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Evaluation of Rock Radiation Hazards for Construction Applications in Parts of Southwestern Nigeria

Omowumi Ademila

Department of Earth Sciences, Adekunle Ajasin University, Akungba-Akoko, Nigeria. omowumi.ademila@aaua.edu.ng

Abstract: **Geophysical investigation involving the radiometric method was carried out around some selected rock outcrops (fine-grained granite (FGG), charnockite (CCK) and granite gneiss (GGN)) in Southwestern Nigeria to assess its natural radioactivity and radiation hazards. Three hundred and six (306) stations were occupied along six traverses varying from 200 – 300 m using gamma-ray spectrometer. The average elemental and activity concentrations for ^{40}K, ^{238}U and ^{232}Th are 2.85±1.08%, 3.08±0.46 ppm, 22.38±8.15 ppm and 892.72±337.83, 38.06±5.67, 90.84±33.09 Bq kg^{-1} respectively. Observed highest values of radioactivity concentration of ^{40}K, ^{238}U and ^{232}Th were 1190.01±605.65 (GGN 2), 46.88±25.75 (CCK 2) and 121.01±20.53 (CCK 1) Bq kg^{-1}. Mean annual outdoor and indoor effective dose rates of 0.114 and 0.442 mSv y^{-1}, hazard indices of 0.639 mSv y^{-1} (H_{ex}) and 0.742 mSv y^{-1} (H_{in}) are below the world stipulated standard. Thus, the rocks pose insignificant radiation hazards to people and are safe as construction materials. The elevated levels of annual gonadal dose equivalent (AGDE) and excess lifetime cancer risk (ELCR) of 777.485 µSv y^{-1} and 1.545×10^{-3} respectively suggest regular monitoring of radioactivity levels of geological materials from sources before their adoption in construction. Appropriate agency should be constituted to consistently monitor radiation and prevent associated health problems.**

Keywords: **Construction materials, Gamma-ray spectrometry, Natural radioactivity, Radiological hazard, Radiometric method.**

I. INTRODUCTION

Radiometric surveys identify and map natural radiometric emanations (gamma rays) from environmental materials like rocks and soils. The availability of rocks and their weathered constitutes (soils) in our environment are the main sources of radiation exposure to the human population (Radiation information network 2004). The importance of rocks and rock aggregates cannot be exaggerated in construction and concrete design globally (Ademila 2019). All detectable gamma radiation from earth materials originates from the natural decay products of only three elements, i.e. uranium, thorium, and potassium. While many naturally occurring elements have radioactive isotopes, only potassium, uranium and thorium decay series, have radioisotopes that produce gamma rays of adequate energy and intensity to be measured by gamma ray spectrometry. This is because they are relatively available in the natural environment.

All natural materials contain radionuclides which are mainly in ^{238}U, ^{232}Th series and the radioactive isotope of potassium, ^{40}K. Human beings are exposed to external radiation from the natural radionuclides of construction or building materials (UNSCEAR 2000). Activities associated with excavating the soils to some depth and blowing up rock outcrops to mine the natural resources, bring these naturally occurring radionuclides to the soil surface. The most suitable rocks proven as road and building stones in the study area are fine grained granite, granite gneiss and charnockite (Ademila 2019). Higher and lower radiation levels are related with igneous rocks, such as granite and sedimentary rocks respectively. These release natural radionuclides and radiations into various constituents of the atmosphere.

Radiation exposure form construction materials can be categorized into external and internal exposures. External exposure is caused by direct gamma-ray irradiation, whereas internal exposure is caused by breathing of the radioactive inert gases radon (^{222}Rn), thoron (^{220}Rn) and their air-borne short-lived progenies. The exposure of human body to ionizing radiation leads to different biological effects which may later

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develop to clinical symptoms (ICRP 1992). Nevertheless, continuous radiation monitoring, assessment and control measure is recommended to prevent possible increase in radiation level (Ademila and Ugo 2018).

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 (Cinar et al. 2017; Ademila et al. 2018). The assessment of radiation levels in different rock aggregates and soils before supply to the end users in construction works becomes necessary since rock radionuclides constitute parts of the radiation exposure to human and environmental health (Ademila 2018). Gamma radiation from radionuclides which are characterized by half-life equivalent to the age of the earth, such as ^{40}K and the radionuclides from the ^{238}U and ^{232}Th and their decay products are the main external sources of radiation to humans (IAEA 2003). Determination of activity concentrations in naturally occurring materials used as building materials become necessary as the major source of radiation exposure to humans are the naturally occurring radionuclides and also for radiation protection and safety.

Rocks have usually been used as construction aggregates for sometime without the knowledge of the activity concentrations of radionuclides present and the potential radiological hazards associated with the building materials. The distribution of these naturally occurring radionuclides depends on the source of the distribution of the rocks and the processes that concentrate them. Studying the levels of radionuclide distribution in the environment presents essential radiological information. Many sicknesses and diseases which should have been efficiently managed if radiological information of an environment was available would not have been attributed to other sources.

Lack of radiological information on the effect of the radiations from the rocks on the people living around the study area necessitated this study by investigating the activity concentration of radionuclides present in the suitable rocks that serve as building/construction aggregates and to evaluate the radiological hazards to people and environmental health. This will provide radiological remedial action on the use of the rocks if necessary and serve as baseline information to assess radioactivity concentrations of construction materials in future.

II. DESCRIPTION AND GEOLOGY OF THE STUDY AREA

The study area (Akure) is the capital of Ondo State of Nigeria, lies between latitudes 7° 13' N and 7° 19' N and longitudes 5° 07' E and 5° 14' E. It is bounded to the north by Ikere and Akure North local government areas, Owo to the east, Ile-Oluji/Oke-Igbo local government area to the west and flanked to the south by Idanre local government area. It is geographically located within the tropical rainforest belt of hot, wet equatorial climatic region. The vegetation is of the rain forest type with evergreen and broad-leaved trees. It is identified with distinct wet and dry seasons, fairly uniform temperature, heavy and well distributed rainfall throughout the year with relatively high humidity. The annual temperature range is between 22°C during harmattan (December to February) and 32°C in March, while the rainfall reach its climax twice in July and September. It varies between 1,500 mm and 3,500 mm per annum. The rainfall distribution decreases from the coast to the hinterland.

