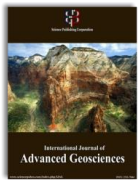
*International Journal of Advanced Geosciences*, 6 (1) (2018) 43-50

**International Journal of Advanced Geosciences**

*Website: www.sciencepubco.com/index.php/IJAG*
*doi: 10.14419/ijag.v6i1.8609*
***Research paper***



# Radiometric evaluation of natural radioactivity and radiation hazard indices in soils from quarries sites in southwestern Nigeria

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**Abstract**

Quarry activities increase the radiation dose received by humans by distributing the radionuclides associated with the natural resources to the soil surfaces. This study assessed the level of natural radiations in soils around two quarry sites to a maximum depth of 2.0 m and up to 500 m away from the sites. Activity concentration of $^{232}$Th, $^{238}$U and $^{40}$K in twenty soil samples collected from the quarries in Ondo State were measured by means of high resolution gamma-ray spectrometry. Average value of $^{232}$Th, $^{238}$U and $^{40}$K measured were 0.0027±0.0003 Bq/kg and 0.0036±0.00036 Bq/kg, 0.028±0.0012 Bq/kg and 0.026±0.0012 Bq/kg and 47.45±0.0313 Bq/kg and 69.42±0.0313 Bq/kg respectively. The estimated absorbed dose rates in all the soils investigated ranged from 0.38 nGy/hr to 15.67 nGy/hr and the annual mean effective dose equivalent varied from 2.13 to 10.28 µSv/yr. The results revealed that the activity concentrations and radiological hazard indices when compared with their corresponding world permissible values are less than the recommended safe levels. This indicates that quarry activities in the areas have not enhanced the background radiation level of the areas. Regular exposure of the quarry workers and the people around the study areas pose no health hazards in the near future.

***Keywords***: *Activity Concentrations; Quarries; Radionuclides; Radiological Hazard Indices; Soils.*

## 1. Introduction

Naturally occurring radionuclides such as $^{40}$K, the decay series of $^{232}$Th and $^{238}$U constitute mainly the radioactivity found nearly everywhere in soil, water and rock (Tzortzis and Tsertos, 2004). These radionuclides are not evenly distributed in soil, water, rock and river sediments, so assessment is important for radiation protection and safety. Natural radioactive concentration mainly depends on geological and geographical condition and appears at different level in soils of each different geological region (UNSCEAR, 2000). Natural sources contribute on average of more than 98% of the human radiation dose excluding medical exposures. Human-beings have always been exposed to ionizing radiations of natural origin like terrestrial and extra-terrestrial radiation. Radiation of extra-terrestrial origin is from high energy cosmic ray particles and at sea level, it is about 30 nGy/hr (UNSCEAR, 2000), while the terrestrial origin is due to the presence of naturally occurring radionuclides. The levels due to the terrestrial background radiation are related to the types of rock from which the soils originate. When rocks are disintegrated through natural process, radionuclides are carried to soil by rain and flows (Taskin et al., 2009). Activities associated with digging of the ground soils to certain depth and blasting of rock outcrops as observed in quarries to extract the natural resources, bring these naturally occurring radionuclides to the soil surface. These activities actually increase the radiation exposure to the workers and environment. Quarrying operations for the purpose of constructions have hazard effects on workers as higher radiation levels are associated with igneous rocks, such as granite, and lower radiation levels with sedimentary rocks. This releases natural radionuclides and radiations into various components of the environments. The interaction of ionizing radiation with the human body leads to different biological effects which may later develop to clinical symptoms (ICRP, 1992). Effects of radiation on humans has shown that exposure to radiation could lead to lung, pancreas, hepatic, bone, skin and kidney cancers, cataracts, sterility, atrophy of the kidney and leukaemia. Radionuclides may be transferred from soils to plants, animals and finally to man. Studying the levels of radionuclide distribution in the environment provides essential radiological information. Many sicknesses and diseases which should have been effectively managed if radiological information of an environment was available would not have been attributed to other sources. Unfortunately, the sicknesses may take years to become evident, and indeed, when manifest it may already be too late. Hence, the knowledge of the natural radioactivity concentration of our environment is essential in the assessment of the degree and extent of radioactive contamination or pollution in the environment. Soil radionuclide activity concentration is one of the major attributes of the natural background radiation. Adequate evaluation of the radiological effects due to the quarry activities has not been conducted in the area. Hence, this study is aimed at measuring the natural radionuclides ($^{40}$K, $^{232}$Th and $^{238}$U) present in the soils of two quarry sites in two different locations of Ondo State in order to determine the radioactivity concentrations and assess the level of radiological effects due to the quarry activities in the selected quarry sites.

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## 2. Location, geomorphology and geologic setting of the study areas

The study areas are Ebenezer Mining and Ceramics Company (Location 1) is situated in ancient city of Akure, Akure South local government area of Ondo State, Southwestern Nigeria. It lies within latitudes 7° 10' N and 7° 19' N and longitudes 5° 07' E and 5° 14' E (Fig. 1). It covers an area extent of about 1.5 km$^2$ and it's easily accessible to other major and urban centres in the state. It is bounded by Owo to the east, Ado –Ekiti to the north and Ondo to the south, all within 50 km radius. Within 100 km radius, it is bounded by Ikare, IkoleEkiti, IjeroEkiti to the north and Okitipupa to the south.

