Quantification of radiological hazards associated with natural radionuclides in soil, granite and charnockite rocks at selected fields in Ekiti State, Nigeria

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ABSTRACT

Assessment of activity levels of radionuclides that exist in soil, granite, and charnockite rock samples is very crucial because it exhibits an enhanced elemental concentration of uranium (U) and thorium (Th) contributing higher natural background activity than usual in the environment and it may cause health risk to human health through the external and internal exposure. This study determined the radioactivity levels of ^{238}U, ^{232}Th, and ^{40}K radionuclides in soil, granite, and charnockite rock samples collected from selected fields in Ekiti State, Nigeria using Caesium iodide CsI(Tl) scintillation gamma spectrometer. It also evaluated indices of the radiological parameters consisting of radium equivalent activity (Ra$_{eq}$), absorbed dose rate (D$_R$), annual effective dose equivalent (AEDE), internal hazard index (H$_{in}$), and excess lifetime cancer risk (ELCR). The calculated average activity concentrations of ^{238}U, ^{232}Th, and ^{40}K are 30.40 ± 0.71 Bq kg^{-1}, 3.31 ± 0.05 Bq kg^{-1}, and 222.25 ± 14.72 Bq kg^{-1}, respectively, which were lower than their respective world average values. Comparatively, potassium concentrations in these collected samples have a higher value than concentrations of uranium and thorium (^{40}K > ^{238}U > ^{232}Th). All the evaluated values of the radiological parameters (except D$_R$) of the appraised radionuclides were below the global permissible limits. The granite rocks, charnockite rocks, and soils from Ekiti State in Nigeria do not pose any hazardous risk to humans, but continued monitoring is

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necessary when these materials are used as building materials, which cause long-term radiation exposure.

1. Introduction

Humans are exposed to radiation from a variety of sources, including cosmic rays, naturally occurring radionuclides in rock, soil, water, air, and plants, as well as manmade radioactivity from fallout from nuclear tests and medical procedures [1]. People will always encounter rocks and metals in their daily lives. Rocks and metals are essential for modern civilization and also contain radionuclides, playing a critical role in infrastructure, technology, and industry, from building construction to manufacturing advanced electronic devices. They are indispensable for economic development and technological advancement [2–7]. The majority of the components in houses, such as tiles, kitchenware, and ornamental materials, are created out of rocks. Granite and charnockite play an important role in ornamental materials, building materials, decorative materials, or kitchen counter tops. Igneous rocks (granite and charnockite) are known to contain minerals that can trap naturally occurring radioactive elements like uranium and thorium. When these elements decay, they release radiation in the form of alpha, beta, and gamma particles [8]. Typical granite is chemically composed of 70–77 % silica (SiO_2), 11–13 % alumina (Al_2O_3), 3–5% potash (K_2O), 3–5% soda (Na_2O), 1 % lime (CaO), 2–3% total iron, and less than 1 % magnesia (MgO) and titania (TiO_2) [9]. Whereas, the chemical compounds found in charnockite are Aluminum Oxide (Al_2O_3), CaO, Iron(III) Oxide (FeO), Potassium Oxide (K_2O), MgO, MnO, Sodium Oxide (Na_2O), Phosphorus Pentoxide (P_2O_5), Silicon Dioxide (SiO_2), Titanium Dioxide (TiO_2) [10]. In general, a trace amount of uranium in granite has been evaluated at 1–10 parts per million, while for potassium in crustal rocks is 2.5 % [11]. The types of rocks have an impact on the background radiation on Earth.

When exposed to materials with high concentrations of naturally occurring radionuclides, they have the potential to cause cancer. Therefore, from the perspective of radiation protection and human health safety, monitoring of natural radionuclides in the environment is important [12]. Recently, Oluwatoyin et al. [13] reported that Ekiti State in Nigeria has been under continuous geological investigation by corporate organizations, universities, and private individuals. Over recent years, a number of studies have been conducted to investigate the natural radioactivity and the associated radiological hazards linked to natural radionuclides in soils, sediments, and rocks in Nigeria. In 2021, Laniyan and Adewumi [14] conducted a study on the health risk profile of natural radionuclides in soils, sediments, tailings, and rocks around mining sites in Nigeria. The study found that the Anka, Arufu, and Ijero mining areas had higher concentrations of ^{238}U, ^{232}Th, and ^{40}K radionuclides, as well as radium equivalent activity, compared to the world average. Furthermore, the radiation in all media from these areas posed an excess life cancer risk (ELCR) that exceeded the limit set by UNSCEAR in the 2000 report [15]. Ofomola et al. [16] conducted a study on the environmental risk of natural radioactivity and toxic elements in rocks and soil at a quarry site in Nkalagu, Southeastern Nigeria. They calculated that the average activity concentrations in rock samples for ^{40}K, ^{226}Ra, and ^{232}Th were 302.93 Bq kg^{-1}, 72.09 Bq kg^{-1}, and 46.62 Bq kg^{-1} respectively. Meanwhile, the mean concentrations for soil samples were found to be 180.00, 56.65, and 42.92 Bq kg^{-1} respectively. The authors also confirmed that the mean concentration of the analyzed toxic elements (Fe, Zn, Cr, Pb, and Cd) were all within the permissible limit set by the World Health Organization (WHO) for soil samples. In a recent study conducted by Olabamiji et al., in 2023 [17], the activity concentrations of natural radionuclides and associated elements in Pegmatite rocks were investigated across several states in Nigeria, including Oyo, Kogi, Nasarawa, Niger, and Osun. They concluded that the Pegmatite rocks do not pose any radiation hazards, as the values of the radiological hazard indices and geochemical analysis were within safe limits.