The study area lies within the Precambrian rocks of the Basement Complex of Southwestern Nigeria (Figure 1). The Basement Complex rocks of Nigeria forms a part of the African Crystalline Shield which occurs within the Pan-African Mobile Belt that lies between the West African and Congo Cratons and South of the Tuareg Shield which were affected by the Pan-African Orogeny. The Southwestern basement falls within the triangular part of the Nigerian basement, an extension of the Dahomeyide Shield of the West African Craton. It is characterized by four of the six petrological units of the Basement Complex of southwestern Nigeria as identified by Rahaman (1988), which are the migmatite-gneiss-quartzite complex, charnockitic and dioritic rocks, older granites and unmetamorphosed dolerite dykes (Olarewaju 1981). The migmatie-gneiss-quartzite complex consisting mainly of granite gneiss, grey gneiss and quartzite. The lithological units generally occur as low-lying outcrops. Though, granite gneiss occurs as slightly elevated to hilly outcrops. The charnockitic rocks compose of coarse-grained, massive fine-grained and the gneissic fine-grained varieties. These rocks are generally low lying outcrops with smooth rounded boulders and few low lying hills, forming oval to sub circular and elongated bodies. Granites occur as small conical hills (inselbergs) in several places. The texture ranges from fine to coarse grained and based on this, three principal varieties are recognized within the area. These are fine-grained biotite granite, medium to coarse grained non-porphyritic biotite-hornblende granite and the coarse porphyritic biotite-hornblende granite. The dolerite dykes, are mainly black and fine-grained lithological units. They are considered as the youngest members of the Basement Complex. On the other hand, quartzite occurs as elongated bands in the gneisses. The rock is widely fractured. The migmatie-gneiss-quartzite complex in Southwestern Nigeria is affected by three major geotectonic events ranging from Early Proterozoic of 2000 Ma to Pan-African events of ~600 Ma (Ajibade and Fitches 1988; Oyinloye 2011). The rocks of the basement have been affected by medium pressure Barrovian metamorphism (Rahaman et al. 1983; Oyinloye 2011). It is located on a gently undulating terrain surrounded by isolated hills and inselbergs, underlain by granites, charnockites, quartzites, granite gneisses and migmatite gneisses (Olarewaju

1981). The dominant rock types in the study area are charnockites, granite gneiss and migmatitic rocks (Figure 2). The area is majorly drained by River Ala, River Owena, River Ogburugburu and their major tributaries with a dendritic drainage pattern.

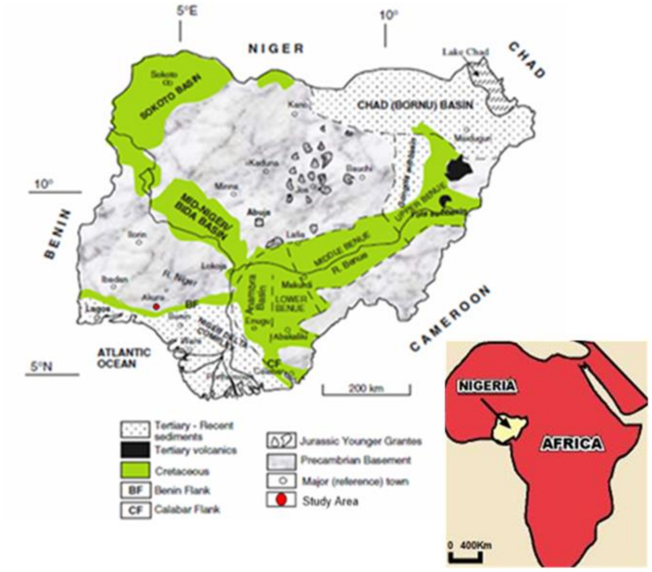


Fig. 1. Geological Map of Nigeria showing the study area (Modified after Obaje 2009)

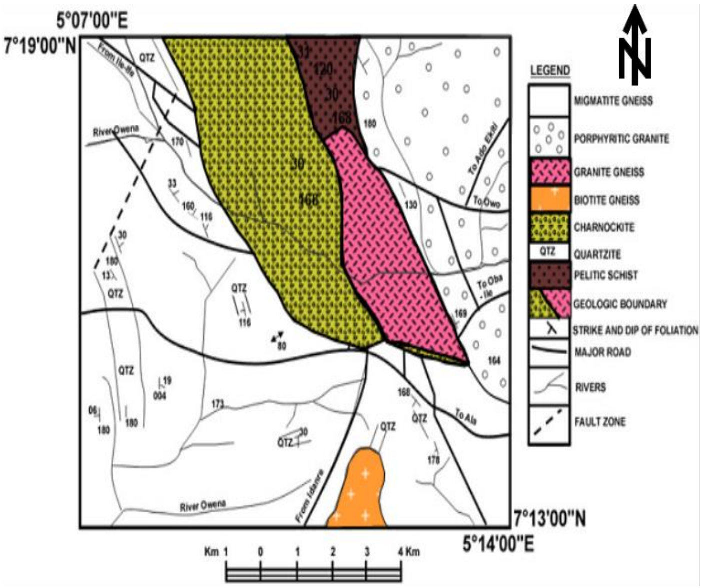


Fig. 2. Geologic map of the study area (Modified after Olorunfemi et al. 1999)

III. MATERIALS AND METHODS

A. Field Measurements

This research entails comprehensive geological field mapping to determine the local geology of the area. At each location, rock outcrops were carefully examined and described. Measurements were taken along six traverses (two traverses were established on the same rock type in different locations of the study area) on fine grained granite, granite gneiss and charnockite for radiometric analysis. The traverses varied from 200 - 300 m with station spacing of 5 m. These rock types, among others, were selected not only because of their massive occurrence/abundance and their usage as construction aggregates, but also their low water absorption, abrasion values, flakiness and elongation indices, high strength values (tensile strength and unconfined compressive strength) and sound petrographic characters (Ademila 2019).

