Artvin Çoruh Üniversitesi
Doğal Afetler Uygulama ve Araştırma Merkezi
Doğal Afetler ve Çevre Dergisi

Artvin Çoruh University
Natural Hazards Application and Research Center
Journal of Natural Hazards and Environment

Araştırma Makalesi / Research Article, Doğ Afet Çev Derg, 2019; 5(2): 214-223, DOI: 10.21324/dacd.475998

In situ natural radioactivity and radiological hazard assessments of granite gneiss outcrops in parts of the Southwestern Basement Complex of Nigeria

Adedibu Sunny Akingboye[1,*], Omowumi Ademila[1]

[1]*Department of Earth Sciences, Adekunle Ajasin University, P.M.B. 001 Akungba-Akoko, Ondo State, Nigeria.*

Abstract

Radioactive emission (gamma ray) emanating from rock materials constitutes threats to humans and their environment. Hence, the natural radioactivity and radiological hazard indices of some granite gneiss outcrops with their residual soils from two different localities within the Southwestern Basement Complex of Nigeria were assessed using Gamma-ray spectrometry. The study aimed at determining the natural radiation levels of granite gneissic rocks and associated radiological threats to people living in the study area from gamma ray exposure. Data were collected along six geophysical traverses of 200 m each with station spacing of 5 m using the portable hand-held Gamma-ray Spectrometer. The results of weighted mean values of the elemental and activity concentrations for ^{40}K, ^{238}U, and ^{232}Th are 2.00 ± 1.43%, 3.13 ± 0.90 ppm, 12.32 ± 4.99 ppm and 629.28 ± 447.29, 38.58 ± 11.02, 49.96 ± 20.23 $Bq\ kg^{-1}$ respectively. The obtained mean concentration ratios of 1.32 for U/Th and 2.14 for Th/U were higher than 0.26 and lower than 3.5 global standard ratios respectively. The increase in activity concentrations and concentration ratio may have suggested the enrichment of radioactive minerals in the granite gneissic rocks. The annual outdoor and indoor effective doses of gamma ray exposure for people living in the study area were below the world permissible standard of 1 $mSv\ y^{-1}$, thus, the area is radiologically safe. However, increase in estimated mean of AGDE and ELCR; 525.620 $\mu Sv\ y^{-1}$ and 1.273 $x10^{-3}$ above the world permissible standards of 300 $\mu Sv\ y^{-1}$ and $0.29x10^{-3}$ respectively does not translate to significant radiological threats. Therefore, control measure by constant monitoring of the radioactivity levels of the area and rocks should be practiced.

Keywords

Ground Radiometric Survey, Gamma-Ray Spectrometry, Natural Radioactivity, Granite Gneiss, Akunu-Akoko, Ayere

Nijerya'nın Güneybatı Temel Kompleks Bölgesinde Yüzeye Çıkan Granit Kayaların Doğal Radyoaktivite ve Radyolojik Tehlikelerinin Yerinde Değerlendirilmesi

Özet

Kaya materyallerinden kaynaklanan radyoaktif emisyon (gama ışını) insanlara ve çevresine tehdit oluşturur. Bu nedenle, Nijerya'nın Güneybatı Temel Kompleksi'nde iki farklı bölgeden yüzeye çıkan granit kayalar ile bunların kalıntısı olan toprakların doğal radyoaktivite ve radyolojik tehlike endeksleri Gamma-ray spektrofotometre kullanılarak değerlendirilmiştir. Bu çalışmada, granit yapıdaki kayaların doğal radyasyon düzeylerinin ve bağlantılı radyolojik tehlikelerin çalışma alanında yaşayan ve gama ışınına maruz kalan insanlar üzerindeki etkilerinin belirlenmesi amaçlanmıştır. Veriler, taşınabilir Gamma-ray Spektrometresi kullanılarak her biri 200 m'lik altı jeofizik travers boyunca 5 m'lik istasyon aralığı ile toplanmıştır. ^{40}K, ^{238}U ve ^{232}Th için temel ve aktivite konsantrasyonlarının ağırlıklı ortalama değerlerinin sonuçları sırasıyla %2.00 ± 1.43, 3.13 ± 0.90 ppm, 12.32 ± 4.99 ppm ve 629.28 ± 447.29, 38.58 ± 11.02, 49.96 ± 20.23 $Bq\ kg^{-1}$ dir. Elde edilen U/Th (1.32) ve Th/U (2.14) ortalama konsantrasyon oranları, sırasıyla, genel standart oranları olan 0.26'dan yüksek ve 3.5'tan düşüktür. Aktivite konsantrasyonları ve konsantrasyon oranlarındaki artış, yüzeye çıkan granit kayalarda radyoaktif minerallerin zenginleştiği anlamına gelebilir. Çalışma alanında yaşayan insanlar için gamma ışını maruziyetinde uygulanan yıllık dış ve iç etkili dozları dünyanın izin verilen 1 $mSv\ y^{-1}$ standardının altında olduğundan, alan radyolojik olarak güvenlidir. Bununla birlikte, AGDE ve ELCR'nin tahmini ortalamaları olan 525.620 $\mu Sv\ y^{-1}$ ve 1.273 $x10^{-3}$ değerlerindeki artışın, izin verilen 300 $\mu Sv\ y^{-1}$ ve 0.29 $x10^{-3}$ standart miktarların üzerinde olması da ciddi radyolojik tehditler anlamına gelmemelidir. Bu nedenle, alanın ve kayaların radyoaktivite seviyesinin sürekli izlendiği kontrol önlemleri tatbik edilmelidir.

Anahtar Kelimeler

Yer Radyometrik Araştırması, Gama-Işını Spektrometresi, Doğal Radyoaktivite, Metamorfik Granit Kaya, Akunu-Akoko, Ayere

* Corresponding Author: Phone: +234 (0) 7032462342 Fax: +234 (0) 7032462342
E-mail: adedibu.akingboye@aaua.edu.ng (Akingboye A.S), omowumi.ademila@aaua.edu.ng (Ademila O.)

