{C_{n,b}^{1/2}}{t_b}\right)F \quad (4)$$

where $C_{n,b}$ is the net background count of a corresponding peak, F is the conversion factor from counts per second (cps) to Bq kg^{-1} and t_b total time for counting of background radiation in seconds (s). The LLD values of 0.03, 0.01, and 0.10 Bq kg^{-1} were obtained for ^{238}U, ^{232}Th, and ^{40}K respectively.

Evaluation of radiation hazard indices

Radium equivalent activity

The radium equivalent activity is an index that is used to express the activity due to the radionuclides present in the soil with a single value. Beretka and Mathew,[40,41] suggested the expression to evaluate the radium equivalent activity given in equation (5).

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (5)$$

where A_{Ra}, A_{Th}, and A_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K respectively. The index is usually estimated based on the assumption that activity values of 370 Bq kg^{-1} for ^{226}Ra, 259 Bq kg^{-1} for ^{232}Th, and 4810 Bq kg^{-1} for ^{40}K all produce the same gamma dose rate.

Gamma absorbed dose rate

The gamma absorbed dose rate is an index used to quantify the external absorbed gamma dose rate in the air due to the presence of radionuclides in the soil at a height of 1 m above the ground level. It is estimated using the activity concentration

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values of ^{238}U, ^{232}Th, and ^{40}K in equation (6) given by UNSCEAR[3]:

$$D_\gamma\left(nGy\,h^{-1}\right) = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad (6)$$

where A_U, A_{Th}, and A_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively.

Annual effective dose equivalent

The annual outdoor effective dose is estimated from the absorbed gamma dose rate in the air[42-44] using equation (7).

$$D_{eff}\left(mSv\,y^{-1}\right) = D_\gamma\left(nGy\,h^{-1}\right)\times 8766\left(h\,y^{-1}\right) \times 0.7\left(Sv\,Gy^{-1}\right)\times O.F \quad (7)$$

where 8766 is estimated hours per year, 0.7 is a conversion factor from Gy to Sv and $O.F$ is the occupancy factor. 0.2 is taken as an occupancy factor outdoor.[3] Equation (7) is compressed as:

$$D_{eff(out)}\left(mSv\,y^{-1}\right) = D_\gamma \times 1.23\times 10^{-3} \quad (8)$$

External hazard index

The external hazard index is an index which is commonly used to limit absorbed gamma radiation dose to 1.5 mSv y^{-1}. The index is evaluated using the following relation based on infinitely thick walls without windows and doors[45]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \le 1 \quad (9)$$

H_{ex} values less than unity are considered as not posing significant radiation hazard.

Excess lifetime cancer risk

The Excess Lifetime Cancer Risk (ELCR) is an index that describes the probability of risk of cancer to the population as a result of exposure from radiation from the soil in an environment.[46] This index is generally used to evaluate the probability of cancer development over a lifetime period, considering 70 years as average life duration for humans at a given exposure level.[46] The ELCR can also be described as a value that represents the number of expected extra cancer cases in a given population that has been exposed to ionizing radiation at a certain dose level. The ELCR is estimated using equation (10):

$$ELCR = D_{eff} \times DL \times RF \quad (10)$$

where D_{eff} is the annual effective dose equivalent, DL is the duration of life (70 years), and RF is the risk factor, 0.05 Sv^{-1}.[47]

Statistical analysis

Statistical analysis was performed to separate the means values of ^{238}U, ^{232}Th, and ^{40}K in soil overlying the 3 lithologies. The data were subjected to Analysis of Variance (ANOVA) and the means were separated using Tukey test. All analyses were carried out using Minitab, version 17.0 and Excel softwares.

Results

The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil overlying the 3 lithologies in the study area: granite gneiss, banded gneiss, and mica schist with their radium equivalent activities are presented in Table 1. As presented in the table, the activity concentrations of ^{238}U in granite gneiss, banded gneiss, and mica schist range from 34.1 ± 3.5 to 43.1 ± 4.5 Bq kg^{-1}, 25.8 ± 2.7 to 43.9 ± 4.5 Bq kg^{-1}, and 12.2 ± 1.3 to 26.5 ± 2.7 Bq kg^{-1} respectively. Their respective mean values are 37.7 ± 2.9, 31.9 ± 6.3, and 21.2 ± 4.1 Bq kg^{-1} respectively. The overall average activity concentration of ^{238}U is 30.3 ± 8.2 Bq kg^{-1}. The values of activity concentrations for ^{232}Th in soil samples range from 3.0 ± 0.5 to 3.7 ± 0.6 Bq kg^{-1}, 2.2 ± 0.4 to 3.6 ± 0.6 Bq kg^{-1}, and 0.9 ± 0.2 to 2.2 ± 0.4 Bq kg^{-1} for granite gneiss, banded gneiss, and mica schist respectively. Their average values are 3.2 ± 0.2, 2.8 ± 0.4, and 1.7 ± 0.4 Bq kg^{-1} respectively, while the overall average activity concentration of ^{232}Th is 2.6 ± 0.7 Bq kg^{-1}. The activity concentrations of ^{40}K range from 209.7 ± 7.0 to 318.8 ± 10.6 Bq kg^{-1}, 220.6 ± 7.4 to 265.2 ± 8.9 Bq kg^{-1}, and 114.3 ± 3.8 to 272.9 ± 9.1 Bq kg^{-1} for granite gneiss, banded gneiss, and mica schist range respectively. Their respective average activities are 245.6 ± 35.2, 242.1 ± 12.9, and 196.7 ± 44.4 Bq kg^{-1} respectively with the overall average activity of 228.1 ± 40.3 Bq kg^{-1}. The mean values of the concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil overlying the 3 lithologies were significantly different ($P < .05$), but the mean values obtained under Granite Gneiss and Banded Gneiss were similar ($P > .05$). The differences in the means occurred in soil overlying Mica Schist for ^{232}Th, and ^{40}K, but were all similar for ^{40}K. The world average values of the activity concentrations of the radionuclides (^{40}K ^{238}U, ^{232}Th) in the soil of the study area are presented in Table 1. The spatial distribution of the activities of ^{40}K ^{238}U, ^{232}Th, and the radium equivalent activity in the study area is presented in Figures 5 to 8. The Pearson's correlation coefficient obtained for the 3 radionuclide pairs are .60, .62 and .98 for $^{40}K/^{238}U$, $^{40}K/^{232}Th$, and $^{238}U/^{232}Th$ respectively.