Ballister Mining Company (Location 2) is found on kilometer 20, Owo-Benin express way in Ose local government area of Ondo State, Nigeria. It is situated on latitudes 7° 01' N and 7° 02' N and longitudes 5° 42' E and 5° 44' E (Fig. 1). It's bounded by major cities and town like Kabba to north, to the east by Benin City, and to the west by Akure. It is accessible by network of tarred and untared roads. The towns are situated in the humid tropical region of Nigeria, characterized by alternating wet and dry seasons with a mean annual rainfall of over 1500 mm. They are also characterized with a fairly uniform temperature and high relative humidity. The areas are drained by three major rivers Ala, Ogbese and Ose which are seasonal. The rivers dominate the drainage system of the study area and it's mainly dendritic. It has an average elevation of about 378 m. The study area falls within the Precambrian Basement Complex rocks of southwestern Nigeria (Rahaman, 1989) (Fig. 2). The geological history of the areas is similar to the structural evolutions that had affected the Basement Complex of Nigeria. The study areas are underlain by migmatite-gneiss-quartzite complex of the West African Basement rocks, which forms part of the Pan-African mobile belt. Charnockites, grey gneiss, granite gneiss, porphyritic granite and migmatitic rocks are the predominant rock types in the study area (Fig. 3). Granite gneiss is the metamorphosed granites, widely distributed in the study area and it is of two types; the biotite rich gneiss and the banded gneiss. The biotite rich gneiss is fine to medium grained and show strong foliation trending westwards and is usually dark in colour. The banded gneiss show parallel alignment and alteration. It occurs mostly as hills, boulders and flat lying exposures which are dark to light grey in colour and porphyroblastic in texture. There are several quartzite intrusions cutting across the granite and other felsic and basic rocks.