Gönderim Tarihi / Received : 30/10/2018
Kabul Tarihi / Accepted : 18/03/2019

1. Introduction

Radiometric survey is a rapid and cost-effective method for measuring natural radioactivity such as potassium, K (%), uranium, U (ppm) and thorium, Th (ppm) of crustal materials, and assessing the level of natural and terrestrial radiation doses of an area, as well as geological mapping (UNSCEAR 1993; Cinar et al. 2017; Ademila et al. 2018).

Naturally occurring radioactive emission (gamma ray) emanating from rock materials can be assessed through Gamma-ray spectrometer by counting the number of times each gamma ray of particular energy intersects it. Ground measurement can be taken by placing the Gamma-ray spectrometer directly on the ground, or at a low constant height above the ground to minimise the effects of local variation in relief and radionuclide distribution. Such measurements indicate the variations in radioactivity responses from earth's layers of few centimeters to 1.0 m thick. The response of the gamma ray detector depends on the size, location and geometry of radioactive source. However, the source-detector geometry must be constant for all measurements to achieve substantial results along the profile. The range of energy spectrum measured by gamma-ray spectrometer is from 0–3 MeV. This range marks the bandwidth for energies of geological interest lying between 0.2 and 3 MeV. Peaks of the detected spectrum can be attributed to K, U and Th (IAEA 2003).

The distribution of naturally occurring radionuclides depends on the origin and nature of the rocks, as well as processes that concentrate them. Potassium, thorium and uranium are approximately 2.35%, 12 ppm and 3 ppm respectively in crustal rocks. Potassium is majorly produced in the earth's crust by potassic feldspars (e.g. orthoclase of approximately 13%) and micas – biotite and muscovite of about 8% (Kearey et al. 2002). It is the most abundant radionuclide in crustal rocks. Uranium and thorium are concentrated in liquid phase and become incorporated into more silica-rich products during the formation of granitic rocks from magmatic processes through partial melting and fractional crystallisation. Hence, rocks of granitic origin are greatly rich in uranium and thorium with average concentrations of 5 ppm and 15 ppm respectively. Their concentrations in basaltic or ultramafic rocks are less than 1 ppm (Tzortzis et al. 2003). Rocks' radionuclides can be altered by weathering and metamorphism. During weathering, oxidation takes place in rocks and oxidizes uranium easily to water-soluble form. This is leached and deposited in sediments at far distances from their source rocks. On the other hand, thorium tends to remain in the parent rocks, or transported over relatively short distances in the form of solid mineral such as zircon and monazite because it has no soluble ion (Yu et al. 1993).

The terrestrial radiation from primordial radionuclides such as ^{40}K, ^{238}U and ^{232}Th and their decay products; cosmogenic radionuclide produced by interaction of cosmic rays with atoms in the atmosphere, and human produced radionuclides contribute to the natural radiation of the environment (IAEA 2003; UNSCEAR 2008; Tzortzis and Tsertos 2004). The widespread of rocks and their weathered constituents (soils) in the environment are the main sources of radiation exposure to human population (Radiation information network 2004). Higher and lower radiation levels are associated with igneous and sedimentary rocks respectively. Nevertheless, sedimentary rocks such as shales and phosphate rocks produce relatively high radionuclides emission. These radiations combined generally increase the levels of total doses (outside and inside irradiation) to which human beings are exposed. Consequently, the assessment of radiation levels in different rock aggregates and soils before supply to the end users in construction works becomes necessary since rocks radionuclides constitute parts of the radiation exposure to human and its environment (Akkurt et al. 2010; Uyanik et al. 2013; Çetin 2016; Ademila 2018). This will definitely reduce the exposure of workers, users of such building materials and the populace to radionuclide radiations. However, *in situ* radioactivity and radiological levels of selected rock types in Ondo and Kogi States, Nigeria have not been studied to considerable extent.

This study, therefore, aimed at assessing the natural radioactivity and radiological hazard indices of the granite gneissic rocks around Akunu-Akoko and Ayere areas due to their massive occurrence. The steady growing population of the areas has called for this immediate investigation because of the importance of the rock in construction works as aggregate for concretes, roads, buildings and as ornamental stones.

2. Location and Geologic Setting

The study area extends from Akunu-Akoko at the the northern end of Ondo State to Ayere town at the southwestern end of Kogi State (sharing boundary with Ondo State). It lies between latitude 07º35′ and 07º45′ N and longitude 005º55′ and 006º00′ E. The Precambrian Basement Complex of Nigeria lies within the Pan-African mobile belt, east of the West African Craton and northwest of the Congo-Gabon Craton (Figure 1a) (Woakes et al. 1987; Obaje 2009).

The study area is underlain by rocks of the Migmatite-Gneiss Complex of the Precambrian Southwestern Basement rocks of Nigeria. The study area has geological history similar to the structural evolutions that have affected the Basement Complex of Nigeria. The rocks present in the study area include grey gneiss, granite gneiss, charnockite, Older granite of Pan-African age and other felsic and mafic intrusives (Figure 1b). The grey gneiss dominates the extreme eastern to northeastern parts, granite gneiss occupies the southern and northern parts, charnockite extends from the western through the central to southeastern parts, and granite dominates the eastern flank of the study area. The charnockitic and granite gneissic rocks cover about 85% of the study area.