The radium equivalent activities for the soil samples obtained from the 3 lithologies were evaluated based on the activities of ^{238}U, ^{232}Th, and ^{40}K using equation (1). The radium equivalent activities of the soil samples overlying the granite gneiss, banded gneiss, and mica schist lithologies range from 55.4 to 69.3 Bq kg^{-1}, 47.3 to 67.3 Bq kg^{-1}, and 22.3 to 46.3 Bq kg^{-1} with average values of 61.2 ± 4.8, 54.5 ± 7.1, and

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Table 1. Activity concentrations of radionuclides and their radium equivalent activities in the granite gneiss (GG), banded gneiss (BG), and mica schist (MS) lithologies.

SAMPLE ID	^{40}K (BQ KG^{-1})	^{238}U (BQ KG^{-1})	^{232}TH (BQ KG^{-1})	RAEQ (BQ KG^{-1})
GG1	318.8 ± 10.6	37.3 ± 3.9	3.2 ± 0.6	66.4
GG2	271.1 ± 9.1	43.1 ± 4.5	3.7 ± 0.6	69.3
GG3	242.7 ± 8.1	39.9 ± 4.1	3.1 ± 0.5	63.0
GG4	233.2 ± 7.8	34.6 ± 3.6	3.0 ± 0.5	56.9
GG5	226.4 ± 7.6	37.1 ± 3.8	3.0 ± 0.5	58.9
GG6	209.8 ± 7.0	37.6 ± 3.9	3.3 ± 0.6	58.4
GG7	216.9 ± 7.2	34.1 ± 3.5	3.2 ± 0.5	55.4
Mean (GG)	245.6a ± 35.2	37.7a ± 2.9	3.2a ± 0.2	61.2a ± 4.8
BG1	265.2 ± 8.9	37.2 ± 3.8	3.1 ± 0.5	62.0
BG2	246.7 ± 8.2	26.4 ± 2.7	2.4 ± 0.4	48.8
BG3	237.0 ± 7.9	43.9 ± 4.5	3.6 ± 0.6	67.3
BG4	239.8 ± 8.0	25.8 ± 2.7	2.2 ± 0.4	47.3
BG5	235.0 ± 7.9	26.3 ± 2.7	2.4 ± 0.4	47.8
BG6	220.6 ± 7.37	33.4 ± 3.5	2.8 ± 0.5	54.4
BG7	250.7 ± 8.37	30.4 ± 3.1	2.8 ± 0.5	53.7
Mean (BG)	242.1a ± 12.9	31.9a ± 6.3	2.8a ± 0.4	54.5a ± 7.1
MS1	223.6 ± 7.5	22.9 ± 2.4	1.9 ± 0.3	42.8
MS2	180.8 ± 6.0	26.5 ± 2.7	2.2 ± 0.4	43.5
MS3	188.5 ± 6.3	22.8 ± 2.4	1.8 ± 0.3	39.9
MS4	189.8 ± 6.3	20.7 ± 2.1	1.7 ± 0.3	37.7
MS5	206.7 ± 6.9	21.0 ± 2.2	1.7 ± 0.3	39.2
MS6	114.3 ± 3.8	12.2 ± 1.3	0.9 ± 0.2	22.3
MS7	272.9 ± 9.1	22.7 ± 2.3	1.8 ± 0.3	46.3
Mean (MS)	196.7a ± 44.4	21.2b ± 4.1	1.7b ± 0.4	38.8b ± 7.3
Overall mean	228.1 ± 40.3	30.3 ± 8.2	2.6 ± 0.7	51.5 1 ± 1.4
World average	420	33	45	-

Means that do not share a letter are significantly different.

38.8 ± 7.3 Bq kg^{-1} respectively. Table 2 presents a comparative study of the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K obtained in this study with previous studies by other researchers in Nigeria.

