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Estimation of Natural Radioactivity and Radiological Risk in Granites from Major Quarries in Osun State Nigeria

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ABSTRACT: The activity concentrations of^{238}U, ^{232}Th and ^{40}K in eighty granite samples from eight major quarry sites (Granite Producers (IQ), Krystal Vountain (KQ), Clario Nig. Ltd. (CQ), Omidiran Nig. Ltd. (OQ), Wolid Quarry (WQ),SlavaYetidepe (YQ), Ayofe/Irepodun and Sons (AQ) and EsproAsphat (EQ)) in Osun State Nigeria were determined by employing high-purity germanium detector. Measured activity concentration values of^{238}U varied from 1.53±0.22 to 58.98±8.84 Bq kg^{-1} with a mean (± standard deviation (SD)) value of 8.80±8.26Bq kg^{-1}, of^{232}Th varied from 1.62±0.35 to 77.85±11.68 Bq kg^{-1} with a mean (±SD) value of 13.20±11.13 Bq kg^{-1} while that of ^{40}K varied from 56.53±23.47 to 672.54±100.88Bq kg^{-1} with a mean (±SD) value of 191.05±121.25Bq kg^{-1}. The activity concentrations, along with appropriate dose conversion factors, were used to calculate the radiological hazard indices: absorbed dose rate in air, annual indoor effective dose equivalent, radium equivalent activity, annual gonadal dose equivalent, external hazard index, internal hazard index, representative gamma index, alpha index and excel lifetime cancer risk to assess the radiation hazard due to natural radionuclides in the granite samples. The mean values of all the hazard indices are lower than internationally acceptable limits for building materials recommended by the International Commission on Radiological Protection (ICRP) and United Nations Scientific Committee on Effects of Atomic Radiation (NSCEAR). Therefore, people working in the quarries, granite end-users, and the general public are safe from radiological health risks from the quarries, since there is no significant health risk.

KEYWORDS: Activity concentration, Radionuclides, Granite, Radiation dose, Radiological parameters

I.INTRODUCTION

Naturally occurring radionuclides are found throughout the earth's crust, and they form part of the natural background of radiation to which man is exposed (NRC, 1999). The existence of these unstable elements in soil, rock, water, and air along with cosmic radiation leads to continuous and largely inescapable radiation exposures of all humans. Exposures vaster than these as a result of the uninterrupted natural background can arise from human activities that move naturally occurring radionuclides from normally unreachable locations to locations where man is present or concentrate naturally occurring radionuclides. Activities of human beings that can elevate exposures to naturally occurring radionuclides by relocation or concentration involve quarrying, milling of mineral ores, extraction crude oil extraction and refining processes, use of groundwater for household purposes, and dwelling in houses. (EPA 1993, NRC, 1999).
The presence of naturally occurring radionuclides in construction materials originating from quarry products offers radiation exposure both inside and outside the building environments mainly due to gamma radiation from^{40}K and members of the uranium and thorium decay series.
Quarry products consist of a wide number of different natural rocks with different mineral contents, crushed into various sizes at quarries. This includes different geological materials such as granite, gneiss, diorite, granodiorite, and other rocks that after an industrial process are suitable for use as a building material and ornamental rocks (Ministry of Energy, British Columbia 2014).
Granite as a natural and abundant resource has great values that can be utilized for the development of south-western Nigeria as it has been widely used as building construction material (Gbadebo*et al.*, 2010). When used as cut-stones or dimension stones, they are considered by many as the premium material for beauty and durability in institutional and

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monumental constructions. Granite as cut-stones can be used in flagging, roofing slates, and mills stock slates. They can be used as curbing and paving blocks and in laboratory furniture and sinks. They have been exploited to line tube mills for grinding one or other materials. However, the only most noticeable usage of these dimension stones till date is its utilization as aggregates in small scale and monumental constructions. The natural radiations from these granitic bodies and other geological formations are other sources of environmental hazard (Fernandez *et al.*, 1992; UNSCEAR, 2000; Doveton and Merriam, 2004).

Researchers from different regions of the world have carried out works on natural radioactivity in granites, unfortunately, none is available for radionuclide level in granite samples of the selected quarries from the surveyed published works. Consequently, knowledge of the level of natural radioactivity in granites from major operational quarries in Osun State is of great significance. The aim of the study is to estimate the natural radioactivity level and associated risks in granites from major quarry sites in Osun State Southwest Nigeria.