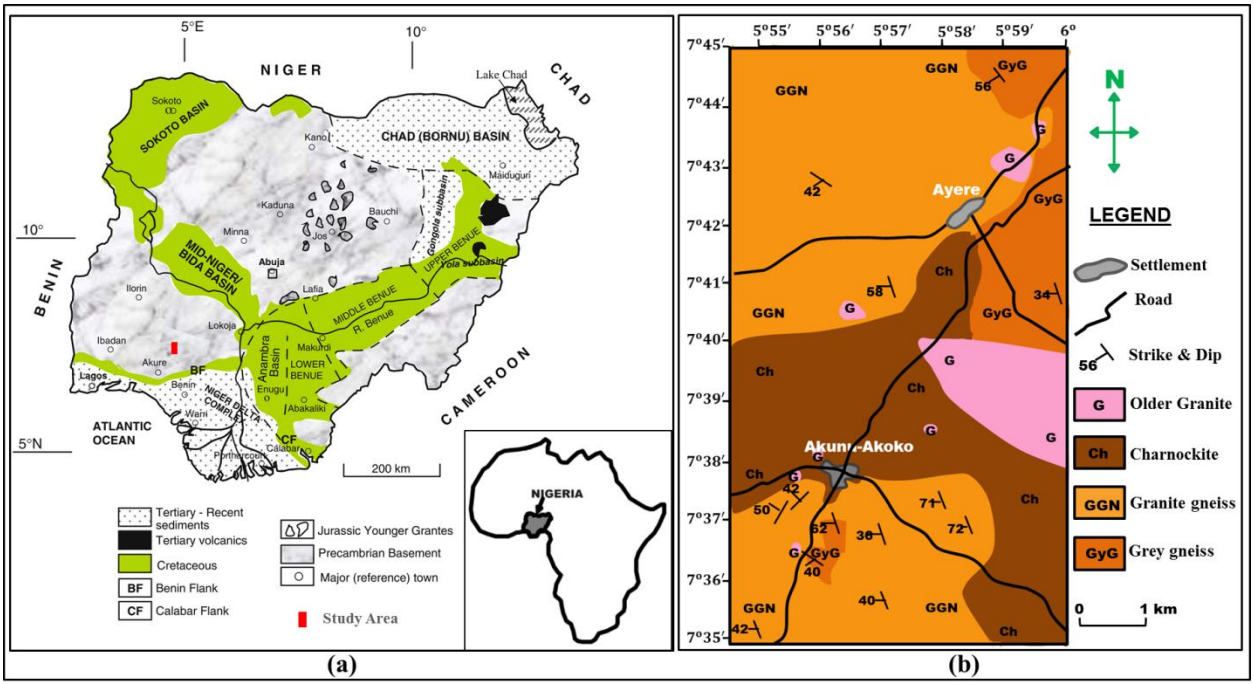

Figure 1: (a) Geological Map of Nigeria showing the study area (modified after Obaje 2009), (b) Geological map of the study area.

3. Materials and Methods

3.1. Field Measurements

The field methods used for this study involved geological mapping and radiometric surveying that ultilised Gamma-ray spectrometry. The various rock types in the study area were first mapped to prepare a detailed geological map particularly to know the extent of the granite gneissic rock and its boundaries with other rock types. During the geological field mapping, areas of interest to layout geophysical traverses were established.

The *in situ* radioactivity measurements employed a highly sensitive portable hand-held spectrometer designed by GF-Instrument Inc. (512-channels [NaI(TI)] scintillation detector). The instrument is calibrated for constants associated with the instrument count rates, environmental dose rate, stripping ratios and sensitivity constants. These account for the correction of the background radiations due to internal radioactivity of the instrument, cosmic and atmospheric radon effects. The instrument is capable of recording full gamma ray spectrum and summing their channels over broad energy windows for estimation of elemental concentrations of K, U and Th (IAEA 2003).

A total of six (6) geophysical traverses consisting of traverses (TRs) 1 – 3 and TRs 4 – 6 were occupied around Akunu-Akoko and Ayere respectively (Figure 2). Each of the six traverses has a spread length of 200 m with station interval of 5 m. A total number of 246 stations were occupied to measure the *in situ* natural gamma radiation levels of K (%), eU (ppm) and eTh (ppm) associated with the granite gneiss outcrops and residual soils in the study area. Two repeated readings were taken at each station for K (%), eU (ppm), eTh (ppm), total count (TC) (cps), and dose rate. Thereafter, the acquired field data were computed to determine the mean values of radioelements, absorbed dose rate, annual effective doses, activity concentration index, and other radiological parameters. The results were interpreted using different pictorial representations such as profiles and charts.

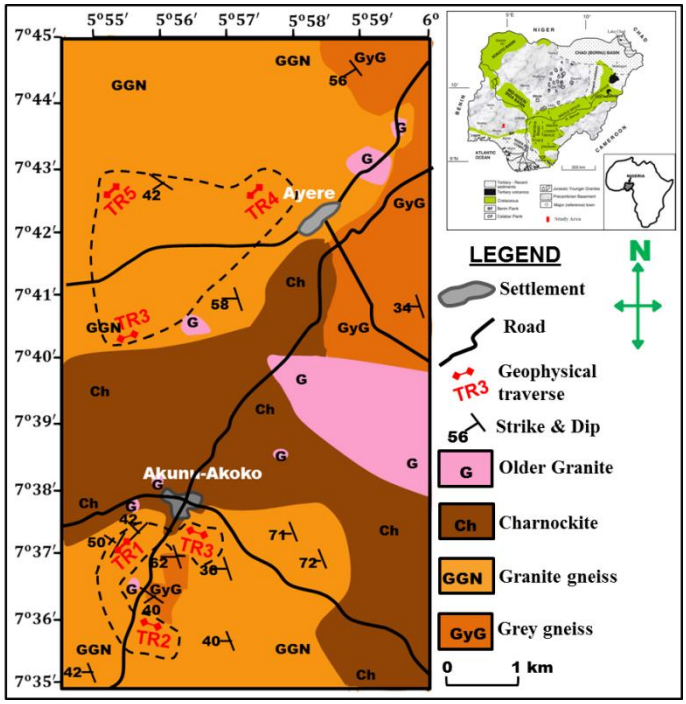

Figure 2: Geological map of the study area showing the layouts of the geophysical traverses (denoted as TRs 1 – 6 and enclosed by broken lines) over the granite gneiss outcrops in the study area.