The radiation hazard indices for granite gneiss, banded gneiss, and mica schist were evaluated and presented in Table 3. The absorbed gamma dose rate for granite gneiss lithology varies from 26.7 to 33.5 nGy h^{-1} with an average value of 29.6 nGy h^{-1}. For banded gneiss, the value ranges from 23.2 to 30.1 nGy h^{-1} with an average value of 26.5 nGy h^{-1}. Also, the value ranges from 10.9 to 23.0 nGy h^{-1} with an average value of 19.0 nGy h^{-1} for mica schist. Their means were significantly different at 5% level of significance, with both Granite and Banded Gneisses giving similar ($P > .05$) absorbed dose, annual effective dose, external hard index, and excess lifetime cancer risk. However, their values were significantly lower with Mica Schist

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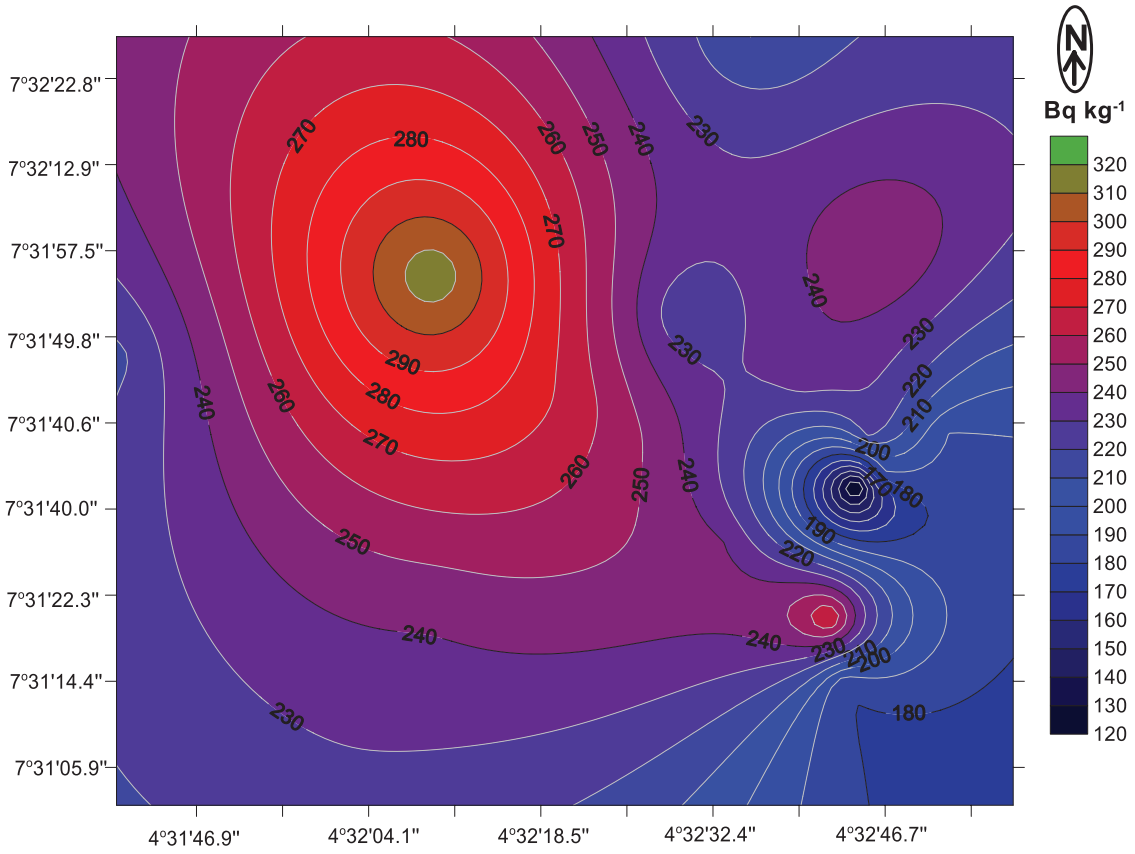


Figure 5. Spatial distribution of ^{40}K within the study area.