II.METHODOLOGY

A. GEOLOGY OF THE STUDY AREA

The study area (Fig. 1) is an inland state located in south-western Nigeria with coordinates 6° 55′ N 4° 06′ E and 8° 07′ N 5° 05′ E and a total area of about 9251 km^2. It is delimited within the North by Kwara State, within the east partially by Ekiti State and partially by Ondo state, in the south by Ogun State and in the west by Oyo State (Osun State Government, 2014). The State is underlain by metamorphic rocks of the basement complex, which outcrop over many parts. Rocks of the basement complex are schists, associated with quartzite ridges of the type found in llesa area. The metamorphic rocks are mostly undifferentiated; however, two specific rock groups may still be identified. The first group consists of the migmatite complex, including banded magmatic and Augen gneisses and pegmatites with outcrops in llesa and lfe areas. Metasediments consisting of schists and quartzites, calcsilicates, meta-conglomerates, amphibolites, and metamorphic iron beds form the second group. They are found in Iwo and lkire areas. Other parts of the state are underlain by undifferentiated metamorphic rocks (Ajeigbe*et al.*, 2014, Physical setting, 2003). Figure 1 is a map of Osun State showing all the local government areas in the state. The coloured regions are the five local governments where quarry sites under study are located.

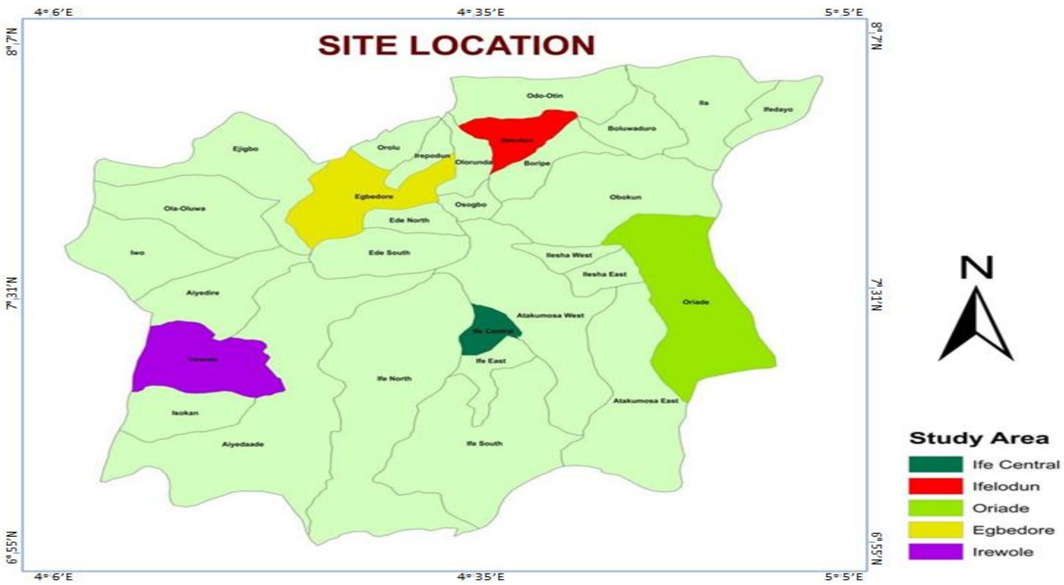

Figure 1.Map of Osun State Nigeria.

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B. SAMPLE COLLECTION AND PREPARATION

Eighty (80) granite samples were collected from eight major operational quarry sites in Osun State. The quarries spread across five local government areas of the State. Each granite sample was packed into a polyethylene bag and clearly labeled to prevent cross-contamination. Table 1 shows quarry names, sample codes, sample numbers and GPS locations. The samples were crushed with a Laboratory Jaw Crusher serial number 2180 manufactured by FritschGmbH Germany. The samples were packed into 1 dm^3Marinelli beakers. The beakers were thick enough to prevent the permeation of radon. The beakers were closed by screw caps and the plastic tape was wrapped over the caps and then stored for four weeks to allow time for ^{222}Rn to attain a state of secular equilibrium with its short-lived daughters prior to gamma spectroscopy (ASTM, 1986).