The radiometric survey employed Gamma ray spectrometry. The ground radiometric measurements utilized a highly sensitive portable hand-held Gamma-ray spectrometer. The instrument was calibrated for constants associated with the instrument count rates and environmental dose rate, to correct for the background radiations (especially the internal radioactivity of the instrument, cosmic radiation, and atmospheric radon effects), stripping ratios and sensitivity constants. The instrument has the capacity of recording full gamma ray spectrum and summing their channels over broad energy windows for assessment of elemental concentrations of K, U and Th (IAEA 2003). A total number of 306 stations were occupied to quantify the natural gamma radiation levels of K (%), eU (ppm) and eTh (ppm) related with the 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 range of radioelements, absorbed dose rate, annual effective doses, activity concentration index, and other radiological parameters. The results were interpreted using different pictorial representations to determine the significant relationships between the radiations from the different rock outcrops.

B. *Estimation of Radiation Hazard Parameters*

1) *Absorbed Dose Rate (D)*

Gamma radiation effects are usually expressed in terms of the absorbed dose rate in air, which emanate from radioactive sources in the rock outcrops and soils in the study area. This quantity is used to measure the radiation exposure to human body so as to assess the amount of radiological hazards to humans due to the concentrations of ^{238}U, ^{232}Th and ^{40}K in the environmental materials. The absorbed dose rates in air (nGyh^{-1}) along the traverses established were computed using the expression given by UNSCEAR (2000):

$$D = (0.462\ C_U + 0.621\ C_{Th} + 0.0417\ C_K)\ \text{nGyh}^{-1} \qquad (1)$$

Where: D is the absorbed dose rate in nano grey per hour (nGyh^{-1}), C_U, C_{Th} and C_K represent the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bqkg^{-1} were estimated from the measured elemental concentrations of ^{238}U (ppm), ^{232}Th (ppm) and ^{40}K (%) respectively using the conversion factors stipulated by IAEA (2003) as follows:

$$1\ \text{ppm} = 10^{-4}\ \% \tag{2}$$

$$1\%\ ^{40}\text{K} = 313\ \text{Bqkg}^{-1} \tag{3}$$

$$1\ \text{ppm}\ ^{238}\text{U} = 12.35\ \text{Bqkg}^{-1} \tag{4}$$

$$1\ \text{ppm}\ ^{232}\text{Th} = 4.06\ \text{Bqkg}^{-1} \tag{5}$$

2) Annual Effective Dose Equivalent (H_E or AEDE)

Annual effective dose equivalent (H_E) or AEDE is an important quantity used when assessing building materials like bricks, soils, concrete, granite gravels, stones or rocks for construction. These construction materials are capable of increasing the level of indoor radiation and shield radiation from the air (i.e. outdoor radiation) (UNSCEAR 2000; Tzortzis et al. 2003). These factors may contribute to the increase in radiation doses to the people. On the 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 factors respectively. Conversion coefficient value of 0.7 Sv y^{-1} was used for converting the absorbed dose in air to effective dose rates (H_E) in units of mini Sievert per year (mSv y^{-1}) (UNSCEAR 2000). Hence, (H_E) is calculated by using Equation 6:

$$H_E = D \times T \times F \tag{6}$$

Where D is the dose rate (nGy h^{-1}), T is the indoor/outdoor occupancy time for one year 24h × 365.25 ≈ 8760 hrs and F is the conversion factor ($F = 0.7 \times 10^{-6}$ 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:

$$H_E\ (\text{outdoor})\ (\text{mSv y}^{-1}) = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \tag{7}$$

$$H_E\ (\text{indoor})\ (\text{mSv y}^{-1}) = D \times 8760 \times 0.8 \times 0.7 \times 10^{-6} \tag{8}$$

The H_E (indoor) occurs in a house where radiation hazards due to the use of construction materials are taken into cognizance. H_E (outdoor) considers the absorbed dose emitted from radionuclide in the vicinity of the location.

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

Natural radionuclide in soil, rocks, sediments and other environmental constituents produce external radiation to which all humans are exposed. External and internal exposures are major ways of radiation hazard threat to the people from construction materials. Radiation exposure threat to respiratory organs may be as a result of increase above the safe limit of internal exposure to radionuclide (Tufail et al. 2007). Thus, assessment of health implications of people exposure to the radiation of the earth's surface materials containing ^{238}U, ^{232}Th and ^{40}K radiation hazards from the external and internal sources are important. The external and internal radiological hazards from the rocks of the study area were quantified by the external and internal hazard indices (H_{ex} and H_{in}) which are given by the following equations (Ramasamy et al. 2009):

$$H_{ex} = C_U/370 + C_{Th}/259 + C_K/4810 \ \leq 1 \tag{9}$$

$$H_{in} = C_U/185 + C_{Th}/259 + C_K/4810 \ < 1 \tag{10}$$

Where C_U, C_{Th} and C_K are the activity concentration in Bqkg^{-1} for ^{238}U, ^{232}Th, and ^{40}K respectively. The external (H_{ex}) and internal (H_{in}) radiation hazard indices must be less than 1 (one) for the radiation hazard to be negligible (Beretka and Mathew 1985). Thus, the construction materials would be safe if the external and internal hazard indices, H_{ex} and $H_{in} \leq 1$. Thus, for the safe use of environmental materials in building construction, the permissible limit of the external and internal hazard indices should be less or equal to one. The European Commission (EC) suggested that gamma index (I_γ) could be used to examine if the materials meet the limits of dose criteria. In this study, gamma index (I_γ) is used to estimate the level of gamma radiation hazard related with the natural radionuclides in selected rock outcrops of the study area. I_γ must be less than one for radiation hazard to be insignificant and for the safe use of materials in the construction of engineering structures. For the evaluation of excess gamma radiation from the rock outcrops to ensure the safety of the construction materials, gamma index, I_γ is calculated using the following Equation 11 (EC 1999).