Because natural radiation is the external dose to which most of the world's population is exposed, assessing the effects of gamma radiation is critical. Therefore, this study will serve the primary purpose of assessing and quantifying the radiological hazards linked to naturally occurring radioactive materials in the soil and geological formations within the Ekiti State of Nigeria. The significance of this work is multifaceted: (i) it will help in assessing radiation risks, which ensures the safety of both residents and workers in the Ekiti State of Nigeria. Additionally, (ii) it will contribute to environmental impact assessments for sustainable land use and management, (iii) the findings also will inform geological resource management practices, especially in the construction sector, where granite and charnockite are commonly used as building materials [16]. Therefore, the primary objectives of this work are (i) to assess the concentration of naturally occurring radioactive elements ^{238}U, ^{232}Th, and ^{40}K in granite rocks, charnockite rocks, and soil samples using CsI(Tl) gamma spectrometer, (ii) to examine the radiological risk factors attributed to natural radionuclides by radium equivalent activity (Ra_{eq}), absorbed dose rate (D_R), annual effective dose equivalent (AEDE), internal hazard index (H_{in}), and excess lifetime cancer risk (ELCR) and (iii) to document the baseline data on radiation exposure and background radiation levels of rocks and soils from Ekiti State, Nigeria for future research.

2. Materials and methods

2.1. Sampling sites description

Samples were collected from three selected fields within two Local Government Areas in the Northern part of Ekiti State. These include Moba and Ido-Osi Local Government areas. The area is located within 6 0 27′2‵‵N, 3 0 28′15‵‵E and 7 0 48′0‵‵N, 5 0 10′0‵‵E. The population of the area is about 364,596 according to the Nigeria Population Census 2006. The area covers approximately 427.1 km^2 land area. The study area falls within the Basement Complex rocks geological area of Nigeria. The majority of the rocks in the research region are igneous and metamorphic. The predominant lithologic units are medium-grained migmatite-gneisses (MMG), medium-

grained banded gneisses (MBG), medium-grained granites (MGR), and coarse-grained charnockites (CCH). Top soils are typically lateritic in composition [18]. Fig. 1 shows the geographical map for the study area.