C. SAMPLE MEASUREMENT AND ANALYSIS OF SPECTRA

The activity concentrations of the samples were determined by using a computerized gamma-ray spectrometry system with high purity germanium (HPGe). The relative efficiency of the detector system was 40 %, and resolution of 1.8 keV at 1.33 MeV of ^{60}Co. The gamma spectrometer was coupled to conventional electronics connected to a multichannel analyzer card (MCA) installed in a desktop computer. A software program called MAESTRO- 32 was used to accumulate and analyze the data (MAESTRO-32, 2008). The detector was located inside a cylindrical lead shield of 5 cm thickness with an internal diameter of 24 cm and height of 60 cm. The lead shield is lined with various layers of copper, cadmium, and Plexiglas, each 3 mm thick. A counting time of 36,000 seconds (10 h) was used to acquire spectral data for each sample**.** The activity concentrations of the uranium-series were determined using γ-ray emissions of ^{214}Pb at 351.9 keV (35.8%) and ^{214}Bi at 609.3 keV (44.8%) for ^{238}U, and for the ^{232}Th-series, the emissions of ^{228}Ac at 911 keV (26.6%), ^{212}Pb at 238.6 keV (43.3%) and ^{208}Tl at 583 keV (30.1%) were used. The ^{40}K activity concentration was determined directly from its emission line at 1460.8 keV (10.7%) (See figure 2).

D. CALCULATION OF ACTIVITY CONCENTRATION

The specific activity concentrations (A_{sp}) of ^{238}U, ^{232}Th, and ^{40}K in Bq kg^{-1} for the rock samples were determined using the following expression (Tzortzis*et al*, 2003).

$$A_{sp} = \frac{N_{sam}}{\gamma_E . \varepsilon . T_c . M} \quad (1)$$

where:

N_{sam} = net counts of the radionuclide present in the sample, γ_E = gamma yield (gamma-ray emission probability), ε = total counting efficiency of the detector system, T_c = sample counting time and M = mass of sample (kg).

E. EVALUATION OF RADIOLOGICAL PARAMETERS

1) Absorbed Dose Rate in Air (D)

Radiation exposure resulting from radionuclides in granite can be determined in terms of many parameters. A direct link between ^{238}U, ^{232}Th, and ^{40}K (Bq kg^{-1}) concentrations in the granite samples was used to calculate the absorbed dose rate given by the relation (2) UNSCEAR, (2010).

$$D\ (nGy\ h^{-1}) = 0.462C_U + 0.604C_{Th} + 0.0417C_K \quad (2)$$

where:

D is the absorbed dose rate in nG y^{-1}, C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively. The dose coefficients in units of nG y^{-1} per Bq kg^{-1} were taken from UNSCEAR, (2010).

2) Annual Effective Dose Equivalent (AEDE)

The absorbed dose rate in the air at about 1metre above the ground surface does not directly provide the radiological hazard to which an individual is exposed (Jibiri*et al*, 2007). Using an indoor occupancy factor of 0.8 and conversion

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factor of 0.7 SvG y^{-1}, the AEDE due to terrestrial gamma radiation was calculated using the following formula (UNSCEAR, 1998, Ajayi, 2002).

$$AEDE\ (mSv\ y^{-1}) = Absorbed\ Dose\ rate\ (\ nGy\ h^{-1}) \times 8760\ h\ \times 0.8\ \times 0.7\ Sv\ G\ y^{-1} \times 10^{-6} \qquad (3)$$

1) Radium equivalent activity (Ra_{eq})

For the purpose of comparing the radiological effect of the activity of materials that contain ^{238}U, ^{232}Th, and ^{40}K by a single quantity which take into account the radiation hazards associated with them, a common index termed Radium equivalent activity (Ra_{eq}) is used (Thabayneh and Jazzar, 2012). $Ra_{eq}$was calculated using the relation (Shittu*et al*, 2015).

$$Ra_{eq} = C_U + 1.430C_{Th} + 0.077C_K \qquad (4)$$

where:

C_U, C_{Th}, and C_K are the radioactivity concentration of ^{238}U, ^{232}Th and ^{40}K in the granite samples.