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

Where C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bqkg^{-1} respectively.

4) Annual Gonadal Dose Equivalent (AGDE)

The Annual Gonadal Dose Equivalent (AGDE) or annual genetically significant dose equivalent (AGSDE) is a parameter for detecting the genetic significance of the yearly dose equivalent received by the people's reproductive organs (gonads) (Morsy et al. 2012). AGDE was calculated because of gonads such as bone marrow and bone surface cells that are sensitive to radiation. An increase in AGDE above the permissible limit in humans over time can cause leukemia in the bone marrow (i.e. cancer of the bone marrow) (UNSCEAR 2000). Hence, AGDE received by humans from such building material was evaluated using Equation 12 (Mamont-Ciesla et al. 1982).

$$\text{AGDE}\ (\mu\text{Sv/y}) = 3.09C_U + 4.18C_{Th} + 0.314C_K \tag{12}$$

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

5) Excess Lifetime Cancer Risk (ELCR)

Excessive lifetime cancer risk is the possibility or threat of an individual to develop a cancerous cell as a result of exposure to toxic and harmful substances from various exposure pathways over time. Excess lifetime cancer risk was estimated using Equation 13 (Taskin et al. 2009), to determine the probability of developing cancer in a person that is exposed to such radiation (from birth till death) over a lifetime.

$$ELCR = H_E\,(\text{indoor}) \times LE \times RF \qquad (13)$$

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 (1992) used RF = 0.05 as cancer risk factor for people in an area.

6) Activity Utilization Index (I)

Distribution of natural radioactivity in environmental constituents is not uniform. Rocks radionuclides constitute parts of the radiation exposure to human and its environment. Thus, it becomes very important to evaluate the radiation levels in different rock aggregates and residual soils before supply to end users in construction works. This is to ensure radiation protection, safety of lives of people and secure environmental health (Ademila 2018). Activity concentrations of natural radionuclides in construction materials is a vital factor of the indoor absorbed dose rate, while radiation emitted by sources outdoors is wholly absorbed by the roofs and walls. Therefore, dose rates in air indoors increase following the activity concentration of naturally occurring radionuclides present in the construction rock aggregates used. The rocks were examined for their suitability as building construction materials by estimating the activity utilization index (I). The activity utilization index (I) was calculated using the expression given by Ravisankar et al. 2012b:

$$I = (C_U/50\ Bqkg^{-1})\, f_U + (C_{Th}/50\ Bqkg^{-1})\, f_{Th} + (C_K/500\ Bqkg^{-1})\, f_K \qquad (14)$$

Where C_U, C_{Th} and C_K are the activity concentrations ($Bqkg^{-1}$) of ^{238}U, ^{232}Th and ^{40}K of the rocks under study respectively, f_U (0.462), f_{Th} (0.604), and f_K (0.041) are the fractional contributions to the total dose rate in air due to gamma radiation from the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

IV. RESULTS AND DISCUSSION

Elemental and natural radioactivity concentrations of ^{40}K, ^{238}U and ^{232}Th estimated in the various rock outcrops of the study area are given in Table 1. The range of the elemental concentrations of the radioelements are BDL (FGG 2) – 8.56% (GGN 2) ^{40}K, BDL (all the rock outcrops except GGN 1) – 13.10 ppm (GGN 2) ^{238}U and 4.60 (GGN 2) – 56.50 ppm (GGN 2) ^{232}Th with the weighted mean values of 2.85±1.08%, 3.08±0.46 ppm and 22.38±8.15 ppm for ^{40}K, ^{238}U and ^{232}Th respectively (Table 1). The variation of the elemental concentrations of ^{40}K, ^{238}U and ^{232}Th in different rock outcrops of the study area are shown in Fig. 3. The observed highest values of radioactivity concentration of ^{40}K, ^{238}U and ^{232}Th are 1190.01±605.65 (GGN 2), 46.88±25.75 (CCK 2) and 121.01±20.53 (CCK 1) Bq kg^{-1}, while the lowest values are 280.73±151.59 (FGG 2), 32.93±16.90 (FGG 1) and 49.58±11.84 (FGG 2) Bq kg^{-1} respectively (Fig. 4). The weighted mean values are 892.72±337.83, 38.06±5.67 and 90.84±33.09 Bq kg^{-1} respectively (Table 1). The variation of the activity concentration in the rocks (Fig. 4) may be due to the mineral content in the different rock types. In comparison with the world average value, the elemental concentrations of ^{40}K, ^{238}U and ^{232}Th are above the average crustal concentrations of 2 – 2.5%, 2 – 3 ppm, and 8 – 12 ppm (IAEA 2003) and the natural radioactivity of the rocks are above the normal environmental activity concentration level of 420, 33 and 45 Bq kg^{-1} (UNSCEAR 2000) respectively. The increased level of activity concentrations above world range suggests presence of radioactive minerals in the rocks and topsoil produced by K-feldspar, silica, and U- and Th-bearing minerals. The variations in activity concentrations of these radionuclides in the rocks are due to the variations in the chemical composition of the geological formations. The results as shown in Fig. 4 indicated that the activity concentration values are in the order $^{40}K > {}^{232}Th > {}^{238}U$ in all the locations of the rock outcrops. The spatial distribution of the radionuclides across the rock outcrops which revealed dominance of ^{40}K could be as a result of higher silica content in the rocks and feldspathic classification of rock formation of the study area (Fig. 4). However, decrease in ^{40}K radionuclide along FGG 2 could probably be due to deep weathering of the potassic feldspar and other radioactive bearing minerals in the rocks. High radiation levels from natural radionuclide have been associated with granitic and silicic igneous rocks (Brimhal and Adams 1982). The mean values of the total count (TC) emission rate per second of the natural radionuclides range from 372.47±5.48 (GG1) – 412.09±13.70 cps (FGG 2) with weighted mean of 394.58±16.27 cps (Table 1).