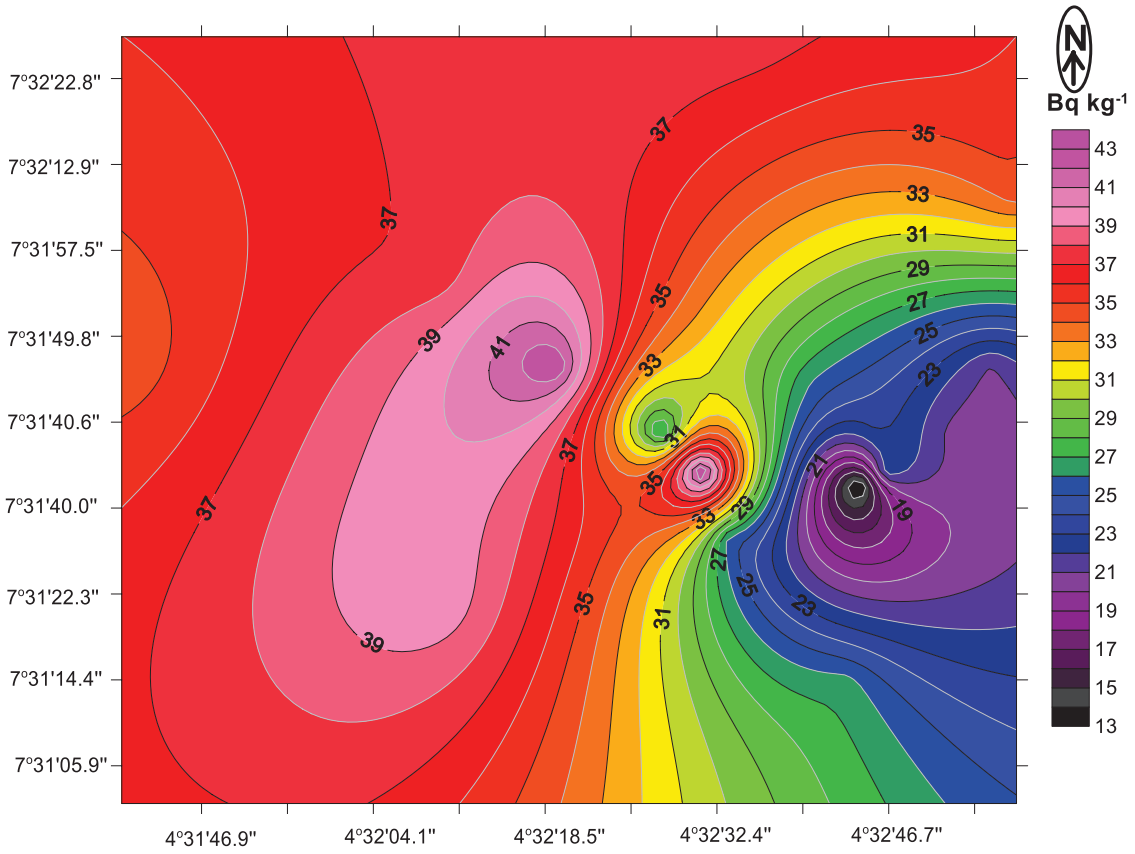


Figure 6. Spatial distribution of ^{238}U within the study area.

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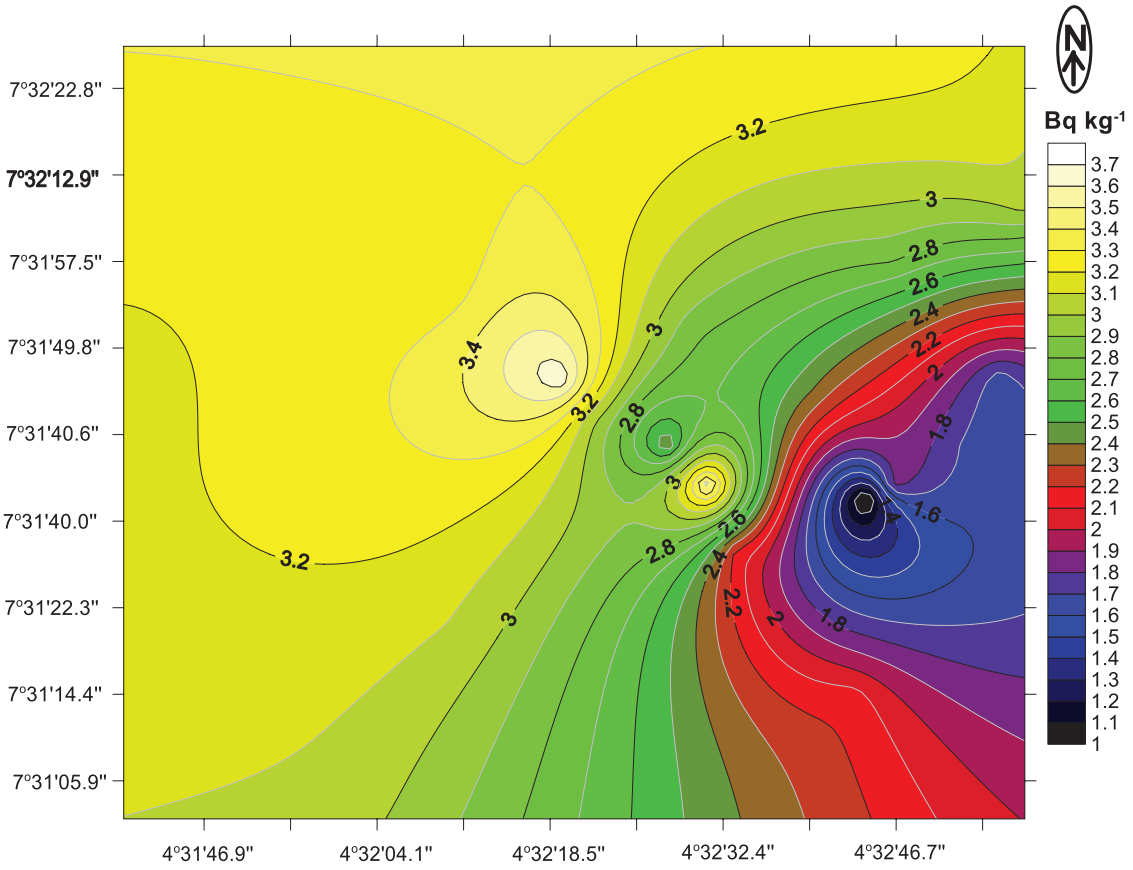


Figure 7. Spatial distribution of ^{232}Th within the study area.