2) Hazard Indices

To estimate the gamma-radiation dose expected to be delivered externally from building materials, a model was suggested by various researchers to limit the radiation dose from the building materials to 1.5 mSv y^{-1} (Fares *et al*, 2011). In this model, the external hazard index (H_{ex}) is defined as (Beretkaand Mathew, 1985)

$$H_{ex} = \frac{C_U}{370\ Bq\ kg^{-1}} + \frac{C_{Th}}{259\ Bq\ kg^{-1}} + \frac{C_K}{4810\ Bq\ kg^{-1}} \qquad (5)$$

where:

C_U, C_{Th}, and C_K are the radioactivity concentration of ^{238}U, ^{232}Th, and ^{40}K in the granite samples.

Internal exposures arise from the inhalation of radon (^{222}Rn) gas and its short-lived decay products as well as from the inhalation and ingestion of other radionuclides (Ajayi, 2009, Fares *et al*, 2011). To assess the internal exposure to ^{222}Rn gas, the internal hazard index will be determined using (Beretka and Mathew, 1985).

$$H_{in} = \frac{C_U}{185\ Bq\ kg^{-1}} + \frac{C_{Th}}{259\ Bq\ kg^{-1}} + \frac{C_K}{4810\ Bq\ kg^{-1}} \qquad (6)$$

where: C_U, C_{Th}, and C_K are the radioactivity concentration of ^{238}U, ^{232}Th, and ^{40}K in the granite samples.

3) Representative gamma index (I_γ)will be determined using relation (Tufail*et al*., 2006).

$$I_\gamma = \frac{C_U}{150\ Bq\ kg^{-1}} + \frac{C_{Th}}{100\ Bq\ kg^{-1}} + \frac{C_K}{1500\ Bq\ kg^{-1}} \qquad (7)$$

where:

C_U, C_{Th}, and C_K are the radioactivity concentration of ^{238}U, ^{232}Th, and ^{40}K in the granite samples.

4) Alpha index

Various indexes referred to as "alpha-indexes" concerned with the evaluation of excess α-radiation ascribable to the radon inhalation coming from building materials have been invented by researchers (Krieger, 1981; Stoulos et al. 2003). Alpha indexes were calculated in this study using (Righi and Bruzzi, 2006)

$$I_\alpha = \frac{C_U}{200\ Bq\ kg^{-1}} \qquad (8)$$

where C_U is ^{238}U activity concentration in granite sample.

5) Annual gonadal dose equivalent (AGDE)

The gonads, the bone marrow, and the bone surface cells are considered as organs of interest (UNSCEAR, 2000) because they are the most sensitive parts of the human body to radiation. An increase in AGDE has been known to affect the bone marrow, causing destruction of the red blood cells that are then replaced by white blood cells. This situation results in a blood cancer called leukemia which is fatal. The annual gonadal dose equivalent (AGDE) is calculated using the equation (Tufail*et al*., 2006).

$$AGED(mSv\ y^{-1}) = 3.09C_U + 4.18C_{Th} + 0.314C_K \qquad (9)$$

where:

C_U, C_{Th}, and C_K are the radioactivity concentration of ^{238}U, ^{232}Th, and ^{40}K in the granite samples.

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6) Excess lifetime cancer risk (ELCR)

Gamma-emitting radionuclides in and accumulation of radon and its products from building materials in a room are known to produce carcinogenic effects. ELCR deals with the probability of developing cancer over a lifetime at a given exposure level. It is presented as a value representing the number of cancers expected in a given number of people on exposure to a carcinogen at a given dose. It is worth noting that an increase in the ELCR causes a proportionate increase in the rate at which an individual can get cancer of the breast, prostate or even blood. Excess lifetime cancer risk (ELCR) is given as (Taskin*et al.*, 2009).

$$ELCR = AEDE \times DL \times RF \quad (10)$$

where:

AEDE is the Annual Effective Dose Equivalent, DL is the average duration of life (estimated to 70 years), and RF is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP (2012) uses RF as 0.05 for the public (Avwiri, *et al.*, 2014).