3.2. Estimation of Radiation Hazard Parameters

3.2.1. Absorbed Dose Rate (D)

The absorbed dose rates in air ($nGy\ h^{-1}$) along the traverses were computed using the expression given by UNSCEAR (2000):

$$D = 0.0417C_K + 0.462C_U + 0.621C_{Th} \quad (1)$$

Where D is the absorbed dose rate in nano grey per hour ($nGy\ h^{-1}$) while C_K, C_U, and C_{Th} are the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th respectively.

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq kg^{-1} were calculated from measured elemental concentrations of ^{238}U (ppm), ^{232}Th (ppm), and ^{40}K (%) respectively, using the conversion factors recommended by IAEA (2003) as follows:

$$1\ ppm = 10^{-4}\ \% \quad (2)$$
$$1\%\ ^{40}K = 313\ Bq\ kg^{-1} \quad (3)$$
$$1\ ppm\ ^{238}U = 12.35\ Bq\ kg^{-1} \quad (4)$$
$$1\ ppm\ ^{232}Th = 4.06\ Bq\ kg^{-1} \quad (5)$$

3.2.2. Annual Effective Dose Equivalent (H_E)

The annual effective dose equivalent (H_E) is a very important radiological parameter that must be evaluated for construction materials such as stone, bricks, concrete or granite gravels/stones. These construction materials are capable of increasing the level of indoor radiation on the one hand and on the other hand shield radiation from the air (i.e. outdoor radiation) (UNSCEAR 1993, 2000; Tzortzis et al. 2003). Thus, these factors may in turn increase the level of dose rate that people are exposed to. On average, globally, people spend about 20% and 80% of their time outdoor and indoor i.e. 0.2 and 0.8, which are the outdoor and indoor occupancy factor respectively. A conversion coefficient factor was used for converting the absorbed dose in air to effective dose rates (H_E) in unit of *mini Sievert per year* ($mSv\ y^{-1}$) (UNSCEAR 2000). Hence, (H_E) was calculated by using Equation 6:

$$H_E = D * T * F \quad (6)$$

Where D is the dose rate ($nGy\ h^{-1}$), T is the indoor/outdoor occupancy time for one year $24h * 365.25 \cong 8760$ and F is the conversion factor ($F = 0.7 * 10^{-6}\ Sv\ Gy^{-1}$). All values were substituted respectively into Equation 6 to give Equations 7 and 8 for outdoor and indoor annual effective doses respectively:

$$H_E\ (outdoor)(mSv\ y^{-1}) = D\ * 8760\ * 0.2\ * 0.7 * 10^{-6} \quad (7)$$
$$H_E\ (indoor)(mSv\ y^{-1}) = D\ * 8760 * 0.8\ * 0.7 * 10^{-6} \quad (8)$$

3.2.3. External (H_{ex}) and Internal (H_{in}) Radiation Hazard Indices

The external (H_{ex}) and internal (H_{in}) radiation hazard indices were evaluated by using Equations 9 and 10 respectively (Ramasamy et al. 2009):

$$H_{ex} = C_U/370 + C_{Th}/259 + C_K/4810 \leq 1 \quad (9)$$
$$H_{in} = C_U/185 + C_{Th}/259 + C_K/4810 < 1 \quad (10)$$

Where C_U, C_{Th}, and C_K are the activity concentration in $Bq\ kg^{-1}$ for ^{238}U, ^{232}Th, and ^{40}K respectively. Both the external and internal radiation hazard indices must be less than unity for the radiation hazard indices to be negligible (Beretka and Mathew 1985). Respiratory diseases like asthma may be caused by increase above the permissible limit of internal exposure to radionuclide (Tufail et al. 2007).

3.2.4. Activity Concentration Index (I_γ)

Activity concentration index is used to estimate the gamma radiation hazard associated with the natural radionuclide. The activity concentration index was estimated using Equation 11 (EC 1999):

$$I_\gamma = C_K/3000\ + C_U/300 + C_{Th}/200 \leq 1 \quad (11)$$

Where C_K, C_U, and C_{Th} are the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th in $Bq\ kg^{-1}$ respectively. The representative gamma index must be lower than unity for radiation hazard to be insignificant.

3.2.5. Annual Gonadal Dose Equivalent (AGDE)

The Annual Gonadal Dose Equivalent (AGDE) was also calculated because of gonads such as bone marrow and bone surface cells that are sensitivity to radiation. Increase above the permissible level of AGDE in humans over time can cause leukemia in the born marrow (i.e. cancer of the born marrow) (UNSCEAR 1988). Therefore, AGDE received by the humans was evaluated using Equation 12 (Mamont-Ciesla et al. 1982).

$$AGDE\ (\mu Sv\ y^{-1}) = 3.09C_U\ + 4.18C_{Th} + 0.314C_K \quad (12)$$

Where C_U, C_{Th}, and C_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively in rocks.

3.2.6. Excess Lifetime Cancer Risk (ELCR)

Excess lifetime cancer risk was calculated using Equation 13 (Taskin et al. 2009*)* to determine the possible chance of developing cancer in a person that is exposed to such radiation (from birth till death) over a lifetime.

$$ECLR = H_E\ (indoor) * LE * RF \quad (13)$$

Where H_E (indoor) is the indoor annual effective dose, *LE* is the lifetime expectance (70 years), and *RF* is the risk factor (Sv^{-1}). For stochastic calculation, ICRP (1990) used *RF = 0.05* as cancer risk factor for the general public.

4. Results and Discussion

The range and mean values of measured elemental and activity concentrations of natural radionuclides (^{40}K, ^{238}U, and ^{232}Th) for all traverses are shown in Table 1. The mean elemental concentrations of ^{40}K, ^{238}U, and ^{232}Th ranges from 0.44 (TR3) – 3.68 % (TR5), 2.09 (TR1) – 4.26 ppm (TR6), and 5.86 (TR5) – 21.26 ppm (TR6) respectively. The mean activity concentrations of natural radionuclides for ^{40}K, ^{238}U, and ^{232}Th ranges from 138.71 (TR3) – 1150.70 Bq kg^{-1} (TR5), 25.82 (TR1) – 52.62 Bq kg^{-1} (TR6), and 23.81 (TR5) – 86.33 Bq kg^{-1} (TR6) respectively. Weighted mean values for the *in situ* elemental and activity concentrations of ^{40}K, ^{238}U, and ^{232}Th are 2.00 ± 1.43 %, 3.13 ± 0.90 ppm, 12.32 ± 4.99 ppm and 629.28 ± 447.29, 38.58 ± 11.02, 49.96 ± 20.23 Bq kg^{-1} respectively. The Total Count (TC) emission rate per second of the natural radionuclides ranges from 366.2 (TR3) – 385.4 cps (TR5) with weighted mean of 375.57 ± 8.37 cps.