2.2. Samples collection and preparation

Three types of samples were collected in this study: Granite rocks, Charnockite rocks and Soil samples, with a total of twenty samples collected for measurement. The samples were collected from three towns within the two Local Governments Areas, which include: Otun-Ekiti, Ayetoro-Ekiti and Usi-Ekiti (Fig. 1). The rock samples were collected from the un-weathered parts of the parent rocks using chisel and hammer, while the soil samples were collected at the base of the parent rocks. The collection depth for the soil samples is about 0–10 cm after the removal of the debris and dead leaves from the top layer of the soil. The samples collected were packed in labeled polythene bags, and taken to the laboratory for processing and measurements. The coordinates of sample locations in longitude and latitude are shown in Table 1. In the laboratory, the samples were well crushed by a crushing machine and pulverized to fine powder. With the use of methylated spirit and cotton-wool, the machines were well-cleaned after each sample had been processed into powder to avoid contamination between samples. Each sample was then weighed and 300g of each was sealed in an air-tight,
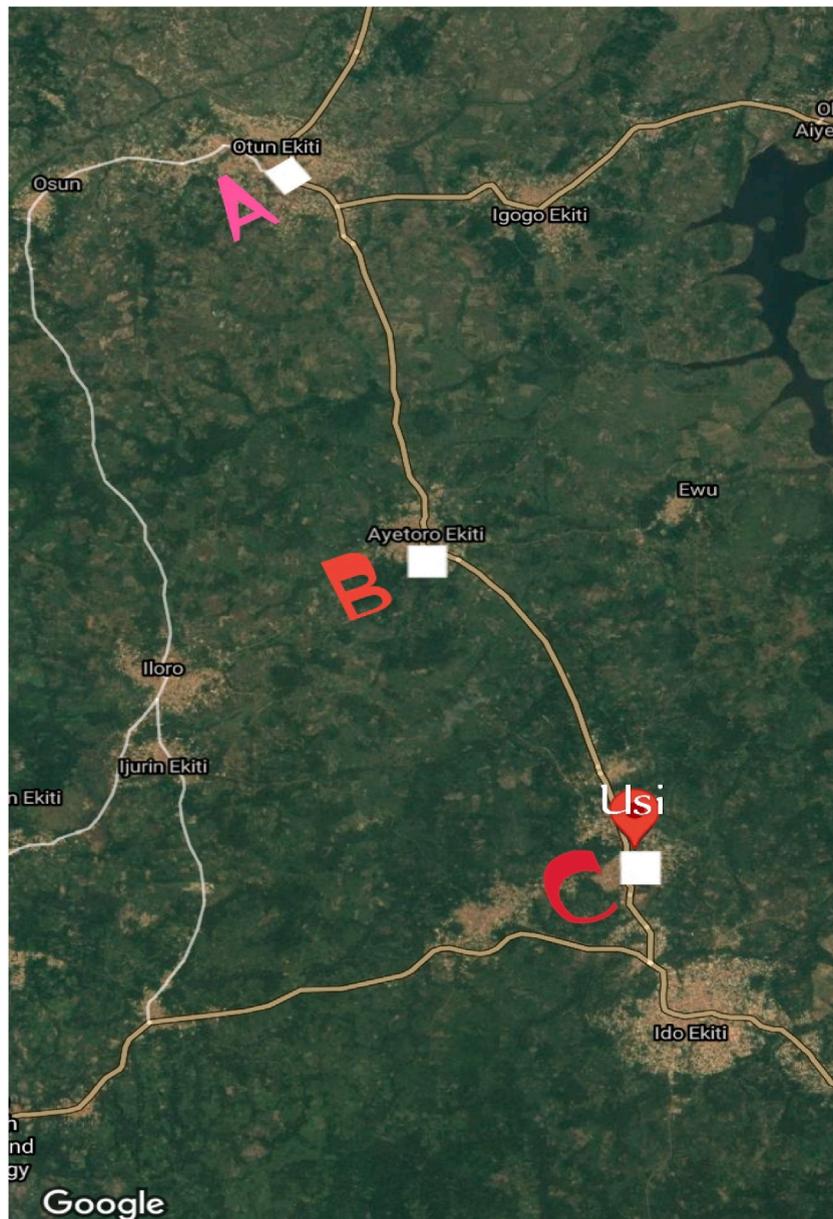

Fig. 1. Geological illustration of study area.

Table 1
Latitude and Longitude of the sample sites.

Sample ID	Location	Sample	Latitude	Longitude
A1.	Ayetoro	Granite	5° 9′15.47″E	7°55′5.96″N
A2.	Ayetoro	Granite	5° 9′15.47″E	7°55′5.96″N
A3.	Ayetoro	Granite	5° 7′50.79″E	7°58′52.41″N
A4.	Ayetoro	Granite	5° 7′56.45″E	7°58′51.29″N
A5.	Ayetoro	Charnockite	5° 8′35.44″E	7°56′11.40″N
A6.	Ayetoro	Charnockite	5° 8′35.37″E	7°56′11.77″N
A7.	Ayetoro	Soil	5° 7′50.79″E	7°58′52.41″N
A8.	Ayetoro	Soil	5° 9′15.47″E	7°55′5.96″N
A9.	Otun	Granite	5° 8′15.18″E	7°57′49.15″N
A10.	Otun	Granite	5° 8′12.58″E	7°57′49.39″N
A11.	Otun	Granite	5° 8′18.36″E	7°57′53.06″N
A12.	Otun	Charnockite	5° 7′52.14″E	7°58′58.01″N
A13.	Otun	Charnockite	5° 7′52.54″E	7°58′58.51″N
A14.	Otun	Charnockite	5° 7′50.79″E	7°58′52.41″N
A15.	Otun	Soil	5° 8′12.58″E	7°57′49.39″N
A16.	Otun	Soil	5° 8′18.36″E	7°57′53.06″N
A17.	Otun	Soil	5° 7′52.54″E	7°58′58.51″N
A18.	Usi	Granite	5°10′28.53″E	7°52′24.08″N
A19	Usi	Granite	5°10′29.18″E	7°52′23.96″N
A20.	Usi	Soil	5°10′28.92″E	7°52′23.70″N

radon impermeable container for a period of 4 weeks (28 days) to allow daughter products to come into radioactive secular equilibrium with their parents. The experimental flowchart for the work is presented in Fig. 2.