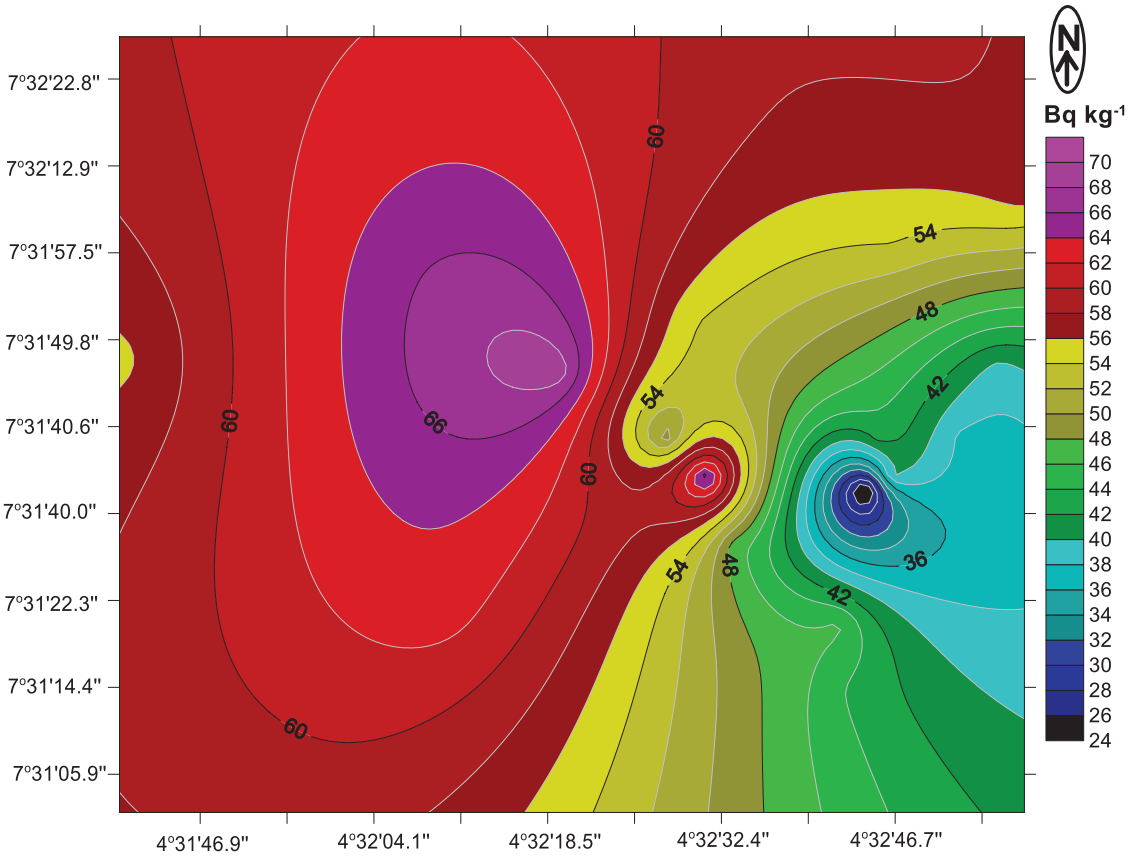


Figure 8. Spatial distribution of radium equivalent activity within the study area.

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Table 2. Comparison of activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in present study with similar studies in Nigeria.

REGION	^{238}U (BQ KG^{-1})	^{232}TH (BQ KG^{-1})	^{40}K (BQ KG^{-1})	REFERENCE
Owo, Ondo State	64.6	110.2	1190.1	Aladeniyi et al[48]
Orlu, Imo State	4.2	1.6	134.1	Mbonu and Ben[49]
Igbokoda, Ondo State	11.5	9.9	194.7	Ajanaku et al[50]
Ado-Odo, Ogun State	40.4	94.4	134.2	Joel et al[51]
Esan Land, Edo State	2.1	6.9	57.8	Popoola et al[52]
Benue State	22.5	8.9	164.6	Kungur et al[53]
Nigeria (All 6 geopolitical zones of Nigeria)	33.9	12.4	73.3	Farai et al[54]
Ile-Ife, Osun State	30.3	2.6	228.1	Present Study

Table 3. Radiation doses and health hazard index in granite gneiss (GG), banded gneiss (BG), and mica schist (MS) lithologies.