The absorbed dose rate (D) values vary from 58.02±11.51 (FGG 2) to 141.01±22.79 nGy h^{-1} (CCK 2) with a mean value of 90.09±31.82 nGy h^{-1} (Table 2). The estimated mean value of the absorbed dose rate of 90.09±31.82 nGy h^{-1} is slightly higher than the world average value of 60 nGy h^{-1}, but within the world permissible range of 28 – 120 nGy h^{-1} for rocks and soils (UNSCEAR 2000). The levels of gamma radiation in the rock outcrops are due to mineralogical compositions and activity concentrations of radionuclide in the geological materials.

The calculated annual outdoor and indoor effective dose rates range from 0.073 (FGG 2) – 0.178 mSv y^{-1} (CCK 2) and 0.285 (FGG 2) – 0.692 mSv y^{-1} (CCK 2) with averages of 0.114 mSv

y^{-1} and 0.442 mSv y^{-1} respectively (Table 2). Higher values of annual outdoor effective doses beyond the permissible limit of 0.07 mSv y^{-1} (UNSCEAR 2000) are obtained in all the traverses of the rock outcrops except FGG 2. Also, indoor effective doses of all the rock outcrops are below the standard value of 0.41 mSv y^{-1} (UNSCEAR 2000) except CCK 2 and GGN 1 which are slightly above this recommended level. CCK 2 and GGN 1 with annual outdoor effective dose rates of 0.178 and 0.147 mSv y^{-1} are about two times higher than the recommended limit, others are slightly higher. Nevertheless, the observed annual outdoor and indoor effective doses are below the world maximum permissible level of 1 mSv y^{-1} (ICRP 1992). The mean external and internal hazard values range from 0.341 (FGG 2) – 0.809 (CCK 2) and 0.431 (FGG 2) – 0.936 (CCK 2) respectively (Table 2).

The calculated external and internal hazard values of all the rocks are below the recommended level of 1 (Table 2 and Fig. 5). There is no radiological hazard emanating from external and internal exposure of the people living in and around the study area and interaction with the rocks would not cause significant radiological risk. Therefore, these geological materials can safely be used in building construction. Radiation hazard threat to respiratory organs may be as a result of increase above the safe limit of internal exposure to radionuclide (Tufail et al. 2007). This indicates that utilization of the rocks in the study area would not lead to respiratory tract disease such as asthma and other external diseases like skin cancer, erythema and cataracts.

Table 1. Mean activity concentration of radionuclides in the selected rock types

Rock outcrop/ Traverse		Elemental Concentration			Activity Concentration			Total count (cps)
		K (%)	U (ppm)	Th (ppm)	K (Bq/kg)	U (Bq/kg)	Th (Bq/kg)	
Fine grained Granite 1	Range	0.37-5.03	BDL-6.32	4.80-24.90	115.81-1574.39	BDL-78.05	19.49-101.09	383.40-451.70
(FGG 1)	Mean±SD	2.40±1.33	2.67±1.37	12.41±4.13	755.67±42.21	32.93±16.90	50.38±16.76	408.30±15.95
Fine grained Granite 2	Range	BDL-2.47	BDL-5.6	7.70-19.60	BDL-773.11	BDL-69.16	31.26-79.58	362.80-438.60
(FGG 2)	Mean±SD	0.90±0.48	2.72±1.39	12.21±2.92	280.73±151.59	33.60±17.11	49.58±11.84	412.09±13.70
Charnockite 1	Range	0.61-5.83	BDL-9.70	19.10-38.80	190.93-1824.79	BDL-119.80	77.55-157.53	370.90-401.60
(CCK 1)	Mean±SD	3.06±1.25	3.46±2.61	29.81±5.06	957.78±389.84	42.74±32.23	121.01±20.53	385.50±7.57
Charnockite 2	Range	1.04-7.32	BDL-8.90	17.70-48.40	325.52-2291.16	BDL-109.92	71.86-196.50	378.80-442.60
(CCK 2)	Mean±SD	3.70±1.40	3.80±2.09	28.21±6.91	1156.57±438.71	46.88±25.75	114.53±28.07	405.91±16.11
Granite gneiss 1	Range	1.32-5.41	0.20-6.20	12.10-41.20	413.16-1693.33	2.47-76.57	49.13-167.27	364.10-387.10
(GGN 1)	Mean±SD	3.24±1.14	2.77±1.69	22.92±6.84	1015.57±356.19	34.19±20.82	93.05±27.78	372.47±5.48
Granite gneiss 2	Range	1.54-8.56	BDL-13.10	4.60-56.50	482.02-2679.28	BDL-161.79	18.68-229.39	368.10-401.60
(GGN 2)	Mean±SD	3.80±1.94	3.08±3.20	28.69±12.77	1190.01±605.65	38.01±39.54	116.50±51.86	383.21±8.84
Weighted Mean		2.85±1.08	3.08±0.46	22.38±8.15	892.72±337.83	38.06±5.67	90.84±33.09	394.58±16.27