2.3. Sample measurements

After 4 weeks of sealing the samples, the samples were then assayed for the activity concentrations of ^{40}K, ^{238}U and ^{232}Th. A Thallium doped Ceasium Iodide (CsI(Tl)) scintillation gamma-ray spectrometer model-URSAII(200137) was used, which is located at the Physics Department, Obafemi Awolowo University, Ile-Ife, Nigeria. The setup consists of two main components; (i) the RAP640 1 × 1 CsI(Tl) detector, which is protected by a specially made lead (Pb) shielding array, and (ii) the electronic counting component, which consists of a high-voltage power supply (HVPS) system, a preamplifier, a converter system (converting analog signal to digital signal) and a multichannel analyser. All the electronic systems are combined in a single unit referred to as the Universal Radiation
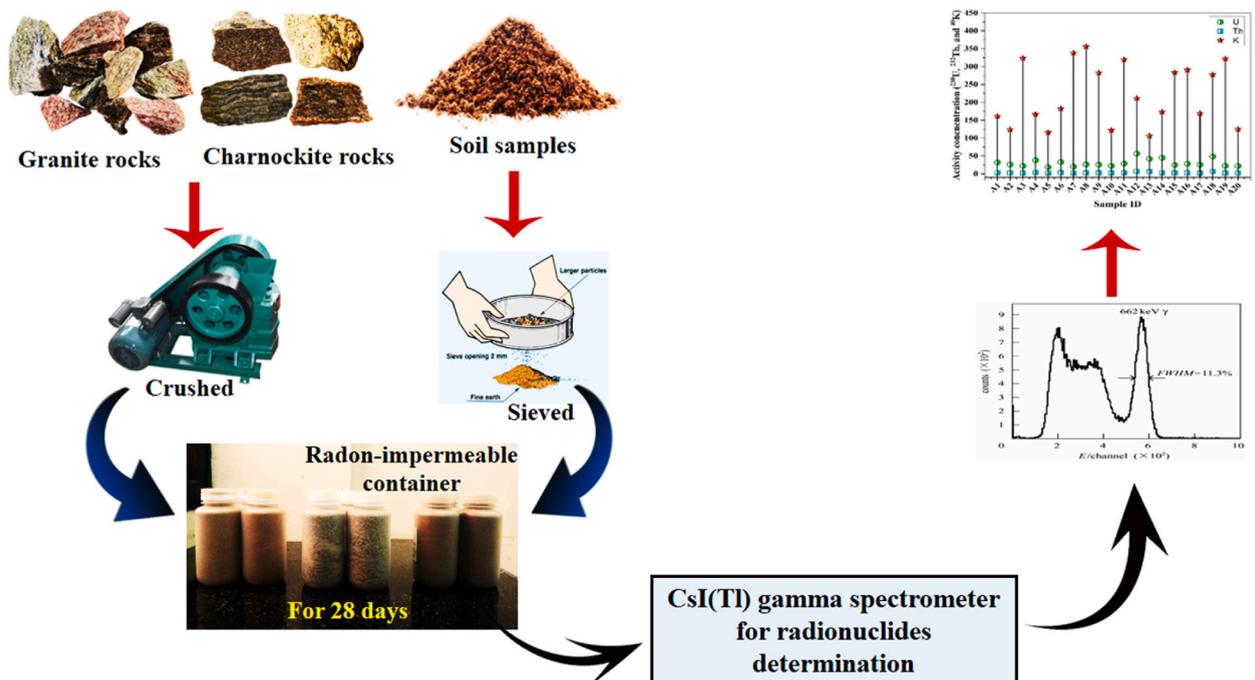

Fig. 2. Experimental flowchart for the study.

Spectrum Analyzer (URSA II). The visual display unit is a laptop computer system. Each sample was counted for 10 hours. The energy calibration of the detector was done with [133]Ba, ^{137}Cs and ^{60}Co point sources. The peak area corresponding to 1.764 MeV of [214]Bi (progeny of [226]Ra) was used to evaluate [238]U, while that of 2.614 MeV of [208]Tl (progeny of [232]Th) was used for [232]Th and the peak area corresponding to 1460 keV of [40]K was used directly [19]. The standard sample used for efficiency calibration has the following activities; 479 Bq kg^{-1} for [40]K, 587 Bq kg^{-1} for [238]U and 11 Bq kg^{-1} for [232]Th. The activity concentration, C (Bq kg^{-1}) of the radionuclides in all samples in this work was computed using the comparative method (Equation (1)).

$$C_x = C_s \frac{M_s(A_x - A_0)}{M_x(A_s - A_0)} \left(Bq\ kg^{-1}\right) \tag{1}$$

Where A_s represents the area of the standard sample, A_x is the area of the measured sample, A_0 is the area of background, M_s is the mass of the standard sample, M_x is the mass of the measured sample, C_x is the activity concentration of the measured sample, C_s is the known activity concentration of the standard sample.