SAMPLE ID	ABSORBED DOSE (NGY H^{-1})	ANNUAL EFFECTIVE DOSE (MSV Y^{-1}) OUTDOOR	EXTERNAL HAZARD INDEX (H_{EX})	EXCESS LIFETIME CANCER RISK (10^{-3})
GG1	32.5	0.04	0.18	0.140
GG2	33.5	0.04	0.19	0.140
GG3	30.4	0.04	0.17	0.140
GG4	27.6	0.03	0.15	0.105
GG5	28.4	0.03	0.16	0.105
GG6	28.1	0.03	0.16	0.105
GG7	26.7	0.03	0.15	0.105
Mean (GG)	29.59a	0.04a	0.17a	0.120a
BG1	30.1	0.04	0.17	0.140
BG2	23.9	0.03	0.13	0.105
BG3	32.3	0.04	0.18	0.140
BG4	23.2	0.03	0.13	0.105
BG5	23.4	0.03	0.13	0.105
BG6	26.3	0.03	0.15	0.105
BG7	26.2	0.03	0.15	0.105
Mean (BG)	26.50a	0.03a	0.15a	0.115a
MS1	21.0	0.03	0.12	0.105
MS2	21.1	0.03	0.12	0.105
MS3	19.5	0.02	0.11	0.070
MS4	18.5	0.02	0.10	0.070
MS5	19.3	0.02	0.11	0.070
MS6	10.9	0.01	0.06	0.035
MS7	23.0	0.03	0.13	0.105
Mean (MS)	19.04b	0.02b	0.10b	0.080b
Overall mean	25.0 ± 5.4	0.03 ± 0.01	0.14 ± 0.03	0.11 ± 0.03

Means that do not share a letter are significantly different.

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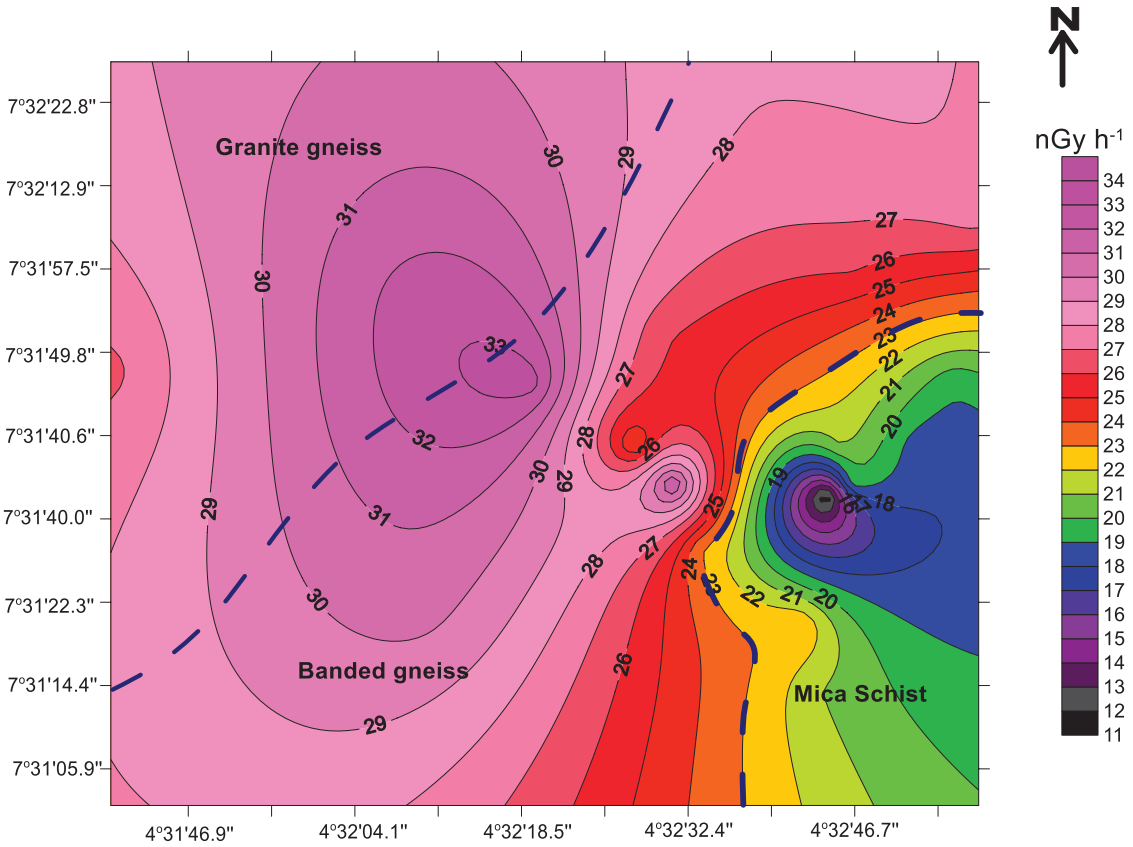


Figure 9. Interpolated estimation map of the absorbed gamma dose rate.

($P < .05$), when compared to those observed at Granite Gneiss and Banded Gneiss. A contour map showing the spatial distribution of the absorbed gamma dose rate in the study area is presented in Figure 9.

The average outdoor annual effective dose due to gamma radiation from the radionuclides in the soil is estimated to be 0.04, 0.03, and 0.02 mSv y^{-1} for granite gneiss, banded gneiss, and mica schist respectively. Also, the evaluated external hazard index for granite gneiss, banded gneiss, and mica schist are 0.17, 0.15, and 0.10 respectively.