SD = standard deviation, BDL = below detection limit

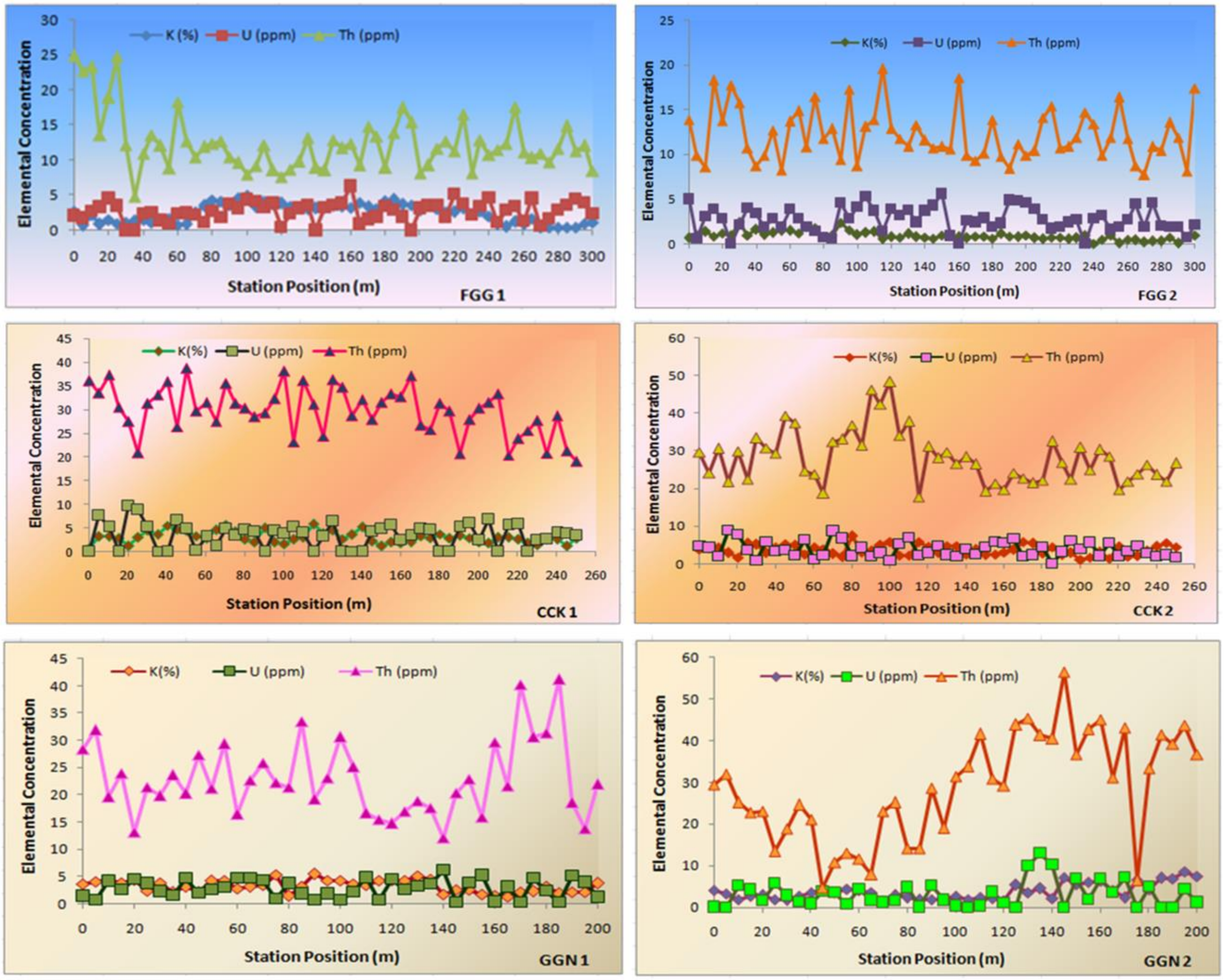
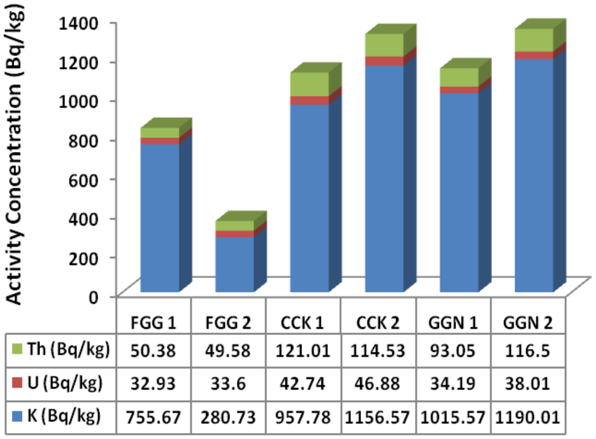


Fig. 3. Elemental concentrations of K (%), U (ppm), and Th (ppm) along the rock outcrops



	FGG 1	FGG 2	CCK 1	CCK 2	GGN 1	GGN 2
Th (Bq/kg)	50.38	49.58	121.01	114.53	93.05	116.5
U (Bq/kg)	32.93	33.6	42.74	46.88	34.19	38.01
K (Bq/kg)	755.67	280.73	957.78	1156.57	1015.57	1190.01

Fig. 4. Distribution of the activity concentrations of natural radionuclides in the different rock types

Gamma index ((I_γ) takes into consideration the ways and level of quantity of materials used in building construction. For suitability of rock or stone used in construction applications, I_γ should be less than one (UNSCEAR 2000). The estimated gamma radiation hazard level associated with the measured activity concentration of the natural radionuclides of the rock range from 0.453 (FGG 2) – 1.044 (CCK 2) (Table 2). The values of I_γ for all the rocks selected are ≤ 1 (Fig. 5). The value of $I_\gamma \leq 0.5$ corresponds to a dose rate limit of 0.3 mSv y^{-1}, whereas $0.5 \leq I_\gamma \leq 1$ corresponds to a dose rate limit of 1 mSv y^{-1} (European Commission 1999). The rocks can safely be used as building stones for different applications with $I_\gamma \leq 1$ as the materials will distribute an effective dose rate lower than 1 mSv y^{-1} to the residents of such buildings and end users of the geological materials in construction works. The obtained gamma radiation index (I_γ) values in the present study are not above the permissible limit of unity (1) (Fig. 5) and recommended value of 1 mSv y^{-1} for annual effective dose rates. Therefore, the radiological risks to the general public from the rock outcrops and residual soils in the study area are considered insignificant, although, excessive radiation doses to the body from prolong exposure may pose radiological threats in future. Gamma index, $I\gamma \leq 2$ 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 value). Area with $I\gamma > 6$, has annual effective dose rates above 1 mSv y^{-1}, which is higher than the recommended level, hence pose risk to the people in the vicinity of the rocks (European Commission 1999).