3. Results and discussion

3.1. Activity concentration of ^{238}U, ^{232}Th and ^{40}K

Table 2 depicts the variations of the activity concentrations of [238]U, [232]Th, and [40]K among the measured samples via gamma spectrometry. The average value for [238]U was 30.40 ± 0.71 Bq kg^{-1} with values ranging from 18.63 ± 0.54 Bq kg^{-1} to 56.66 ± 1.16 Bq kg^{-1}. The average activity concentration for [232]Th is 3.31 ± 0.05 Bq kg^{-1} with a range of 1.89 ± 0.04 to 7.03 ± 0.07 Bq kg^{-1}. With a range between 115.40 ± 10.90 and 355.49 ± 19.13 Bq kg^{-1} for [40]K, it has an average value of 222.25 ± 14.72 Bq kg^{-1}. These calculated values are lower than world average values 33, 45, and 420 Bq kg^{-1} for [238]U, [232]Th, and [40]K, respectively [15,19–21]. The maximum activity concentration of [238]U was found in the granite and charnockite samples A4, A12–A14, and A18 when compared to the world recommended limit, while the lowest activity concentration was found in the soil samples as can be observed in Fig. 3. On the other hand, the activity concentrations of [232]Th and [40]K for all the samples were considerably lower than the world average value. The rock samples (granite and charnockite) naturally have a higher concentration of radionuclides.

3.2. Radiological parameters

Radiological parameters such as radium equivalent activity, absorbed dose rate, annual effective dose equivalent, internal hazard index and excess lifetime cancer risk associated with radionuclides [238]U, [232]Th and [40]K, were calculated for collected samples and it shown in Table 3. These collected values are compared with world recommended value proposed by UNSCEAR in 2000.

3.2.1. Radium equivalent activity, Ra_{eq}

Environmental materials such as rocks, soil, and sediments have a non-uniform distribution of the elements [238]U, [232]Th, and [40]K. In order to compare the particular activity of materials having various levels of [238]U, [232]Th, and [40]K, uniformity with regard to radiation

Table 2
Measured activity concentrations (Bq kg^{-1}).

| Samples	^{238}U (Bi – 214) (Bq kg^{-1})	^{232}Th (Tl – 208 (Bq kg^{-1})	^{40}K (Bq kg^{-1})
A1	32.10 ± 0.72	3.14 ± 0.05	160.74 ± 12.87
A2	26.14 ± 0.65	2.79 ± 0.04	123.65 ± 8.86
A3	21.80 ± 0.59	2.33 ± 0.04	323.55 ± 18.25
A4	38.27 ± 0.78	4.37 ± 0.06	165.89 ± 13.07
A5	18.63 ± 0.54	1.89 ± 0.04	115.40 ± 10.90
A6	32.78 ± 0.72	3.70 ± 0.05	182.38 ± 13.70
A7	20.09 ± 0.57	2.03 ± 0.04	337.98 ± 18.66
A8	26.44 ± 0.65	2.64 ± 0.04	355.49 ± 19.13
A9	25.79 ± 0.64	2.70 ± 0.04	282.33 ± 17.05
A10	21.98 ± 0.59	2.26 ± 0.04	121.59 ± 11.19
A11	28.80 ± 0.68	3.00 ± 0.05	319.43 ± 18.14
A12	56.66 ± 1.16	7.03 ± 0.07	211.23 ± 14.75
A13	42.09 ± 0.93	6.11 ± 0.07	106.13 ± 10.45
A14	44.91 ± 0.85	3.23 ± 0.05	173.11 ± 13.35
A15	24.72 ± 0.63	2.72 ± 0.04	283.36 ± 17.08
A16	28.15 ± 0.67	2.86 ± 0.04	290.36 ± 17.33
A17	25.90 ± 0.64	2.17 ± 0.04	168.99 ± 13.19
A18	48.57 ± 1.04	6.60 ± 0.07	277.18 ± 16.90
A19	22.47 ± 0.60	2.42 ± 0.04	321.49 ± 18.20
A20	21.72 ± 0.59	2.29 ± 0.04	124.68 ± 11.33
Mean	30.40 ± 0.71	3.31 ± 0.05	222.25 ± 14.72
World average value	33	45	420
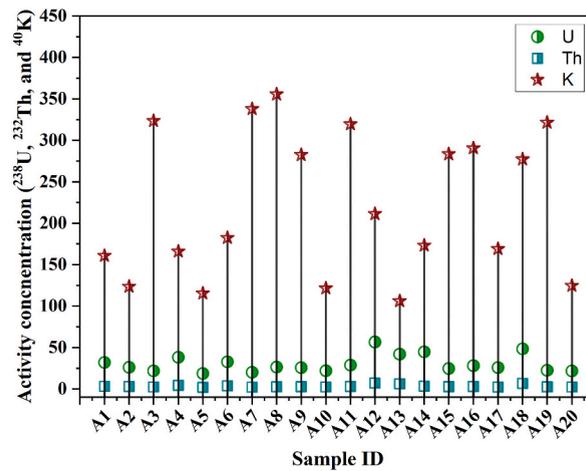
Fig. 3. Variation of the activity concentration of the collected samples.