III.RESULTS AND DISCUSSIONS

A. ACTIVITY CONCENTRATIONS OF NATURAL RADIONUCLIDES

The analytical results of the activity concentration measurements of ^{238}U, ^{232}Th and ^{40}K for each granite sample are displayed in Table 2 together with their uncertainties. The activity concentration of ^{238}U varied from 1.53±0.22 Bq kg^{-1} in Wolid Quarry sample (WQ6) to 58.98±8.84 Bq kg^{-1} in EsproAsphat sample (EQ3) with a mean (± Standard Deviation (SD)) value of 8.80±8.26 Bq kg^{-1}. That of ^{232}Th ranged from 1.62±0.35 Bq kg^{-1} in SlavaYetidepe sample (YQ9) to 77.85±11.68 Bq kg^{-1} in EsproAsphat sample (EQ3) with a mean (±SD) value of 13.20±11.13 Bq kg^{-1} and of ^{40}K varied from 56.56±23.47 Bq kg^{-1} in Wolid Quarry sample (WQ4) to 672.54±100.88Bq kg^{-1} in Krystal Vountain sample (KQ3) with a mean (±SD) value of 191.05±121.25 Bqkg^{-1}. Thus all the mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K for all the granite samples are less than worldwide average of 35 Bq kg^{-1}, 30 Bq kg^{-1} and 400 Bq kg^{-1}respectively reported by UNSCEAR (1988 and 2000). They are also lower than the 50 Bq kg^{-1}, 50 Bq kg^{-1} and 500 Bqkg^{-1} reported in UNSCEAR (2008) for ^{238}U, ^{232}Th and ^{40}K respectively for building materials. The mean activity concentration values obtained for these primordial radionuclides in the investigated granites are compared with those obtained in other parts of the world in Table 3. The table shows that the mean activity concentration values for all the radionuclides are lower than those obtained in other studies. The table also shows that radioactivity in granite samples vary from country to country and region to region in the same country (Egypt, India, Turkey and Greece) depending on their local geology.

Of the 80 granite samples measured, “EQ3” presents the highest activity concentrations for ^{238}U (58.98±8.84 Bq kg^{-1}) and ^{232}Th (77.85±11.68 Bq kg^{-1}) while “KQ3” presents the highest activity concentration level of 672.54±100.88 Bq kg^{-1} for ^{40}K. “EQ2” and “EQ1” display the second (36.73±7.01 Bq kg^{-1}) and third (34.24±6.04 Bq kg^{-1}) highest activity concentration of ^{238}U while “EQ2” and “EQ4” show the second (47.62±7.14 Bq kg^{-1}) and third (43.86±4.18 Bq kg^{-1}) highest activity concentration of ^{232}Th. “EQ2” and “KQ7” show the second and third highest activity concentration of ^{40}K extending to 470.13±70.52 Bq kg^{-1} and 426.68±64.00 Bq kg^{-1} respectively. Only three (about 4%) samples “EQ1”, “EQ2” and “EQ3” show activity concentrations of above 30 Bq kg^{-1} for ^{238}U. These three samples were collected from the same quarry site and of same size (three-quarters inch). The same three samples and “EQ4” (half-inch size) exhibit activity concentration of ^{232}Th above 40Bq kg^{-1}. Sixteen samples made up of eight “$\frac{3}{4}$-inch”, five “$\frac{1}{2}$-inch” and three “stone dust” display activity concentrations of ^{40}K above 300 Bq kg^{-1}. This represents 20% of the 80 samples. “WQ6”, “YQ9” and “WQ4” show the lowest activity concentration 1.53±0.22 Bq kg^{-1}, 1.62±0.35 Bq kg^{-1} and 56.56±23.47 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively.

In general, the granite samples have low activity concentrations of the primordial radionuclides. This may be because they were extracted from rocky mountains that are compatible with the concentrations of the radioactive elements and the regions from where they were collected (Harb*et al.*, 2014).

B. RADIATION HAZARD INDICES

The calculated radiological hazard indices are displayed in Table 4.

1) Absorbed Dose rate in air

To ascertain the health risk due to the exposure to natural radionuclides in granite on quarry workers, granite end-users and the general public in the study area, the radiation hazard indices were calculated (Table 4).

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The calculated absorbed dose rate in air in the study area ranged from 7.10nGy h^{-1} to 91.32nGy h^{-1} with a mean value of 20.00nGy h^{-1}. The absorbed dose rate in air in highest inEsproAsphat sample(EQ3) and lowest inWolidQuarru sample(WQ6).
The highest contribution to the absorbed dose rate in air comes from ^{232}Th (about 46%), followed by ^{40}K (about 38%) and then ^{238}U (about 16%). The absorbed dose rate in the air in all locations is below the world average value of 60 nGy h^{-1} (UNSCEAR, 2000) and 84 nGy h^{-1} (UNSCEAR, 2008). They compared for the granite samples in figure 2 or 3

2) Annual Effective Dose Equivalent (AEDE)