The evaluated excess lifetime cancer risk for granite gneiss, banded gneiss, and mica schist are 0.120×10^{-3}, 0.115×10^{-3}, and 0.080×10^{-3} respectively. These values correspond respectively to the probabilities 1.2, 1.15, and 0.8 persons in a population of 10 000 developing cancer with 70 years considered as average lifetime duration.

Discussion

The average value of activity concentration of ^{238}U obtained for soil samples collected from the granite gneiss lithologies exceeds the world average value of 33 Bq kg^{-1},[1,3] whereas, that of banded gneiss and mica schist are below. This is attributable to high uranium mineralization of granitic rocks.[55] Generally, the average activity concentrations for ^{238}U, ^{232}Th, and ^{40}K across all the lithologies are below their respective world average values. The activity concentration of ^{232}Th across the area is generally much lower to the world average value with the ratio of about (1:17). The results of the activity concentration of radionuclides in the 3 lithologies exhibit low values of standard deviation indicating that each of the radionuclides is uniformly distributed across each of the lithologies. Also, the spatial spread of the radionuclides across the 3 lithologies as presented in Figures 5 to 7 shows minimum variability. The spatial gradient of 40K (Figure 5) clearly delineates 2 regions of concentrations: $180 \le K \le 230$ Bq kg^{-1} which falls mostly on the south east of the study area dominated by mica schist and $230 \le K \le 300$ Bq kg^{-1} in the north west area dominated by granite gneiss. Similarly, the spatial gradient of ^{238}U (Figure 6) shows that mica schist region exhibits lowest range of concentrations, typically between 15 Bq kg^{-1} and 31 Bq kg^{-1}. The granite gneiss and banded gneiss regions have concentration distributions between 31 Bq kg^{-1} and 41 Bq kg^{-1}. The spatial distribution of ^{232}Th (Figure 7) shows spatial concentration gradient with the granite gneiss, banded gneiss and mica schist lithologies exhibiting highest, medium and lowest concentrations respectively.

Comparison of the level of radionuclide concentrations obtained in this study with similar studies previously carried out in Nigeria by other researchers is shown in Table 2. The study revealed that average ^{238}U concentration in this study is higher than those obtained in parts of Imo, Ondo, Edo, and Benue[48-54] States. The value however compares with the

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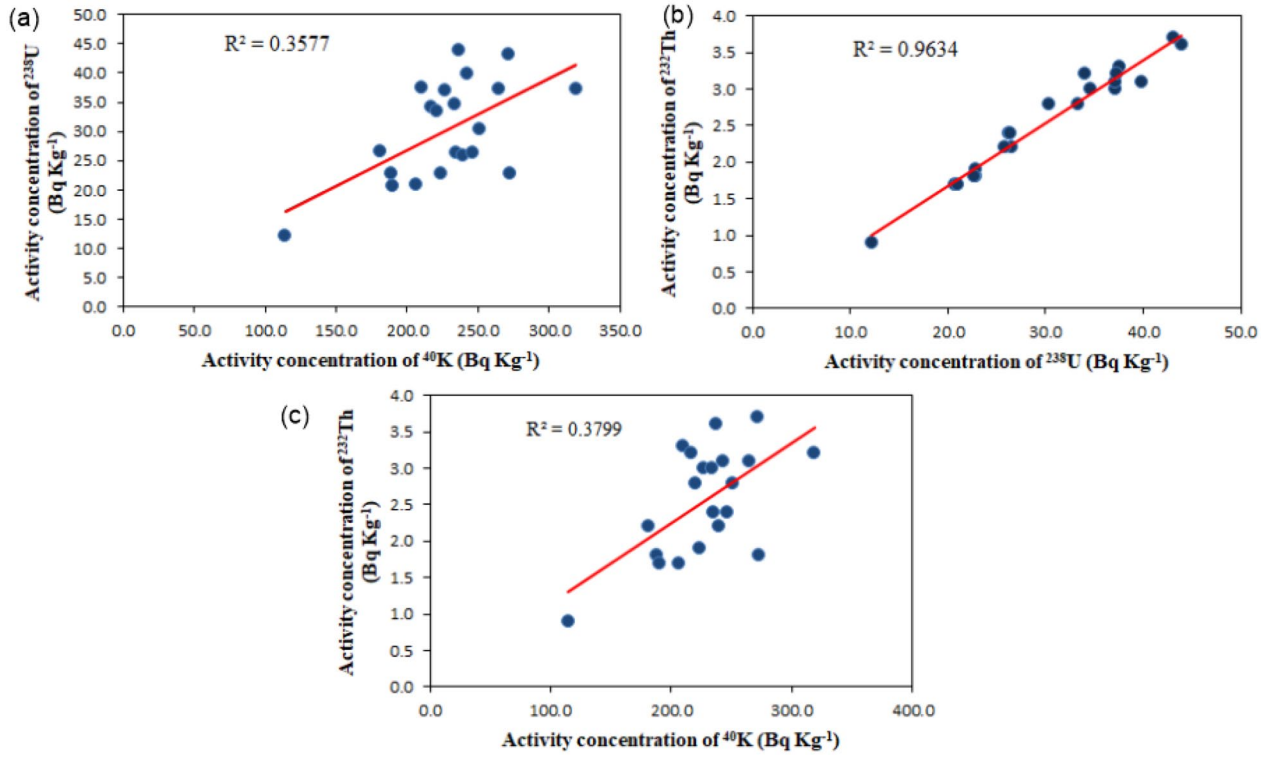