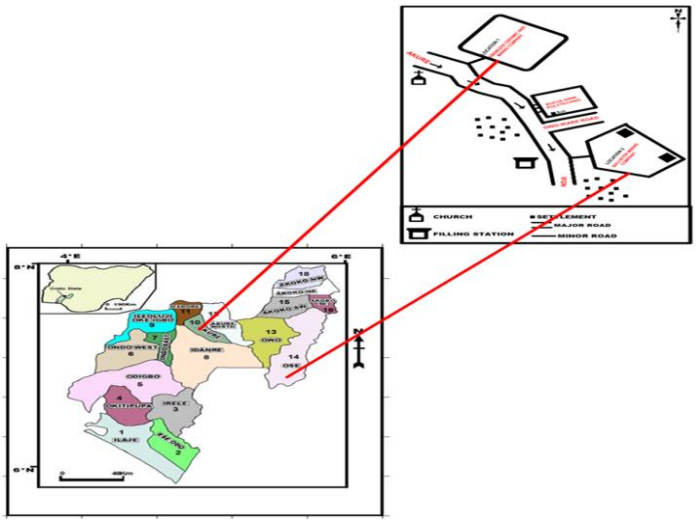


**Fig. 1:** Map of Ondo State Showing the Location of the Study Areas.

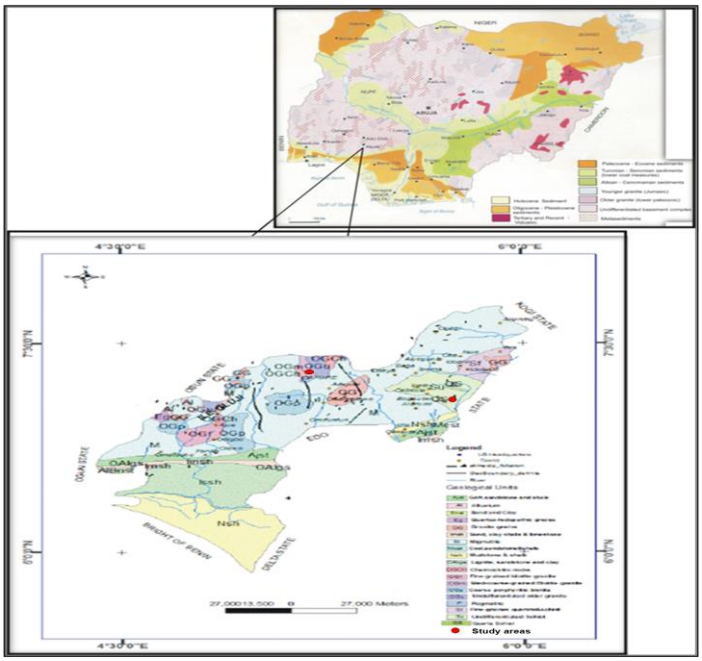


**Fig. 2:** Geological Map of Ondo State Showing the Study Areas.

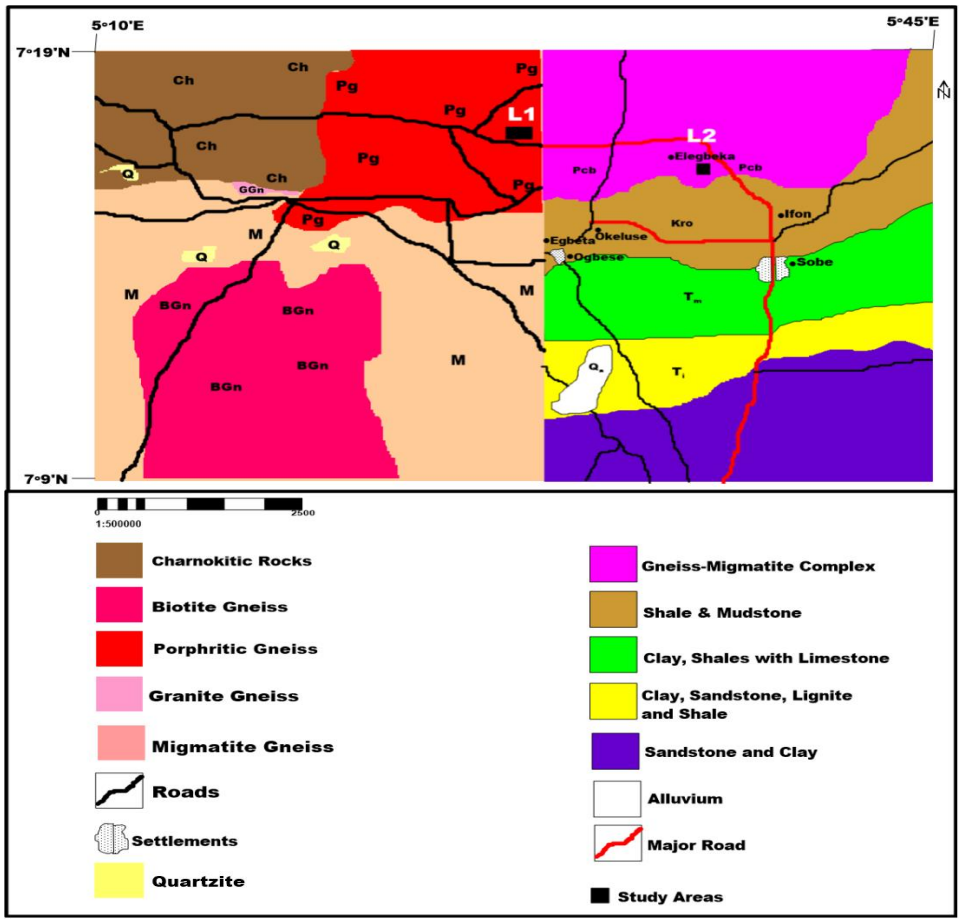


**Fig. 3:** Geological Map of the Study Areas.

## 3. Materials and methods

### 3.1. Soil sample collection and preparation

A total of 20 soil samples were collected from the study areas, 10 samples from each location. Out of the 10 samples taken from each location, two samples each from four positions were taken at 500 m away from the quarry sites as control. The measurement of radiation from subsurface soils was carried out directly inside the manually dug pits at a maximum depth of 2.0 m. That is, the gamma ray spectrometer was employed in recording in-situ the radioactivity measurement at the point of each sample collection to determine the exposure rate due to background radiation. The soils of the study areas are generally lateritic with some clay intercalation. About 2 kg soil samples were collected in polythene bags and labeled according to the quarry site and location and the GPS coordinates of the locations were recorded. The samples collected were then transported to the laboratory for further processing. The samples were processed following the standard procedures (EML, 1983). The samples were air-dried at room temperature for a week. Then milled and sieved through 2 mm sieve. They were weighed, sealed and stored in the laboratory for four weeks before being analyzed to ensure secular equilibrium between the various radioactive daughters involved. Proper sealing was ensured by providing double seal to the lid of the container.

### 3.2. Gamma spectrometry and determination of activity concentration

A gamma spectrometry system was employed in determining the activity concentrations of the radionuclides in the samples. All the samples were counted for 36,000 seconds (10 hours) and the peak areas corresponding to 1460 keV for $^{40}$K, 352 keV ($^{214}$Pb) for $^{238}$U, and 583 keV ($^{208}$Tl) for $^{232}$Th were considered for the estimation of natural radionuclides in all the samples. The integrated counts recorded under the chosen energy peaks were noted for each spectrum. The specific activity concentration of each radionuclide in the samples was obtained using the comparative method of analysis. In this method, the activity concentration of the sample is determined by comparing the relevant peak area in the sample with area of similar photopeak in a reference standard with already known activity concentration.

The activity concentration (C) in Bq/kg of the radionuclides in the samples was calculated after decay correction using the expression: $C_s$ (Bq/kg) = $C_a$/ $\varepsilon_\gamma \times M_S \times t_c \times P\gamma$.

Where $C_s$ = Sample concentration, $C_a$ = net peak area of a peak at energy, $\varepsilon_\gamma$ = Efficiency of the detector for a gamma energy of interest, $M_s$ = Sample mass, $t_c$ = total counting time, $P_\gamma$ = the abundance of the gamma line in a radionuclide.

### 3.3. Assessment of radiation hazards

In order to assess the radiological impact of the investigated radionuclides in rock aggregates and the soil samples, the knowledge and estimation of the following radiation hazard parameters (indices) are important.