The results of the calculated annual effective dose equivalent (AEDE) are presented in Table 4. They varied from 8.68 µSv y^{-1} in Wolid Quarry sample (WQ6) to 111.99 µSv y^{-1} in EsproAsphat sample (EQ3) with a mean value of 24.52 µSv y^{-1}. When compared with a worldwide annual indoor effective dose of 70 µSv y^{-1} (UNSCEAR, 2010), and the 1 mSv y^{-1} limit recommended for members of the public in UNCSEAR (2008) and ICRP (2010) the results in this work is lower. Since the international upper limit of AEDE is not exceeded in any of the granite samples, the granites of the study area are safe for use as building materials both for dwelling and interior decoration.

3) Radium Equivalent Activity (Ra_{eq})

The radium equivalent activity (Ra_{eq}) values ranged from 14.27Bq kg^{-1}in SlavaYetidepe sample (YQ9) to 201.78Bq kg^{-1} in EsproAsphat sample (EQ3) with the mean value of 42.37Bq kg^{-1}. This mean value is below the permissible maximum value of 370 Bq kg^{-1}reported in UNSCEAR (2000, 2008) for building materials for homes, which corresponds to an effective dose of 1 mSv for the general public. It follows that the investigated granites can be recommended for building family dwellings.

4) Annual Gonadal Dose Equivalent (AGDE)

The annual gonadal dose equivalent (AGDE) is highest inEsproAsphat sample(EQ3) with a value 636.03 mSv y^{-1} and lowest in Wolid Quarry sample (WQ6) with a value of 50.52mSv y^{-1}. The average value of the AGDE is 142.30mSv y^{-1}. An increase in AGED is known to affect organs with rapidly dividing cells like the gonads and the bone marrow, causing destruction of the red blood cells that are then replaced by white blood cells. This situation results in leukemia which is fatal. The mean value is lower than the maximum permissible value of 300 mSv y^{-1} (UNSCEAR, 2000). Therefore, the quarry workers, granite end-users and the general populace in the study area are not at risk of developing blood cancer due to the exposure to the natural radionuclides present in the study area. However, this maximum value is exceeded in five EsproAsphat samples EQ1, EQ2, EQ3, EQ6 and EQ7 with values 399.77, 460.17, 636.03, 305.84 and 314.46 mSv y^{-1} respectively.

5) Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk (ECLR) ranged from 0.03 in Wolid Quarry sample (WQ6) to 0.39 in EsproAsphat sample (EQ3) with a mean value of 0.09. This mean value is significantly lower than unity, so the probability that the general public would develop cancer consequent to the exposure to radiation emitted from natural radionuclides in the granites is very low or insignificant.
The values of the radiation hazard indices in all locations are below the maximum permissible limit set by ICRP. Hence, radiation emitted from natural radionuclides (^{232}Th, ^{238}U, and ^{40}K) in granites of the study areas do not pose a serious health risk to the quarry workers, granite end-users and the general public of the study area.

6) External and Internal Hazard indices H_{ex} and H_{in}

The external hazard index (H_{ex}) ranged from 0.04 to 0.55 with a mean value of 0.11, while the internal hazard index (H_{in}) ranged from 0.05 to 0.70 with a mean value of 0.10. These values do not exceed the acceptable limit value of unity (ICRP, 2010).This suggests that radiation hazard due to the exposure to natural radionuclides in the study area is negligible for the population.
The external hazard index (H_{ex}) and the internal hazard index (H_{in}) are highest in EsproAsphatgranite sample(EQ3) with value 0.55 and 0.70 respectively. Both hazard indices are lowest in SlavaYetidepe granite sample (YQ9) with values 0.04 and 0.05 respectively.