Figure 3 shows the comparison between the measured elemental concentrations of ^{40}K, ^{238}U, and ^{232}Th around Akunu-Akoko, Ondo State and Ayere, Kogi State. Figures 3a – c show the distributions of the mean elemental concentrations of ^{40}K, ^{238}U, and ^{232}Th in Akunu-Akoko (TRs 1 – 3) respectively. Figures 3d – e show the distributions of the mean elemental concentrations of ^{40}K, ^{238}U, and ^{232}Th in Ayere (TRs 4 – 6) respectively. Figure 4 shows the bar plot of the evaluated total mean activity concentrations of ^{40}K, ^{238}U, and ^{232}Th and the variations of respective activity concentrations along the entire traverses in the study area. It was observed from Figures 3 and 4 that the measured radionuclides ^{40}K, ^{238}U, and ^{232}Th along TRs 4 – 6 are generally higher than the values observed along TRs 1 – 3. The lowest and highest estimated total activity concentrations of the radionuclides are TR3 and TR5 respectively (Figure 4). The natural radioactivity of these rocks increases from Akunu-Akoko towards Ayere area. TRs 4 – 6 show higher elemental concentrations of ^{40}K, ^{238}U, and ^{232}Th above the average crustal concentrations of 2 – 2.5%, 2 – 3 ppm, and 8 – 12 ppm (IAEA 2003) and above the normal environmental activity concentration level of 420, 33, and 45 Bq kg^{-1} (UNSCEAR 2000) respectively. This increase may suggest high enrichment of radioactive minerals in the granite gneissic rocks and topsoil produced by K-feldspar, silica, and U- and Th-bearing minerals. However, decrease in ^{40}K radionuclide along TR3 could probably be due to deep weathering of the potassic feldspar and other radioactive bearing minerals in the rocks.

Table 1: Range, mean and weighted mean concentrations and estimated radionuclides for the study area

TR		K (%)	U (ppm)	Th (ppm)	K ($Bqkg^{-1}$)	U ($Bqkg^{-1}$)	Th ($Bqkg^{-1}$)	D ($nGy\ h^{-1}$)	TC (cps)	U/Th	Th/U
		Elemental Concentration			Activity Concentration						
TR1	Range	0.31–2.31	BDL–5.20	5.00–18.40	97.03–723.03	BDL–64.22	20.30–78.36	36.44–86.61			
	Mean	1.09± 0.48	2.09±1.32	12.11±3.02	339.49±151.53	25.82±16.31	49.15±12.27	56.60±32.55	369.1	0.60±0.51	2.24±1.63
TR2	Range	BDL–2.28	BDL–5.00	5.00–17.80	BDL–713.64	BDL–61.75	20.30–72.27	33.16–82.48			
	Mean	0.72±0.42	2.31±1.34	11.10±2.80	225.51±132.06	28.50±16.55	45.07±11.35	50.56±10.15	369.7	0.71±0.50	3.63±3.99
TR3	Range	BDL–0.90	BDL–5.30	6.80–18.60	BDL–218.70	BDL–65.46	27.61–75.52	35.25–64.10			
	Mean	0.44±0.24	2.69±1.41	11.37±2.71	138.71±75.82	33.26±17.46	46.18±10.99	49.82±7.18	366.2	0.81±0.53	1.81±0.88
TR4	Range	1.81–5.23	0.60–7.90	5.40–25.10	566.53–1636.99	7.41–97.57	21.92–101.91	69.68–117.15			
	Mean	3.40±0.79	3.46±1.85	12.13±5.13	1063.59±246.50	42.68±22.83	49.24±20.82	94.65±10.68	385.4	1.13±0.96	1.89±1.93
TR5	Range	1.21–4.89	1.10–8.40	0.40–11.00	378.73–1530.57	13.59–103.74	1.62–44.66	64.24–101.82			
	Mean	3.68±0.68	3.93±1.77	5.86±2.29	1150.70±212.38	48.59±21.89	23.81±9.28	85.21±7.65	378.4	3.79±9.71	0.70±0.68
TR6	Range	1.50–3.89	1.00–9.70	4.60–60.20	469.50–1217.57	12.35–119.80	18.68–244.41	80.09–218.49			
	Mean	2.74±0.55	4.26±1.92	21.26±14.20	857.69±172.32	52.62±23.73	86.33±57.67	113.69±37.82	384.6	0.88±0.63	2.24±2.64
Weighted Mean (A.M. ± S.D.)		2.00±1.43	3.13±0.90	12.32±4.99	629.28±447.29	38.58±11.02	49.96±20.23	73.09±26.67	375.57±8.37	1.32±1.22	2.14±1.05

**TR – Traverse; BDL – Below Detection Limit; A.M. – Arithmetic Mean, and S.D – Standard Deviation*

The uranium to thorium (U/Th) and thorium to uranium (Th/U) concentration ratios of respective traverses were calculated (Table 1) to determine the elemental abundances or enrichment of the natural radionuclides in the study area. The mean concentration ratios for U/Th and Th/U range from 0.60 (TR1) – 3.79 (TR5) and 0.70 (TR5) – 3.63 (TR2) with weighted mean values of 1.32 ± 1.22 and 2.14 ± 1.05, respectively. The U/Th concentration ratio for study area is generally higher than the global U/Th ratio of 0.26 (Chandrasekaran et al. 2014). The mean Th/U concentration ratio for the study area are lower than the global Th/U ratio of 3.5 (Adams, 1962; Chandrasekaran et al. 2014), except for TR2 with slight increment of 0.13. According to Mishra and Sadasivian (1971), increase of Th/U ratio above the global value may suggest that uranium is in equilibrium with its daughter nuclide.