#### 3.3.1. Radium equivalent activity (raeq)

The radium equivalent activity, $Ra_{eq}$ is used to compare the specific activities of materials containing different quantities of $^{238}$U, $^{232}$Th and $^{40}$K and the potential risk assessment associated with the radionuclides is estimated by calculating the radium equivalent activity ($Ra_{eq}$). It represents a weighted sum of activities of $^{238}$U, $^{232}$Th and $^{40}$K. It is based on the assumption that 1 Bqkg$^{-1}$ of $^{238}$U, 0.7 Bqkg$^{-1}$ of $^{232}$Th and 13 Bqkg$^{-1}$ of $^{40}$K produce the same gamma radiation dose rates. The radium equivalent activity index was estimated using equation 1 (Avwiri et al., 2013) as shown in Tables 1 and 2.

$$R_{aeq}(Bqkg^{-1}) = C_U + 1.43C_{Th} + 0.077C_K \quad (1)$$

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

#### 3.3.2. Air absorbed gamma radiation dose rate

Absorbed dose is a measure of the energy deposited in a medium by ionizing radiation per unit mass. It may be measured as joules per kilogram and represented by the equivalent S.I unit, gray (Gy) or rad. Effects of gamma radiation are normally expressed in terms of the absorbed dose rate in air, which originate from radioactive sources in the rock aggregates and the soil. The activity concentrations correspond to the total absorbed dose rate in air at 1 m above the ground level. The absorbed dose rate in air (D) for the workers in the quarry sites and the entire people living within and around the study areas is calculated using equation 2 and shown in Fig. 5. The gamma radiation doses can be estimated by employing the convenient formula (UNSCEAR, 2000).

$$D = (0.462\ C_U + 0.621\ C_{Th} + 0.0417\ C_K)\ nGyh^{-1} \quad (2)$$

Where: D is the absorbed gamma dose rates in air ($nGyh^{-1}$) at 1 m height above the ground level. $C_U$, $C_{Th}$ and $C_K$ represent the activity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ respectively. It is assumed that the contribution from other radionuclides, such as $^{137}Cs$, $^{235}U$, $^{87}Rb$, $^{90}Sr$, $^{138}La$, $^{147}Sm$ and $^{176}Lu$ to the total dose rate are negligible. UNSCEAR reported that the world average absorbed gamma dose rate mean is 55 nGy/h.

#### 3.3.3. Annual gonadal equivalent dose (AGED)

The gonads, the bone marrow and the bone surface cells are considered as organs of interest by UNSCEAR (2000) because of their sensitivity to radiation. An increase in AGED has been known to affect the bone marrow, causing destruction of the red blood cells that are replaced by white blood cells. This situation results in a blood cancer called leukemia. The AGED received by the resident using such material for building can be evaluated by the following equation (Avwiri et al., 2012).

$$AGED\ (\mu Sv/y) = 3.09C_U + 4.18C_{Th} + 0.314C_K \quad (3)$$

Where $C_U$, $C_{Th}$ and $C_K$ are the radioactivity concentration of $^{238}U$, $^{232}Th$ and $^{40}K$ in rock aggregates and soil samples.

#### 3.3.4. Annual effective dose equivalent (AEDE)

The annual effective dose equivalent (AEDE) received outdoor by a member of the public is calculated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv/Gy and occupancy factor for outdoor and indoor was 0.2 and 0.8 respectively (Veiga et al., 2006).

$$AEDE\ (Outdoor)\ (\mu Sv/y) = D\ (nGyh^{-1}) \times T \times Q \times 0.2 \times 10^{-3} \quad (4)$$

Where D is the absorbed dose rate in air, Q is the conversion factor of 0.7 Sv/Gy, which converts the absorbed dose rate in air to human effective dose received and T is the time for one year, i.e. 8760 hrs.

$$Thus,\ AEDE\ (Outdoor)\ (\mu Sv/y) = D\ (nGyh^{-1}) \times 8760\ (hrs) \times 0.7\ (Sv/Gy) \times 0.2 \times 10^{-3} \quad (5)$$

$$AEDE\ (Indoor)\ (\mu Sv/y) = D\ (nGyh^{-1}) \times 8760\ (hrs) \times 0.7\ (Sv/Gy) \times 0.8 \times 10^{-3} \quad (6)$$

The AEDE indoor occurs within a house whereby the radiation risks due to use of the soil and rock as building materials are taken into consideration. AEDE outdoor involves a consideration of the absorbed dose emitted from radionuclide in the environment such as $^{238}U$, $^{232}Th$, $^{226}Ra$ and $^{40}K$.

#### 3.3.5. Representative gamma index (Iγ)

This is used to estimate the gamma radiation hazard associated with the natural radionuclide in specific investigated samples. The representative gamma index was estimated as follow (Avwiri et al., 2013).

$$I_\gamma = C_U / 150 + C_{Th} / 100 + C_k / 1500 \leq 1 \quad (7)$$

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

#### 3.3.6. Hazard indices (hex and hin)

External radiation hazard index ($H_{ex}$)
External radiation hazards due to natural radionuclides of $^{238}U$, $^{232}Th$ and $^{40}K$ are defined in terms of external or outdoor radiation hazard index, denoted by $H_{ex}$. The external hazard ($H_{ex}$) and internal hazard ($H_{in}$) indices were evaluated by the following relations (Ramasamy et al., 2009):

$$H_{ex} = C_U/370 + C_{Th}/259 + C_K/4810 \leq 1 \quad (8)$$

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

Where $C_U$, $C_{Th}$ and $C_K$ are the radioactivity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ in $BqKg^{-1}$ respectively. $H_{in}$ should be less than unity for the radiation hazard to be negligible. Internal exposure to radon is very hazardous which can lead to respiratory diseases like asthma (Tufail et al., 2007). Natural radionuclide in soil, rocks and sediment produce an external radiation field to which all humans are exposed. $H_{ex}$ must be less than unity for this external radiation hazard to be negligible (Beretka and Mathew, 1985). $H_{ex}$ equal to unity corresponds to the upper limit of radium equivalent dose (370 $Bqkg^{-1}$) (Beretka and Mathew, 1985).