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7) Representative Gamma Index (I_γ)

The representative gamma index (I_γ)ranged from 0.11 in SlavaYetidepe sample (YQ9) to 1.44in EsproAsphat sample (EQ3), with a mean value of 0.32. An increase in the representative gamma index greater than the universal standard of unity may cause radiation risk leading to the deformation of epithelial and blood cells, thereby causing cancer (Turham and Gundiz, 2008). Since the mean value of the representative gamma index is lower than 1 in all the granite samples except EsproAsphat samples EQ2 and EQ3, the populace of the study area does not suffer a significant health risk due to the exposure to radiation from natural radionuclides in the granites of the study area. However, the use of these two samples for interior decoration is discouraged but they can be used for exterior construction

8) Alpha index (I_α)

The alpha index ranged from 0.008 in Wolid Quarry sample (WQ6) to 0.295 in EsproAsphat sample (EQ3) with a mean of 0.044. The alpha index in all the granite samples are lower that the recommended exception level of 0.5 and the recommended upper limit of 1.0 in building materials as safety level given by ICRP (1994) and EC (1990). The highest $I_\alpha$is 0.295 (about 30% of the upper limit of 1.0), the radon exhalation from this sample can only cause indoor radon concentration of about 60 Bq m^{-3}. The mean value of 0.044 (just 4.4% of the upper limit of 1,0) will cause only about 8.80 Bq m^{-3}.

Table 1. Quarry names, sample code, number of samples and GPS location

S/N	Quarry	Number of samples	Sample code	Longitude	Latitude
1	Wolid Quarry Complex	10	WQ	4.348365	7.747812
2	SlavaYetidepe	10	YQ	4.390623	7.755893
3	Ayofe/Irepodun and Sons	10	AQ	4.392271	7.7649281
4	EsproAsphat Prod. Co. Ltd	10	EQ	4.259797	7.429560
5	Granite Producers Ife/Modakeke	10	IQ	4.608602	7.556943
6	Krystal Vountain	10	KQ	4.897970	7.490550
7	Clario Nig. Ltd	10	CQ	4.667675	7.943495
8	Omidiran Nig. Ltd.	10	OQ	4.667675	7.943495

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Table 2. Results of activity concentration Measurements.

Sample Code	Location		Mean Activity Concentrations (Bq kg^{-1})		
	Latitude / N^0	**Longitude / E^0**	**^{238}U**	**^{232}Th**	**^{40}K**
WQ	7.747812	4.348365	4.11 ± 0.73	9.58 ± 1.52	137.38 ± 25.10
YQ	7.755893	4.390623	6.40 ± 0.75	8.21 ± 1.12	109.54 ± 11.06
AQ	7.7649281	4.392271	5.05 ± 0.61	7.38 ± 0.90	144.07 ± 14.76
EQ	7.429560	4.259797	23.75 ± 3.74	34.65 ± 4.96	315.70 ± 48.42
IQ	7.556943	4.608602	7.67 ± 1.15	13.16 ± 1.98	257.20 ± 38.58
KQ	7.490550	4.897970	7.53 ± 1.12	11.27 ± 1.68	236.47 ± 35.47
CQ	7.943495	4.667675	7.85 ± 1.18	11.24 ± 1.69	171.27 ± 25.69
OQ	7.943495	4.667675	8.07 ± 1.21	10.25 ± 1.52	152.37 ± 22.88

Table 3: Comparison of average activity concentrations

Country	Average activity concentration (Bq kg^{-1})			REFERENCE
	^{238}U	**^{232}Th**	**^{40}K**	
Egypt	137	82	1082	Amin, 2012
Egypt	17	18	320	UNSCEAR, 2000
Egypt	15.6	14.5	405.7	Harb et al.2008
USA	40	35	370	UNSCEAR, 2000
Kenya	93.36	105.5	732.64	Kinyua*et al.*, 2011
India	25.9	42.8	560.6	Senthilkuma et al. 2014
India	82	112	1908	Sonkawade*et al.*, 2008
Malaysia	39	52	611	Alnour*et al.*, 2012
Turkey	80	101	974	Aykamis et al. 2013
Turkey	70	83	1234	Cetin *et al.* 2012
Greece	74	85	881	Papadopoulos et al. 2013
Greece	67	95	1200	Stoulos*et al.*, 2003
France	90	80	1200	NEA- OECD, 1979
Poland	31	41	900	Dzaluk*et al.*, 2018
Saudi Arabia	28.8	34.8	665.1	Al-Zahrani, 2017
Jordan	41.5	58.4	897	Sharaf and Hamideen, 2013
Palestine	71	82	780	Thabayneh, 2013
Iran	77.4	44.5	1017.2	Abbasi, 2013
Spain	84	42	1138	Guillen et al. 2014
Abuja, Nigeria	74.74 ± 5.67	199.23 ± 43.30	1021.27 ±7.14	Shittu, *et al.*, 2015
Osun State, Nigeria	8.80 ± 1.31	13.20 ± 1.93	188.95 ± 31.20	Present work
Worldwide	33	45	412	UNSCEAR, 2010

Table 4. Radiological hazard indices.