Table 3
Calculated radiological parameters associated with the radionuclides in collected samples.

Sample ID	Radium equivalent activity (Bq kg^{-1})	Absorbed dose rate D$_R$ (nGy h^{-1})	Annual effective dose equivalent AEDE (mSv y^{-1})	Internal hazard index (H$_{in}$)	Excess lifetime cancer risk ELCR (mSv y^{-1})
A1	48.97	83.76	0.10	0.22	0.36
A2	39.65	65.32	0.08	0.18	0.28
A3	50.05	146.40	0.18	0.19	0.63
A4	57.29	89.50	0.11	0.26	0.38
A5	30.22	57.87	0.07	0.13	0.25
A6	52.11	93.43	0.11	0.23	0.40
A7	49.02	151.45	0.19	0.19	0.65
A8	57.59	162.05	0.20	0.23	0.70
A9	51.39	131.28	0.16	0.21	0.56
A10	34.57	62.22	0.08	0.15	0.27
A11	57.69	148.32	0.18	0.23	0.64
A12	82.98	118.51	0.15	0.38	0.51
A13	59.00	67.39	0.08	0.27	0.29
A14	62.86	94.89	0.12	0.29	0.41
A15	50.43	131.22	0.16	0.20	0.56
A16	54.60	135.81	0.17	0.22	0.58
A17	42.02	83.75	0.10	0.18	0.36
A18	79.35	142.01	0.17	0.35	0.61
A19	50.69	145.90	0.18	0.20	0.63
A20	34.60	63.41	0.08	0.15	0.27
Mean	**52.25**	**108.72**	**0.13**	**0.22**	**0.47**
World Recommended value	**370**	**84**	**0.48**	**1**	**1.16 × 10^{-3}**

exposure has been specified in terms of Ra$_{eq}$ in Bq kg^{-1} [22,23]. This parameter was evaluated with the help of Equation (2):

$$Ra_{eq} = C_U + 1.43\ C_{Th} + 0.077\ C_K \tag{2}$$

Where, C$_U$, C$_{Th}$, and C$_K$ activity concentration of ^{238}U, ^{232}Th, and ^{40}K (Bq kg^{-1}). 1.43 and 0.077 are the conversion factors for ^{232}Th, and ^{40}K. Fig. 4 represents the radium equivalent activity of collected samples. The radium equivalent activity of collected samples is ranged from 30.22 to 82.98 Bq kg^{-1}, with an average value of 52.25 Bq kg^{-1}, which is lower than the world recommended value of 370 Bq kg^{-1} [24,25]. From this obtained result, radiation exposure due to the radionuclides lies within the safety limit. When used as building materials or even as ornamental materials, it is evident that the samples that were collected provide no health risks to consumers.

3.2.2. Absorbed dose rate, D$_R$

The absorbed dose rate was calculated in terms of the gamma-ray exposure for individual due to the radionuclides in the collected granite, charnockite and soil samples using Equation (3) [26,27]:

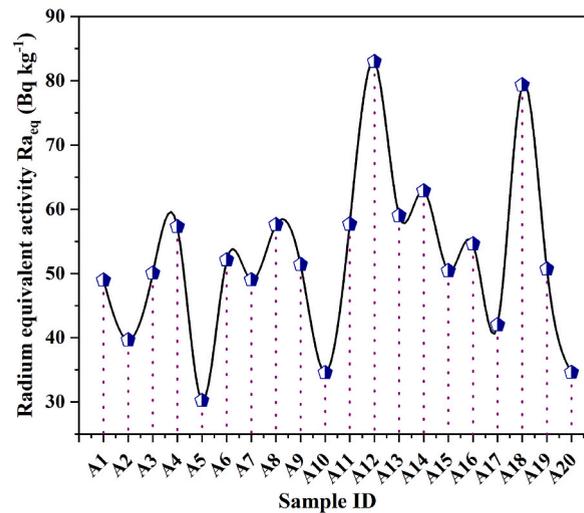$$D_R\ (nGy\ h^{-1}) = 0.462\ C_U + 0.604\ C_{Th} + 0.417\ C_K \tag{3}$$

Fig. 4. Variation of radium equivalent activity for collected samples.