#### 3.3.7. Excess lifetime cancer risk (ELCR)

This is the probability of developing cancer over a lifetime at a given exposure level, considering 70 years as the average duration of life for human being. The Excess Lifetime Cancer Risk (ELCR) was calculated using the following equation (Taskin et al., 2009).

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

Where AEDE is the Annual Equivalent 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, ICRD uses RF as 0.05 for public (Taskin et al., 2009).

### 3.3. Conversions

The elemental concentrations of uranium-238 (ppm), Thorium-232 (ppm) and potassium–40 (%) can be calculated from measured activity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ in $Bqkg^{-1}$ using conversion factors recommended by the IAEA, 2003 as follows:

$$1\ ppm = 10^{-4}\% \quad (12)$$

$$1\%\ K = 313\ Bqkg^{-1}\ of\ ^{40}K \quad (13)$$

$$1\ ppm\ U = 12.35\ Bqkg^{-1}\ of\ ^{238}U \quad (14)$$

$$1\ ppm\ Th = 4.06\ Bqkg^{-1}\ of\ ^{232}Th \quad (15)$$

## 4. Results and discussion

The results of gamma-ray measurements of $^{238}U$, $^{232}Th$ and $^{40}K$ activity concentrations of the quarries soil samples with their radi-

um equivalent activity are given in Tables 1a and 2a, while that at 500 m away from the quarries are given in Tables 1b and 2b (Fig. 4). The activity concentrations vary from site to site, which indicates a large variation in chemical and mineralogical properties of soil samples. Activity concentrations are in the order $^{232}$Th < $^{238}$U < $^{40}$K. The mean radioactivity concentration values of $^{232}$Th, $^{238}$U and $^{40}$K are 0.0027±0.0003 Bq/kg and 0.0036±0.00036 Bq/kg, 0.028±0.0012 Bq/kg and 0.026±0.0012 Bq/kg and 47.45±0.0313 Bq/kg and 69.42±0.0313 Bq/kg respectively for soils within the quarries of Locations 1 and 2 (Tables 1a and 2a). At 500 m away from the quarry sites, the mean values are 0.0008±0.75 Bq/kg and 0.0049±0.0004 Bq/kg, 0.020±0.0012 Bq/kg and 0.052±0.0012 Bq/kg and 41.54±0.0313 Bq/kg and 200.32±0.0313 Bq/kg respectively for the quarries (Tables 1b and 2b). The result shows that the activity concentration within the quarry site of Location 1 is higher than that at 500 m away from the quarry. This could be as a result of temperature, elevation difference and radioactive half-lives, while, the result of Location 2 shows that the activity concentration at 500 m away is higher than the activity concentration within the quarry site as shown in Fig. 4. Although, these activity concentration values obtained in these locations and their environs are below the world permissible value of 30.0 Bq/kg for $^{232}$Th, 35.0 Bq/kg for $^{238}$U and 400.0 Bq/kg for $^{40}$K (UNSCEAR, 2000) (Fig. 4). Change in the soil activity with location depends on the soil physical and chemical properties which are common phenomenon in any appraisal of radiation in the environment. The spatial distribution of the radionuclides across the two locations revealed that the concentration of $^{40}$K was highest even at the neighbouring settlement, making $^{40}$K the dominant radionuclide in the areas (Fig. 4). The relatively high values of $^{40}$K could be as a result of feldspathic characterization of rock formation of the study areas. $^{238}$U and $^{232}$Th has the lowest concentration. The low concentrations especially in some places of the study areas can be attributed to the presence of some local indigenous trees around the sites, which shows that those areas have not been exploited. This corroborated with the result of the radiometric maps generated from the measurements of different points along eleven traverses around the study areas. Radium equivalent activity ($Ra_{eq}$) owing to activity concentration of the three natural radionuclides from the two sites varies from 0.70 to 28.94 Bq/kg. These values are below the world standard of 370 Bq/kg (Fig. 3). The estimated absorbed dose rates in all the soils investigated ranged from 0.38 nGy/hr to 15.67 nGy/hr (Tables 3a, 4a and Fig. 5). The total absorbed dose delivered by these radionuclides for the soils within Location 1 ranged from 0.38 nGy/hr to 3.68 nGy/hr and 1.10 nGy/hr to 3.43 nGy/hr within Location 2, having average values of 1.99 nGy/hr and 2.91 nGy/hr respectively (Tables 3a and 4a). The estimated absorbed dose values for 500 m away from the quarry sites are shown in Tables 3b and 4b. The mean total absorbed doses obtained at 500 m away are 1.74 nGy/hr and 8.38 nGy/hr respectively for the two locations. All these values are less than the recommended world average value of 55 nGy/hr (Fig. 5). The differences arising from these values may be due to the geological settings of the area due to variation from one place to another and from one locality to another even within the same geographical area. The calculated values of annual effective dose ranged between 0.47 to 4.51 µSv/yr with mean value of 2.44 µSv/yr within Location 1 and 1.35 to 4.21 µSv/yr with mean 3.57 µSv/yr within Location 2 (Tables 3a and 4a). The mean values of effective doses obtained for 500 m away from the sites are presented in Tables 3b and 4b. It was found that the effective doses obtained at 500 m away (10.28 µSv/yr) from Location 2 is higher than that obtained at Location 1 (2.13 µSv/yr). The mean effective doses are far below the worldwide recommended limit for normal background effective dose of 70 µSv/yr (Fig. 6). The mean values of annual gonadal equivalent dose (AGED) obtained within the sites are 15.00 mSv/yr and 21.89 mSv/yr, while, AGED calculated for 500 m away from each site are 13.11 mSv/yr and 63.08 mSv/yr respectively as shown in Fig. 7. These values are far below the safe limit of 300 mSv/yr (Fig. 7). This implies that interaction with the soils in the study areas poses no threat to the bone marrow and the bone surface cells of the workers and the populace around the study areas. The range mean excess lifetime cancer risk (ELCR) calculated for the study areas is 0.009 to 0.067 (Fig. 8). These values are below the world standard of $0.29 \times 10^{-3}$ (Taskin et al., 2009) meaning that the probability of the workers and the people living around the quarry sites developing extra cancer due to exposure to natural radioactivity is insignificant right now, however, continuous accumulation may pose radiological health risks to the people living in the areas in future. Also, the calculated values of the external hazard index, internal hazard index and representative gamma index for soils of the areas are less than the world permissible value of unity (Fig. 8). This indicates that interaction with the soils in the study areas will not result to any respiratory tract disease such as asthma and other external diseases like skin cancer, erythema and cataracts (Avwiri et al., 2013) to the workers involving in quarry activities and users of such soils. Generally, the relatively low gamma dose rates measured from the soils of the two quarry sites show that quarry activities in the areas have not enhanced the background radiation level of the areas. This suggests that the soils from these quarry sites can be used as building materials for housing construction without posing a health threat to the general public.