Sample code	D (nGy h^{-1})	AEDE (μSv y^{-1})	Ra_{eq} (Bq kg^{-1})	AGED (mSv y^{-1})	ELCR × 10^{-3}	H_{ex}	H_{in}	I_γ
WQ	10.93	13.41	30.71	109.26	0.05	0.08	0.10	0.24
YQ	8.56	10.50	26.38	88.62	0.04	0.07	0.09	0.20
AQ	7.41	9.09	22.54	78.87	0.03	0.06	0.07	0.17
EQ	21.02	25.78	81.56	266.08	0.09	0.22	0.28	0.6
IQ	13.29	16.29	34.73	124.10	0.06	0.09	0.11	0.27

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KQ	9.52	11.68	32.97	110.69	0.04	0.09	0.11	0.25
CQ	16.88	20.70	46.55	166.17	0.07	0.13	0.15	0.36
OQ	13.16	16.14	40.92	141.41	0.06	0.11	0.13	0.31
MIN	7.41	9.09	22.54	78.87	0.03	0.06	0.07	0.17
MAX	21.02	25.78	81.56	266.08	0.09	0.22	0.28	0.60
MEAN	11.95	14.65	42.08	141.27	0.05	0.11	0.14	0.32
WWA	60	70	370	300	1	1	1	1

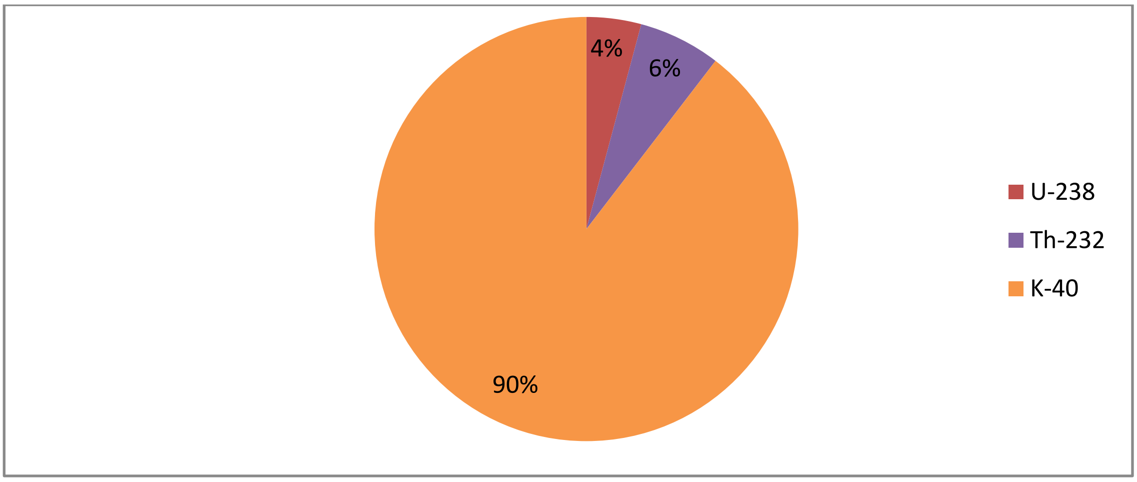

Figure 2. Contributions of U-238, Th-232 and K-40 to the absorbed dose rate in air at the study area

IV.CONCLUSION

Samples of granite from different quarry sites in Osun state have been investigated using high purity germanium detector. The measured values of the activity concentrations of ^{232}Th, ^{238}U and ^{40}K in the samples have been found to be in the ranges of 7.38 ± 0.90 - 34.65 ± 4.96, 4.11 ± 0.73 - 23.75 ± 3.74 and 109.54 ± 11.06 - 315.70 ± 48.42 Bqkg^{-1} respectively. The samples were also found to have a radium equivalent activity in the range from 22.54 - 81.56 Bqkg$^{-1.}$ All the samples were found to have the hazard indices below unity. The average values of radium equivalent activity and dose rate of the analyzed samples are lower than the recommended maximum values of “370 Bqkg^{-1}” and “55nGy/h”, respectively, according to the UNSCEAR (1993, 2000). Therefore, there is no significant health risk to people working in the quarries, granite end-users and the general public.

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