The calculated AGDE due to the activities of ^{40}K, ^{238}U and ^{232}Th is ranged from 399.223 (FGG 2) – 986.769 µSv y^{-1} (CCK 2) (Table 2). Values of AGDE of all the rock outcrops are above the recommended limit of 300 µSv y^{-1} (Xinwei *et al*., 2006). The range of excess lifetime cancer risk (ELCR) estimated for the study area is 0.996×10^{-3} (FGG 2) to 2.421×10^{-3} (CCK 2) (Table 2). These values are above the world standard of 0.29×10^{-3} (Taskin et al. 2009). Consequent upon the elevated levels of annual gonadal dose equivalent (AGDE) and excess lifetime cancer risk (ELCR) with average values of 777.485 µSv y^{-1} and $1.545{\times}10^{-3}$ respectively above recommended limits suggest regular monitoring of the radioactivity levels of geological materials from their sources before their adoption as building materials of civil engineering structures. More importantly, continuous accumulation from prolong exposure may pose radiological health risks in future. These higher values imply higher concentration of radionuclides in the area. All the values of the radiological hazard index for the rocks are less than unity (Fig. 5). This suggests that the rocks are safe and suitable as building construction materials of civil engineering works without constituting health challenge. The estimated values for activity utilization index (I), which can be used to establish the applicability of the rocks in construction vary from 0.932 (FGG 2) – 1.935 (CCK 1) with an average of 1.522 (Table 2). The values of activity utilization index (I) are below the world average of 2 (UNSCEAR 2000), which implies an annual effective dose rate < 0.3 mSv y^{-1}. This result shows that the rocks are safe for use in construction applications.

Descriptive statistics of the radionuclides of the rocks are given in Table 3. The mean and standard deviation of the activities for all the rocks were used to explain the disposition and variation of the data. The uranium to thorium (U/Th) and thorium to uranium (Th/U) concentration ratios of the rocks were calculated (Table 3) to determine the elemental abundances or enrichment of the radionuclides in the study area. The mean concentration ratios for U/Th and Th/U range from 0.38 (CCK 1) – 0.73 (FGG 2) and 1.74 (FGG 1) – 8.30 (GGN 1) (Table 3) with weighted mean values of 0.52 ± 0.15 and 4.95 ± 3.04 respectively. The U/Th concentration ratio for the study area is generally above 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 (Chandrasekaran et al. 2014), except for CCK 1, GGN 1 and GGN 2 with higher values than the global Th/U ratio. High level of concentration ratio (U/Th and Th/U) attributed to the enrichment of radioactive minerals in the rocks and presence of radioactive lateritic clay in the residual topsoil of the study area. Skewness describes the degree of asymmetry of a distribution around its mean. The normal distribution has a skewness of zero. Positive skewness shows a distribution with an asymmetric tail extending towards more positive values, while negative skewness signifies a distribution with an asymmetric tail tending towards negative values. Thus, the activity concentrations of the radionuclides in the rocks have both positive and negative skewness values (Table 3), which connotes that the distributions are irregular in nature. Kurtosis expresses the relative peakedness or flatness of a distribution compared with the normal distribution. Positive kurtosis shows a relatively peaked distribution, while negative kurtosis indicates a relatively flat distribution. Hence, the distributions associated with ^{40}K, ^{238}U and ^{232}Th in this study have negative (flat distributions) and positive (peaked distributions) kurtosis values (Table 3). In summary, the activity concentrations of radionuclides in this study encompass negative skewness values with the exemption of ^{238}U with positive skewness. This indicates that the distributions are asymmetrical. The distributions of ^{40}K radionuclide have positive kurtosis value which suggests peaked distribution, while ^{238}U and ^{232}Th radionuclides have negative kurtosis values of flat distribution (Table 4).

Table 2. Mean values of radiological hazard indices in the rock types

Traverse	D (nGy h^{-1})	H_E (outdoor) (mSv y^{-1})	H_E (indoor) (mSv y^{-1})	H_{ex}	H_{in}	Iγ	AGDE (µSv/y)	ELCR (10^{-3})	I
FGG 1	77.89±20.70	0.098	0.381	0.440	0.529	0.613	548.691	1.337	0.975
FGG 2	58.02±11.51	0.073	0.285	0.341	0.431	0.453	399.223	0.996	0.932
CCK 1	78.20±19.98	0.099	0.384	0.782	0.897	1.007	938.641	1.343	1.935
CCK 2	141.01±22.79	0.178	0.692	0.809	0.936	1.044	986.769	2.421	1.912
GGN 1	116.56±16.59	0.147	0.572	0.663	0.755	0.918	813.494	1.990	1.523
GGN 2	68.87±29.24	0.087	0.338	0.800	0.903	1.016	978.089	1.182	1.856
Average	90.09±31.82	0.114	0.442	0.639	0.742	0.842	777.485	1.545	1.522

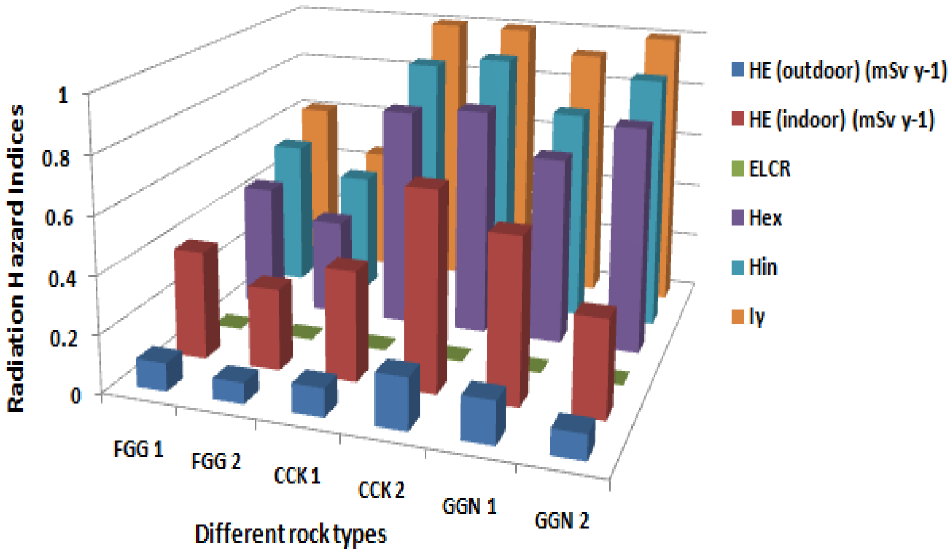


Fig. 5. Radiological hazard indices of the different rock types

Table 3. Statistical description of natural radioactivity concentration measured in different rocks