**Table 1a:** Specific Activity of $^{40}$K, $^{238}$U and $^{232}$Th and Their Radium Equivalent in Soil Samples within Quarry 1

| Sample Code | K (Bq/kg) | U (Bq/kg) | Th (Bq/kg) | Raeq (Bq/kg) |
|---|---|---|---|---|
| EMC 1 | 43.75±0.0313 | 0.022±0.0012 | 0.0106±0.0004 | 3.4057 |
| EMC 2 | 8.88±0.0313 | 0.011±0.0012 | 0.0011±0.0002 | 0.6961 |
| EMC 3 | 22.37±0.0313 | 0.020±0.0012 | 0.0015±0.0003 | 1.7441 |
| EMC 4 | 48.02±0.0313 | 0.044±0.0012 | 0.0004±0.0002 | 3.7418 |
| EMC 5 | 33.84±0.0313 | 0.018±0.0012 | 0.0009±0.0002 | 2.6244 |
| EMC 6 | 69.47±0.0313 | 0.051±0.0012 | 0.0011±0.0003 | 5.4015 |
| EMC 7 | 65.59±0.0313 | 0.022±0.0012 | 0.0018±0.0003 | 5.0750 |
| EMC 8 | 87.67±0.0313 | 0.040±0.0012 | 0.0039±0.0004 | 6.7965 |
| Mean | 47.45±0.0313 | 0.028±0.0012 | 0.0027±0.0003 | 3.6856 |

**Table 1b:** Specific Activity of $^{40}$K, $^{238}$U and $^{232}$Th and Their Radium Equivalent in Soil Samples 500 M Away from the Quarry 1 Locality

| Distance (m) | Sample Code | K (Bq/kg) | U (Bq/kg) | Th (Bq/kg) | $Ra_{eq}$ (Bq/kg) |
|---|---|---|---|---|---|
| 500 m away (East) | EMC 9 | 45.43±0.0313 | 0.019±0.0012 | 0±0 | 3.5175 |
| 500 m away (West) | EMC 10 | 37.65±0.0313 | 0.022±0.0012 | 0.0015±1.4941 | 2.9231 |
| | Mean | 41.54±0.0313 | 0.020±0.0012 | 0.0008±0.7470 | 3.2203 |

**Table 2a:** Specific Activity of $^{40}$K, $^{238}$U and $^{232}$Th and Their Radium Equivalent in Soil Samples within Quarry of Location 2

| Sample Code | K (Bq/kg) | U (Bq/kg) | Th (Bq/kg) | Raeq (Bq/kg) |
|---|---|---|---|---|
| BMC 1 | 77.39±0.0313 | 0.002±0.0012 | 0.002±0.0003 | 5.9639 |
| BMC 2 | 25.70±0.0313 | 0.039±0.0012 | 0.009±0.0004 | 2.0304 |
| BMC 3 | 81.92±0.0313 | 0.036±0.0012 | 0.003±0.0004 | 6.3485 |
| BMC 4 | 71.45±0.0313 | 0.040±0.0012 | 0.002±0.0004 | 5.5447 |

| | | | | |
|---|---|---|---|---|
| BMC 5 | 78.54±0.0313 | 0.018±0.0012 | 0.001±0.0003 | 6.0676 |
| BMC 6 | 70.02±0.0313 | 0.024±0.0012 | 0.001±0.0003 | 5.4170 |
| BMC 7 | 80.68±0.0313 | 0.033±0.0012 | 0.003±0.0004 | 6.2491 |
| BMC 8 | 69.68±0.0313 | 0.018±0.0012 | 0.008±0.0004 | 5.3954 |
| Mean | 69.42±0.0313 | 0.026±0.0012 | 0.004±0.0004 | 5.3771 |