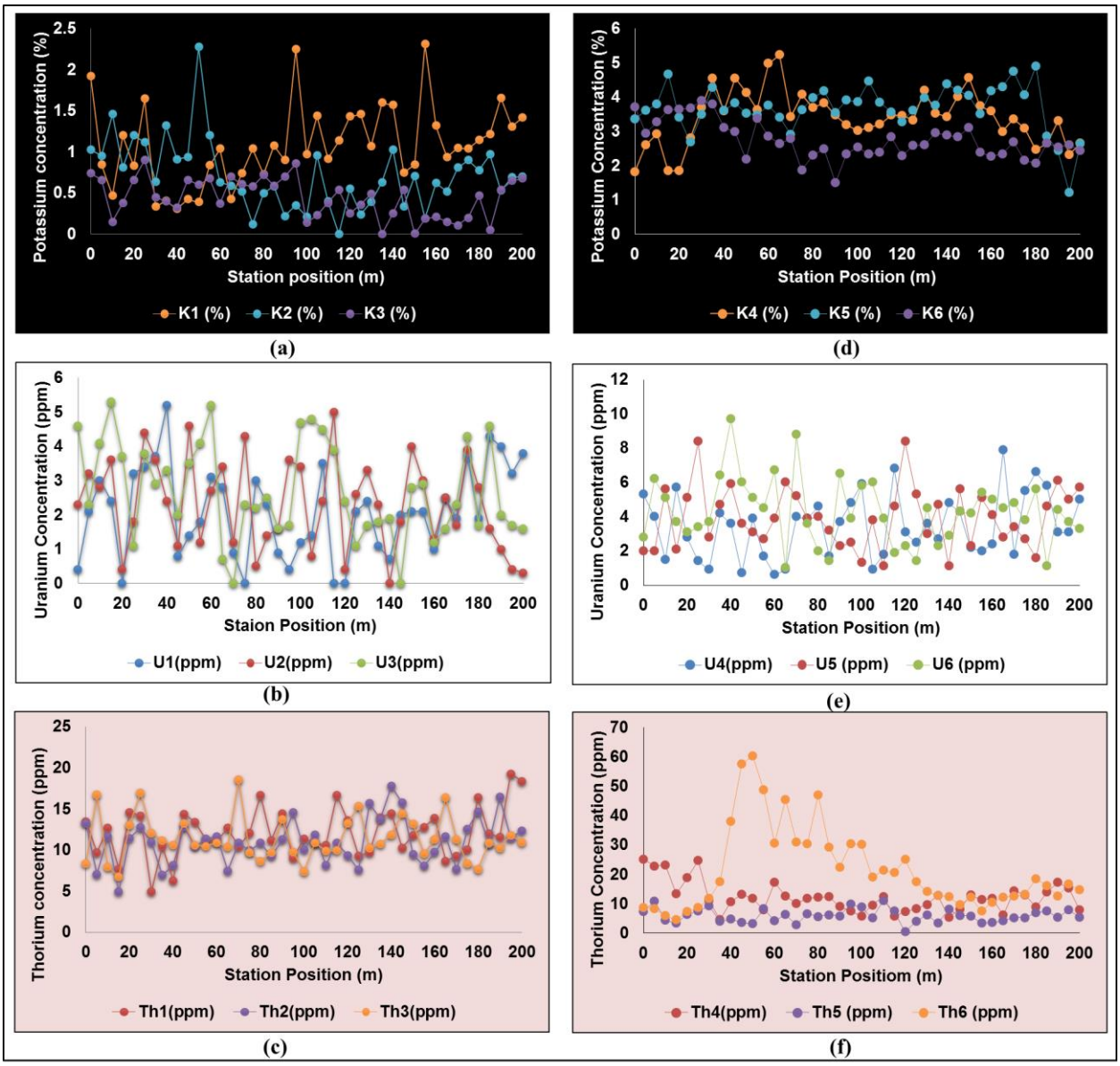

Figure 3: a – c and d – f show the profiles of K (%), U (ppm), and Th (ppm) concentrations observed along traverses 1 – 3 and traverses 4 – 6 respectively around Akunu-Akoko, Ondo State, and Ayere, Kogi State.

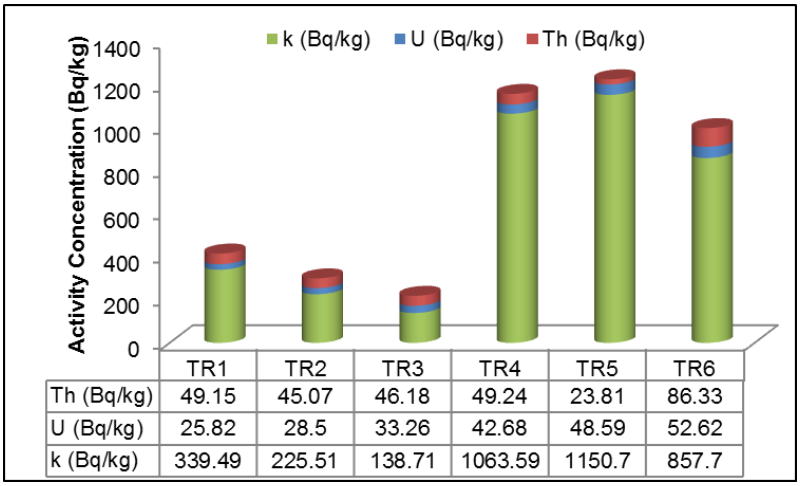

Figure 4: Distribution of the activity concentrations of natural radionuclides of the study area.