Where, 0.462, 0.604 and 0.417 are the conversion factors for ^{232}Th, and ^{40}K (UNSCEAR, 2000), and C_U, C_{Th}, and C_K are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K (Bq kg^{-1}). With an average value of 108.72 nGy h^{-1}, the calculated dose rate of the collected samples ranged from 57.87 to 162.05 nGy h^{-1}. The world's recommended value for the rate of absorbed dosage is 84 nGy h^{-1}, which is lower than the estimated value from the samples that were collected. It indicates that the collected samples have a higher concentration of radionuclides which cause natural radioactivity. In particular, granite and charnockite samples have a higher absorbed dose rate rather than soil samples at each site. The absorbed dose rate of collected samples is illustrated in Fig. 5.

3.2.3. Annual effective dose equivalent, AEDE

The annual effective dose equivalent was derived from the dose rate absorbed by individuals with the help of a conversion factor, and the occupancy factor. Equation (4) was used to calculate the annual effective dose equivalent [28].

$$AEDE \text{ (mSv y}^{-1}) = D_R \text{ (nGy h}^{-1}) \times 8760 \times 0.8 \times 0.7 \times 10^{-6} \tag{4}$$

Where, D_R is the absorbed dose rate, 8760 is the hour per year, 0.8 is the occupancy factor, which represents that an individual spends 80 % of their time indoor and 20 % outdoor, and 0.7 is the dose conversion factor. The calculated average value of annual effective dose equivalent is 0.13 mSv y^{-1} varied from 0.07 to 0.20 mSv y^{-1}. The derived AEDE value of the collected samples is lower than the world recommended value for an annual effective dose of 0.48 mSv y^{-1} [15]. Even though the absorbed dose rate has a higher value, the annual effective dose equivalent is considerably lower than the world permissible value, so these samples do not cause any hazardous effects on human beings. The annual effective dose equivalent of the samples that were obtained is shown in Fig. 6.

3.2.4. Internal hazard index, H_{in}

Internal hazard index was used to evaluate the internal gamma ray exposure due to the presence of radon and its short-lived posterities in collected samples [29,30]. The internal hazard index (H_{in}) is an indicator for calculating the harmful effects of radioactive elements on the lungs and other respiratory organs. This parameter was calculated using Equation (5) [31]:

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{5}$$

Where, C_U, C_{Th}, and C_K are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K (Bq kg^{-1}). The average internal hazard index for collected samples is 0.22 which fluctuates from 0.13 to 0.38. Fig. 7 represents the internal hazard index of collected samples. This average value is significantly below the UNSCEAR [15] suggested internal hazard index upper limit of unity. As a result, when using these rock and soil samples as building materials, radiological risks attributed to the radionuclides are not harmful to human health.

3.2.5. Excess lifetime cancer risk, ELCR

Excess lifetime cancer risk calculated for collected sample in order to estimate the cancer risk for humans. Information regarding the health dangers posed by radionuclides is effectively provided by the evolution of this parameter. To calculate the ELCR, Equation (6) was used,

$$ELCR \text{ (mSv y}^{-1}) = AEDE \text{ (mSv y}^{-1}) \times LF \times RF \tag{6}$$

Where, AEDE is annual effective dose equivalent, LF is lifetime expectancy represents the average lifetime of human being (70 years), and RF is the fatal risk factor per Sv. According to ICRP, 0.05 is used as a risk factor for stochastic effects [15,32,33]. The average value
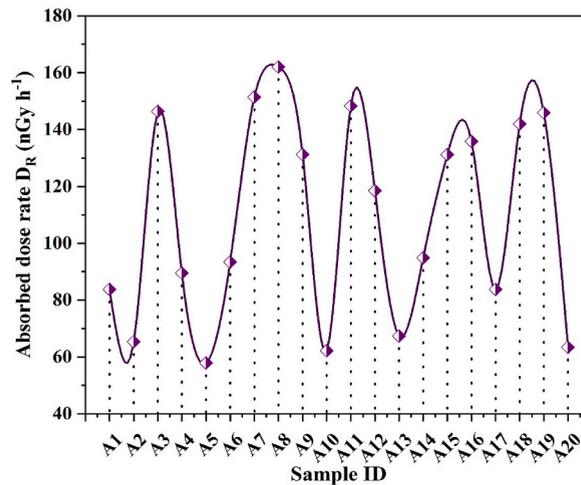
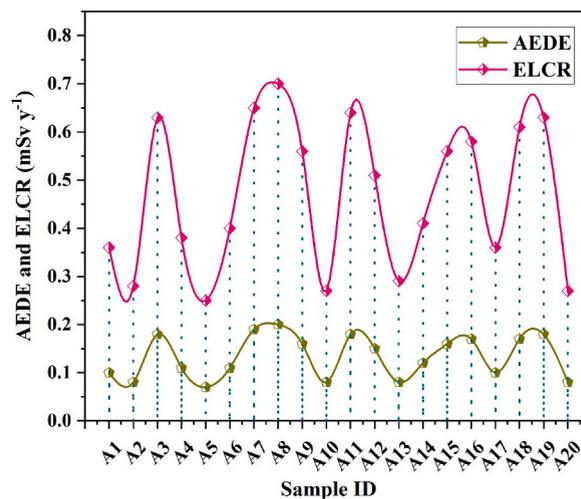**Fig. 5.** Variation of Absorbed dose rate in collected samples.