**Table 2b:** Specific Activity of $^{40}K$, $^{238}U$ and $^{232}Th$ and Their Radium Equivalent in Soil Samples 500 M Away from the Quarry 2 Locality

| Distance (m) | Sample Code | K (Bq/kg) | U (Bq/kg) | Th (Bq/kg) | $Ra_{eq}$ (Bq/kg) |
|---|---|---|---|---|---|
| 500 m away (East) | BMC 9 | 25.70±0.0313 | 0.039±0.0012 | 0.009±0.0004 | 2.0304 |
| 500 m away (West) | BMC 10 | 374.93±0.0313 | 0.066±0.0012 | 0.001±0.0004 | 28.9374 |
| | Mean | 200.32±0.0313 | 0.052±0.0012 | 0.005±0.0004 | 15.4839 |

**Table 3a:** Radiation Hazard Parameters for Soil Samples within Location 1

| Sample Code | D (nGy/hr) | AEDE (μSv/yr) | AGED (mSv/yr) | ELCR ($\times 10^{-3}$) | $H_{ex}$ | $H_{in}$ | $I_\gamma$ |
|---|---|---|---|---|---|---|---|
| EMC 1 | 1.84 | 2.26 | 13.85 | 0.008 | 0.009 | 0.009 | 0.029 |
| EMC 2 | 0.38 | 0.47 | 2.83 | 0.002 | 0.002 | 0.002 | 0.006 |
| EMC 3 | 0.94 | 1.15 | 7.09 | 0.004 | 0.005 | 0.005 | 0.015 |
| EMC 4 | 2.02 | 2.48 | 15.22 | 0.009 | 0.010 | 0.010 | 0.032 |
| EMC 5 | 1.42 | 1.74 | 10.69 | 0.006 | 0.007 | 0.007 | 0.023 |
| EMC 6 | 2.92 | 3.58 | 21.98 | 0.013 | 0.015 | 0.015 | 0.047 |
| EMC 7 | 2.75 | 3.37 | 20.67 | 0.012 | 0.014 | 0.014 | 0.044 |
| EMC 8 | 3.68 | 4.51 | 27.67 | 0.016 | 0.018 | 0.018 | 0.059 |
| Mean | 1.99 | 2.44 | 15.00 | 0.009 | 0.010 | 0.010 | 0.032 |

**Table 3b:** Radiation Hazard Parameters for Soil Samples 500 M Away from Location 1

| Distance (m) | Sample Code | D (nGy/hr) | AEDE (μSv/yr) | AGED (mSv/yr) | ELCR ($\times 10^{-3}$) | $H_{ex}$ | $H_{in}$ | $I_\gamma$ |
|---|---|---|---|---|---|---|---|---|
| 500 m away (East) | EMC 9 | 1.90 | 2.33 | 14.32 | 0.009 | 0.009 | 0.009 | 0.054 |
| 500 m away (West) | EMC 10 | 1.58 | 1.94 | 11.90 | 0.008 | 0.008 | 0.008 | 0.045 |
| | Mean | 1.74 | 2.13 | 13.11 | 0.009 | 0.009 | 0.009 | 0.049 |

**Table 4a:** Radiation Hazard Parameters for Soil Samples within Location 2

| Sample Code | D (nGy/hr) | AEDE (μSv/yr) | AGED (mSv/yr) | ELCR ($\times 10^{-3}$) | $H_{ex}$ | $H_{in}$ | $I_\gamma$ |
|---|---|---|---|---|---|---|---|
| BMC 1 | 3.23 | 3.96 | 24.32 | 0.014 | 0.016 | 0.016 | 0.091 |
| BMC 2 | 1.10 | 1.35 | 8.23 | 0.005 | 0.005 | 0.006 | 0.031 |
| BMC 3 | 3.43 | 4.21 | 25.85 | 0.015 | 0.017 | 0.017 | 0.097 |
| BMC 4 | 3.00 | 3.68 | 22.57 | 0.013 | 0.015 | 0.015 | 0.085 |
| BMC 5 | 3.28 | 4.02 | 24.72 | 0.014 | 0.016 | 0.016 | 0.093 |
| BMC 6 | 2.93 | 3.59 | 22.06 | 0.013 | 0.015 | 0.015 | 0.083 |
| BMC 7 | 3.38 | 4.15 | 25.45 | 0.015 | 0.017 | 0.017 | 0.095 |
| BMC 8 | 2.92 | 3.58 | 21.97 | 0.013 | 0.015 | 0.015 | 0.083 |
| Mean | 2.91 | 3.57 | 21.89 | 0.012 | 0.015 | 0.015 | 0.082 |