Table 2: Mean values of the estimated radiological hazard parameters for the study area

Traverse	Mean						
	H_E ($mSv\ y^{-1}$)		H_{ex}	H_{in}	I_γ	AGDE ($\mu Sv\ y^{-1}$)	ECLR (10^{-3})
	Outdoor	Indoor	Hazard Indices				
TR1	0.069	0.275	0.330	0.400	0.445	391.796	0.962
TR2	0.061	0.246	0.298	0.375	0.396	347.238	0.855
TR3	0.060	0.242	0.297	0.387	0.388	339.324	0.843
TR4	0.115	0.460	0.527	0.642	0.743	671.659	1.599
TR5	0.103	0.414	0.463	0.594	0.665	610.958	1.449
TR6	0.138	0.552	0.654	0.796	0.893	792.773	1.932
Average	0.091	0.364	0.428	0.532	0.588	525.620	1.273

The mean absorbed dose rate (D) ranges from 49.82 (TR3) – 113.69 $nGy\ h^{-1}$ (TR6) with weighted mean 73.09 ± 26.67 $nGy\ h^{-1}$ (Table 1). The highest mean absorbed dose rates are observed at TRs 4 – 6. According to UNSCEAR (2000), the recommended world permissible range for absorbed dose rate is 28 – 120 nGy h^{-1} and world average limit of 60 nGy h^{-1}. The observed values at TRs 4 – 6 are above the world average permissible limit, but are still within the world permissible range for rocks and soils.

The mean annual outdoor and indoor effective dose rates range from 0.060 (TR3) – 0.138 mSv y^{-1} (TR6) and 0.242 (TR3) – 0.552 mSv y^{-1} (TR6) with averages of 0.091 mSv y^{-1} and 0.364 mSv y^{-1} respectively (Table 2). The mean outdoor and indoor effective doses received by an individual are below the average worldwide standards of 0.07 mSv y^{-1} and 0.41 mSv y^{-1} respectively (UNSCEAR 2000), except for TRs 4 – 6 which are slightly above these standard values. However, the observed annual outdoor and indoor effective doses are below the world upper limit of 1 mSv y^{-1} (ICRP 1977) as maximum dose recommended for the public.

The mean external and internal hazard indices range from 0.297 (TR3) – 0.654 (TR6) and 0.375 (TR2) – 0.796 (TR6) with average values of 0.428 and 0.532 respectively (Table 2). The estimated values for both hazard indices are below the world recommended standard of unity (1) (Ramasamy et al. 2009). The calculated gamma concentration index (I_γ) associated with the measured activity of the primordial nuclides also ranges from 0.388 (TR3) – 0.893 (TR6) with average of 0.588 (Table 2). The observed values are also lower than the permissible limit of unity (1) (UNSCEAR 2000).

According to European Commission (1999), values of gamma index (I_γ) of $I_\gamma \leq 2$ corresponds to annual effective dose rate standard of 0.3 mSv y^{-1}, and $2 \leq I_\gamma \leq 6$ corresponds to a criterion of 1 mSv y^{-1} (recommended standard). Area with $I_\gamma > 6$ has annual effective dose rates higher than 1 mSv y^{-1}, which is higher than the recommended level, hence pose danger to the surrounding population. The observed gamma concentration index (I_γ) values for this study are below the permissible limit of unity (1) and recommend standard of 1 mSv y^{-1} for annual effective dose rates. Thus, this suggests that the radioactivity levels of the granite gneiss outcrops and the residual soils in the study area are insignificant. This probably means that no radiological hazard is expected on the public at this time, but continuous accumulation from prolong exposure may pose radiological threats in future.

The estimated mean values for AGDE and ECLR range from 339.324 (TR3) – 792.773 µSv y^{-1} (TR6) and $0.843 * 10^{-3}$ (TR3) – $1.932 * 10^{-3}$ (TR6) with averages of 525.620 µSv y^{-1} and $1.273 * 10^{-3}$ respectively (Table 2). The estimated AGDE and ECLR values are above the world permissible limits of 300 µSv y^{-1} (Xinwei et al. 2006) and $0.29 * 10^{-3}$ (Tufail et al. 2007) respectively.

5. Conclusion

In situ natural radioactivity concentrations of granite gneissic rocks and residual soils around the Basement Complex of Akunu-Akoko and Ayere in Ondo and Kogi State respectively were assessed, using the portable hand-held Gamma-ray Spectrometer. The radiological hazard parameters associated with their radionuclides emission were also calculated to know if the study area is radiologically safe.

The results of the six traverses occupied within the study area showed high elemental and activity concentrations for ^{40}K, ^{238}U, and ^{232}Th, particularly at TRs 4 – 6 (around Ayere). The activity concentrations of ^{40}K, ^{238}U, and ^{232}Th along these TRs were above the worldwide averages of 420, 33, and 45 Bq kg^{-1} respectively. The obtained average of U/Th concentration ratio of 1.32 is higher than the global ratio of 0.26 while that of Th/U concentration ratio of 2.14 is lower than the global Th/U ratio of 3.5. The increase in elemental and activity concentrations above the worldwide averages for the granite gneissic rocks and residual topsoil may have suggested abundant enrichment of the radioactive minerals and presence of radioactive lateritic clay. Decrease below the averages may probably be due to low enrichment caused by weathering activity. The estimated absorbed dose mean of 73.09 nGy h^{-1} for the study area is within the recommended world standard permissible range of 28 – 120 nGy h^{-1}, though slightly above the world average of 60 nGy h^{-1}. The obtained annual outdoor and indoor doses are far below the recommended upper permissible limit of 1 mSv y^{-1}. The averages of the external and internal hazard indices of 0.428 and 0.532, respectively, and gamma activity concentration index of 0.588 are all below the world standard permissible limit of unity. The estimated AGDE and ELCR averages; 525.620 µSv y^{-1} and $1.273 * 10^{-3}$ are above the world permissible limits of 300 µSv y^{-1} and $0.29 * 10^{-3}$ respectively. The estimated radiological parameters below world permissible standards suggested radiologically safe environment. However, the observed increase above the world permissible limits for AGDE and ELCR does not translate into significant or immediate radiological threats to people living in the area. Hence, radioactivity level of rocks and the environment should constantly be monitored.