Figure 10. Correlation plots of (a) ^{238}U against ^{40}K, (b) ^{232}Th against ^{238}U, and (c) ^{232}Th against ^{40}K.

average value obtained for the 6 geopolitical zones of Nigeria.[54] The average concentration of ^{232}Th obtained in this study is lower than those obtained in other parts of the country except for Imo State.[48-54] However, ^{40}K average concentration in the present study is higher than those obtained in most part of the country except for Ondo State.

Test of correlation between the 3 radionuclide pairs: $^{40}K/^{238}U$, $^{40}K/^{232}Th$, and $^{238}U/^{232}Th$ as presented in Figure 10 revealed a strong positive correlation which is significant at .01 level (2-tailed). This also indicates uniform distribution of the radionuclides in the soils of the study area.

The granite gneiss lithology exhibits the highest radium equivalent activity. The average radium equivalent activity for the 3 lithologies is such that $Ra_{eq(granite\ gneiss)} > Ra_{eq(banded\ gneiss)} > Ra_{eq(mica\ schist)}$. The Ra_{eq} values for the 3 lithologies are much less than the recommended limit of 370 Bq kg^{-1} for building materials. The implication is that the soil in all the lithologies is suitable for use in building materials. Comparison of interpolated map for ^{238}U in Figure 6 with the interpolated map of radium equivalent activity in Figure 8 shows that ^{238}U is the major contributor to the radium equivalent activity across the area as the contour lines in both maps exhibit similar trend.

The average outdoor annual effective dose due to gamma radiation from the radionuclides in the soil is estimated to be 0.04, 0.03, and 0.02 mSv y^{-1} for granite gneiss, banded gneiss, and mica schist respectively. These values are much less than the recommended limit of 1 mSv y^{-1} .[42] Also, the evaluated external hazard index for granite gneiss, banded gneiss, and mica schist are 0.17, 0.15, and 0.10 respectively. These values are much less compared to the maximum permissible level of 1. This implies that exposure to gamma radiation from the soil is of insignificant consequence to health. The gamma radiation absorbed dose rate within the geologic areas is of the order: $\gamma_{granite\ gneiss} > \gamma_{banded\ gneiss} > \gamma_{mica\ schist}$. The delineated gamma radiation dose rate of the area shows that granite gneiss lithology has dose rates between the range of 29 and 33 nGy h^{-1}, banded gneiss lithology has between 23 and 32 nGy h^{-1} and mica schist lithology has between 11 and 23 nGy h^{-1}. The gamma dose rate values obtained for all the soil samples in all the lithologies are below the world average value of 60 nGy h^{-1}.[3]

The evaluated excess lifetime cancer risk for granite gneiss, banded gneiss, and mica schist are 0.120×10^{-3}, 0.115×10^{-3}, and 0.080×10^{-3} respectively. These values correspond respectively to the probabilities 1.2, 1.15, and 0.8 persons in a population of 10 000 developing cancer with 70 years considered as average lifetime duration. These values are less than the average value of 0.2×10^{-3} [56] and 0.4×10^{-3} [57] obtained in similar studies within Ekiti State—a basement complex region in Southwest Nigeria and across 6 Southwest States of Nigeria respectively.

Conclusion

A pilot study to evaluate the distribution of ^{238}U, ^{232}Th, and ^{40}K in soil across 3 geological formations within Obafemi Awolowo University, Ile-Ife, Nigeria has been carried out. The average activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in all the lithologies were found to be below the world average value except for

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that of ^{238}U in the granite gneiss lithology. The obtained values for the radiation hazard indices were also found to be below the recommended limits. The study showed that lithologies on which soils are overlying is a strong contributing factor to the concentrations of ^{238}U, ^{232}Th, and ^{40}K found in them. Also, the absorbed dose rate, annual effective dose, external hard index, and excess lifetime cancer risk were also found to vary across the lithologies. This study, however, provides information on the distribution of external gamma radiation from the soil in the study area. It can be concluded on the basis of the evaluated radiation hazard indices that the soil in the study area do not pose significant health hazard to the members of the public.

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Author contribution

Conceptualization: DTE, RIO and MKS; Methodology: DTE, JO, MA, YA; Formal analysis and investigation: DTE, YA, MA and JO; Writing - original draft preparation: DTE and YA; Writing - review and editing: DTE, YA and JO; Funding acquisition: Not Applicable; Resources: DTE; Supervision: MKS and RIO.

Ethics Approval

Ethical clearance was obtained from UI/UCH ethics review committee of the University of Ibadan, Ibadan (Protocol number: UI/EC/16/0352).

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