Fig. 6. variation of annual effective dose equivalent and excess lifetime cancer risk for the collected samples.

of ELCR for collected samples is 0.47 mSv y^{-1}, with a range of 0.25–0.70 mSv y^{-1}. These estimated values are much below the 1.16×10^{-3} mSv y^{-1} global acceptable limit. From this observation, the collected rock and soil samples do not cause any cancer risk to people when used as building or decorative materials.

4. Conclusion

Terrestrial and extraterrestrial gamma radiation associated with rock and soils play an important role in radiation exposure to the environment. This investigation reveals that the radiological impact on humans is due to the environmental materials. The estimated average activity concentration of the radionuclides ^{238}U, ^{232}Th, and ^{40}K in collected samples is 30.40 ± 0.71 Bq kg^{-1}, 3.31 ± 0.05 Bq kg^{-1}, and 222.25 ± 14.72 Bq kg^{-1} respectively, which lower than the world recommended value. The average radium equivalent activity of these collected samples is 52.25 Bq kg^{-1}, this value lies within the world recommended limit of 370 Bq kg^{-1}. The absorbed dose rate for these samples ranged between 57.87 and 162.05 nGy h^{-1} with an average value of 108.72 nGy h^{-1}, which have a higher value than the world recommended limit of 84 nGy h^{-1}. In addition to that, annual effective dose equivalent, internal hazard index, and excess lifetime cancer risk parameters have the average value of 0.13 mSv y^{-1}, 0.22, and 0.47 mSv y^{-1}, respectively. Since these values are below the global allowed limit, there are no radiological risks in these samples. The annual effective dose equivalent has a value that is significantly lower than the global acceptable limit even though the greater value of the absorbed dose rate is estimated. These outcomes reveal that these samples do not pose any hazardous risk to humans, but frequent monitoring is necessary when these materials are used as building materials, which cause long-term radiation exposure. This study will serve as a baseline data for future research.
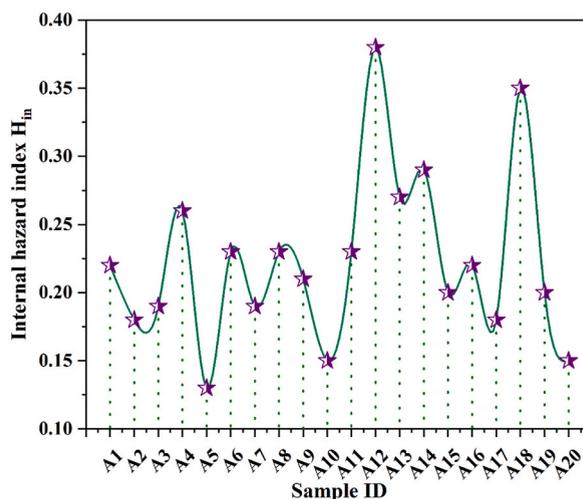
Fig. 7. variation of internal hazard index of collected samples.

Data Availability

All data used in this work have been included in the manuscript.

CRediT authorship contribution statement

Matthew Omoniyi Isinkaye: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Olusola Amos OlaOlorun:** Conceptualization, Investigation, Methodology. **Ananthanarayanan Chandasekaran:** Writing – original draft, Writing – review & editing. **Adebayo Samuel Adekeye:** Investigation, Methodology. **Tunde Emmanuel Dada:** Investigation, Methodology. **Azhagesan Tamilarasi:** Writing – original draft, Writing – review & editing. **Vilvanathan Sathish:** Writing – original draft, Writing – review & editing. **Mayeen Uddin Khandaker:** Conceptualization, Writing - review & editing. **Abdullah Almujally:** Funding acquisition, Writing - review & editing. **Nissren Tamam:** Funding acquisition, Writing - review & editing. **Abdelmoneim Sulieman:** Funding acquisition, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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