References

Adams J.A.S., (1962), *Nuclear radiation in geophysics*, Israel H., Krebs A., (Ed.), Springer-Verlag Berlin Heidelberg, 460p.

Ademila O., (2018), *Radiometric Impact Assessment around Two Quarry Sites, Benin-Owo Expressway, Southwestern Nigeria*, International Journal of Engineering and Geosciences, 3(1), 20-35.

Ademila O., Akingboye A.S., Ojamomi A.I., (2018), *Radiometric survey in geological mapping of parts of Basement Complex area of Nigeria*, Vietnam Journal of Earth Sciences, 40(3), 288-298.

Akkurt I., Oruncak B., Gunoglu K., (2010), *Radioactivity and dose rates in commercially-used marble from Afyonkarahisar-Turkey*, International Journal of Physical Sciences, 5(2), 170–173.

Beretka J., Mathew P.J., (1985), *Natural radioactivity of Australia building materials, industrial wastes and by-products*, Health Physics, 48, 87-95.

Çetin B., (2016), *Determination of natural radioactivity concentrations in surface soils in the Yesilirmak River in Amasya, Turkey*, Acta Physica Polonica A, 130(1), 320-321.

Chandrasekaran A., Ravisankar R., Senthilkumar G., Thillaivelavan K., Dhinakaran B., Vijayagopal P., Bramha S.N., Venkatraman B., (2014), *Spatial distribution and lifetime cancer risk due to gamma radioactivity in Yelagiri Hills, Tamilnadu, India*, Egyptian Journal of Basic and Applied Sciences, 1, 38-48.

Cinar H., Altundas S., Çelik N., Maden N., (2017), *In situ gamma ray measurements for deciphering of radioactivity level in the Sarihan pluton area of northeastern Turkey*, Arabian Journal of Geosciences, 10:435, 1-15.

European Commission (EC), (1999), *Radiological Protection Principles concerning the Natural Radioactivity of Building Materials*, Radiation Protection 112, https://ec.europa.eu/energy/sites/ener/files/documents/112.pdf, 16p.

IAEA (2003), *Radiation protection and the management of radioactive waste in the oil and gas industry*, International Atomic Energy Agency, 173 p.

ICRP, (1977), *Recommendations of the ICRP*, International Commission on Radiological Protection (ICRP), ICRP Pub. 26, Pergamon Press, New York, 87 p.

ICRP, (1990), *Recommendations of the ICRP*, International Commission on Radiological Protection (ICRP), ICRP Pub. 60, Pergamon Press, New York.

Kearey P., Brooks M., Hill I., (2002), *An Introduction to Geophysical Exploration*, 3rd ed., Oxford: Blackwell Science, 262 p.

Mamont-Ciesla K., Gwiazdowski B., Biernacka M., Zak A., (1982), *Radioactivity of building materials in Poland*, Vohra G., Pillai K.C., Sadavisan S., (Ed.), Natural radiation environment, New York: Halsted Press, p. 551.

Mishra U.C., Sadasivan S., (1971), *Natural radioactivity levels in Indian soils*, Journal of Scientific and Industrial Research, 30(2), 59-62.

Obaje N.G., (2009), *Geology and Mineral Resources of Nigeria*, Springer-Verlag Berlin Heidelberg, 221 p.

Radiation information network, (2004), *Radioactivity*, Idaho State University, U.S.A.

Ramasamy V., Suresh G., Meenakshisundaram V., Gajendran V., (2009), *Evaluation of natural radionuclide content in river sediments and excess lifetime cancer risk due to gamma radioactivity*, Research Journal of Environmental and Earth Sciences, 1(1), 6-10.

Taskin H., Karavus M., Ay P., Topuzoglu A., Hindiroglu S., Karahan G., (2009), *Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey*, Journal of Environmental of Radioactivity, 100(1), 49-53.

Tufail M., Akhar N., Jaried S.A., Hamid T., (2007), *Natural radiation hazard in building bricks fabrication from soils of two districts of Pakistan*, Journal of Radiological Protection, 27, 481-492.

Tzortzis M., Tsertos H., Christofides C., Christodoulides G., (2003), *Gamma radiation measurement and dose rates in commercially-used natural tiling rocks (granites)*, Journal of Environmental Radioactivity, 70(1), 223-235.

Tzortzis M., Tsertos H., (2004), *Determination of uranium, thorium and potassium elemental concentration in surface soils in Cyprus*, Journal of Environmental radioactivity, 77, 325-338.

UNSCEAR, (1988), *Sources, effects and risks of ionizing radiation*, United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR), United Nations, New York, 647 p.

UNSCEAR, (1993), *Sources and effects of ionizing radiation*, United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR), United Nations, New York, 920 p.

UNSCEAR, (2000), *Exposure from natural radiation source*, United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR), Report to general assembly, Annex B, United Nations, New York, vol. 1-2, 76 p.

UNSCEAR, (2008), *Sources and effects of ionizing radiation*, United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR), Report to the general assembly with scientific annexes. United Nations, New York, vol. 2, 219 p.

Uyanık N.A., Uyanık O., Gür F., Aydın İ., (2013), *Natural radioactivity of bricks and brick material in the Salihli-Turgutlu area of Turkey*, Environmental Earth Sciences, 68(2), 499-506.

Woakes M., Rahaman M.A., Ajibade A.C., (1987), *Some Metallogenetic Features of the Nigerian Basement*, Journal of African Earth Sciences, 6(5), 655-664.

Xinwei L., Lingqing W., Xiaodan J., (2006), *Radiometric analysis of Chinese commercial granites*, Journal of Radioanalytical and Nuclear Chemistry, 267 (3), 669-673.

Yu K.N., Guan Z.J., Stokes M.J., Young E.C.M., (1992), *The assessment of the natural dose committed to the Hong Kong people*, Journal of Environmental Radioactivity, 17(1), 31-48.