Traverse	Variables	K (Bq/kg)	U (Bq/kg)	Th (Bq/kg)	U/Th	Th/U
FGG 1	Mean±SD	755.67±42.21	32.93±16.90	50.38±16.76	0.70±0.41	1.74±1.30
	Variance	171570.37	285.53	280.92	0.17	1.68
	Skewness	-0.07	-0.10	1.41	0.29	1.59
	Kurtosis	-1.28	-0.11	2.23	-0.56	3.24
FGG2	Mean±SD	280.73±151.59	33.60±17.11	49.58±11.84	0.73±0.43	1.75±1.37
	Variance	22979.13	292.80	140.29	0.18	1.87
	Skewness	1.06	0.01	0.70	0.40	1.88
	Kurtosis	2.07	-0.58	-0.20	-0.45	4.06
CCK1	Mean±SD	957.78±389.84	42.74±32.23	121.01±20.53	0.38±0.31	6.66±20.59
	Variance	151972.26	1038.74	421.57	0.09	423.93
	Skewness	0.43	0.11	-0.33	0.57	4.34
	Kurtosis	-0.30	-0.66	-0.52	0.39	18.48

CCK2	Mean±SD	1156.57±438.71	46.88±25.75	114.53±28.07	0.44±0.26	3.34±3.04
	Variance	192465.73	663.23	787.89	0.07	9.25
	Skewness	0.20	0.59	0.94	0.75	3.03
	Kurtosis	-0.57	-0.26	0.83	0.48	11.34
GGN1	Mean±SD	1015.57±356.19	34.19±20.82	93.05±27.78	0.44±0.35	8.30±15.24
	Variance	126874.31	433.65	771.84	0.12	232.26
	Skewness	-0.01	0.01	0.82	1.00	3.16
	Kurtosis	-1.03	-1.16	0.51	1.09	9.90
GGN2	Mean±SD	1190.01±605.65	38.01±39.54	116.50±51.86	0.42±0.50	7.92±17.89
	Variance	366807.80	1563.78	2689.70	0.25	320.16
	Skewness	0.82	1.27	-0.10	2.34	3.79
	Kurtosis	-0.38	1.45	-0.80	7.91	15.94

SD = standard deviation

Table 4: Summary of descriptive statistics of natural radioactivity concentration measured in the rocks

Variables	K (Bq/kg)	U (Bq/kg)	Th (Bq/kg)	Rock outcrop	U/Th	Th/U
Weighted Mean	892.72	38.06	90.84	FGG 1	0.70±0.41	1.74±1.30
Standard deviation	337.83	5.67	33.09	FGG 2	0.73±0.43	1.75±1.37
Variance	114127.51	32.18	1094.83	CCK 1	0.38±0.31	6.66±20.59
Skewness	-1.44	0.83	-0.65	CCK 2	0.44±0.26	3.34±3.04
Kurtosis	2.00	-0.94	-2.07	GGN 1	0.44±0.35	8.30±15.24
				GGN 2	0.42±0.50	7.92±17.89

Mean±standard deviation

CONCLUSION

Gamma ray spectrometry was employed to assess the radioactivity levels of ^{40}K, ^{238}U and ^{232}Th in different rock outcrops in Basement Complex terrain of parts of southwestern Nigeria. Radiological hazard indices associated with the radionuclide concentrations were estimated to determine their safety and suitability in building construction. The mean elemental and activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the rock outcrops are higher than the global ranges. This high elemental and radioactivity levels may suggest enrichment of radioactive minerals in the rock outcrops and topsoil produced by K-feldspar, silica, and U- and Th-bearing minerals. The spatial distribution of the radionuclides across the rock outcrops which revealed dominance of ^{40}K could be as a result of higher silica content in the rocks and feldspathic characterization of rock formation of the study area. The estimated mean concentration ratios (U/Th and Th/U) are generally higher than 0.26 and 3.5 global standard respectively, except FGG 1, FGG 2 and CCK 2 which are lower than the global Th/U ratio. The variation of the concentration ratio in the rocks suggests varied mineralogical composition of the different rock types. The estimated mean value of the absorbed dose rate of 90.09±31.82 nGy h^{-1} is higher than the world average value of 60 nGy h^{-1}, but within the permissible range of 28 – 120 nGy h^{-1}.

The obtained annual outdoor and indoor doses, external and internal hazard indices and gamma dose contributions from the rocks are all within the safe limit of unity. Hence, the rocks are safe and suitable as building construction materials and pose no radiological risk to people in the study area and end users of the rocks for indoor and outdoor applications. Increased levels of annual gonadal dose equivalent (AGDE) and excess lifetime cancer risk (ELCR) with average values of 777.485 µSv y^{-1} and 1.545×10^{-3} respectively above recommended limits (300 µSv y^{-1} and 0.29×10^{-3}) suggest that excessive radiation doses to the body from continuous accumulation from prolong exposure may pose radiological threat in future.

From the statistical description of natural radioactivity concentration measured in the rock outcrops, the activity concentrations of radionuclides have negative skewness values with the exemption of ^{238}U with positive skewness. The distributions of ^{40}K radionuclide have positive kurtosis value, signifying peaked distribution, while ^{238}U and ^{232}Th radionuclides have negative kurtosis values, indicative of flat distribution. Thus, remediation procedure by consistent monitoring of the radioactivity levels of geological materials from sources before their adoption as building materials of civil engineering structures should be practiced to minimize population exposure and prevent the associated health problems. It is recommended that government should embrace the constitution of appropriate agency to regularly monitor radiation for protection of human health and environmental safety.

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