**Table 4b:** Radiation Hazard Parameters for Soil Samples 500 M Away from Location 2

| Distance (m) | Sample Code | D (nGy/hr) | AEDE (μSv/yr) | AGED (mSv/yr) | ELCR ($\times 10^{-3}$) | $H_{ex}$ | $H_{in}$ | $I_\gamma$ |
|---|---|---|---|---|---|---|---|---|
| 500 m away (East) | BMC 9 | 1.10 | 1.35 | 8.23 | 0.005 | 0.016 | 0.016 | 0.031 |
| 500 m away (West) | BMC 10 | 15.67 | 19.22 | 117.94 | 0.067 | 0.005 | 0.006 | 0.443 |
| | Mean | 8.38 | 10.28 | 63.08 | 0.036 | 0.011 | 0.011 | 0.237 |

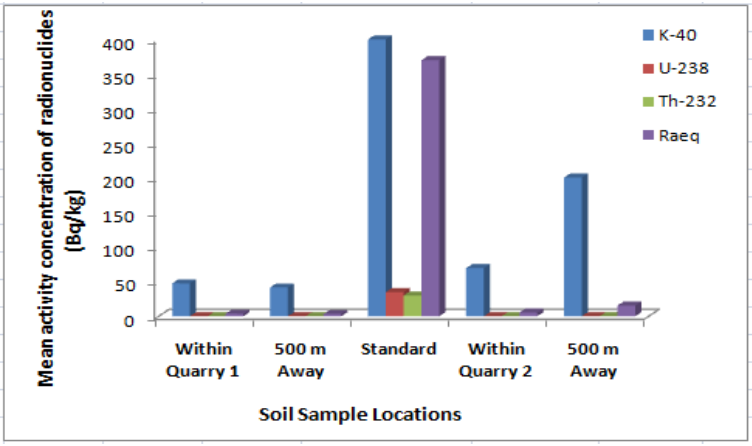


**Fig. 4:** Mean Activity Concentrations of Radionuclides in Soils of the Study Area Compared with the UNSCEAR, 2000.

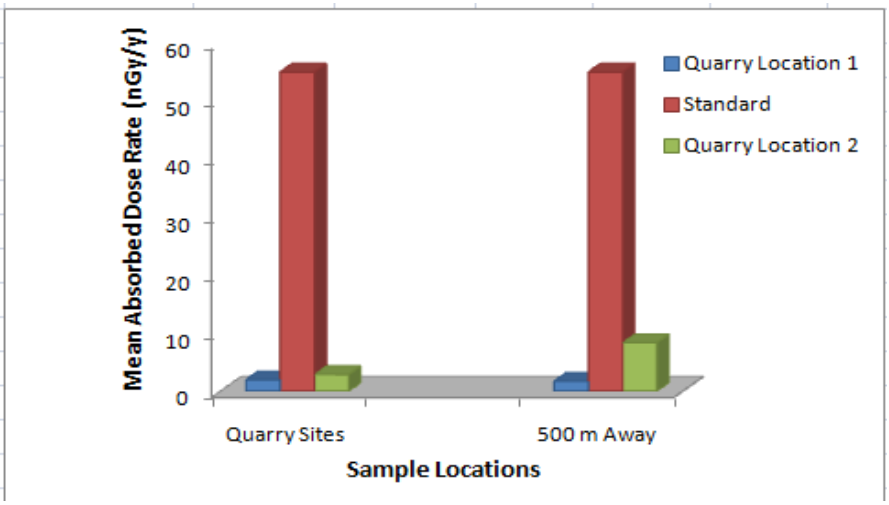


**Fig. 5:** A Comparison of the Mean Absorbed Dose Rate (Ngy/H) in Soil of the Study Areas with the UNSCEAR, 2000.

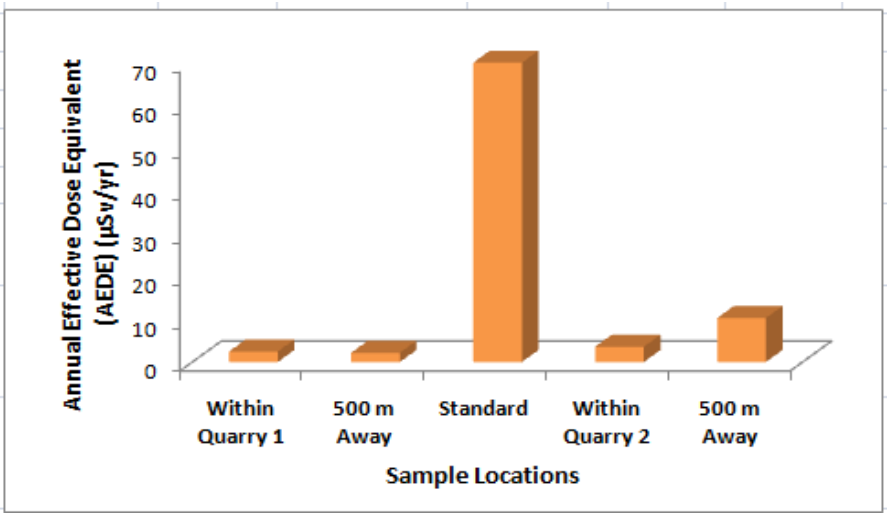


**Fig. 6:** A Comparison of the Annual Effective Dose Equivalent (AEDE) (Outdoor) in Soils of the Study Areas with the UNSCEAR, 2000.

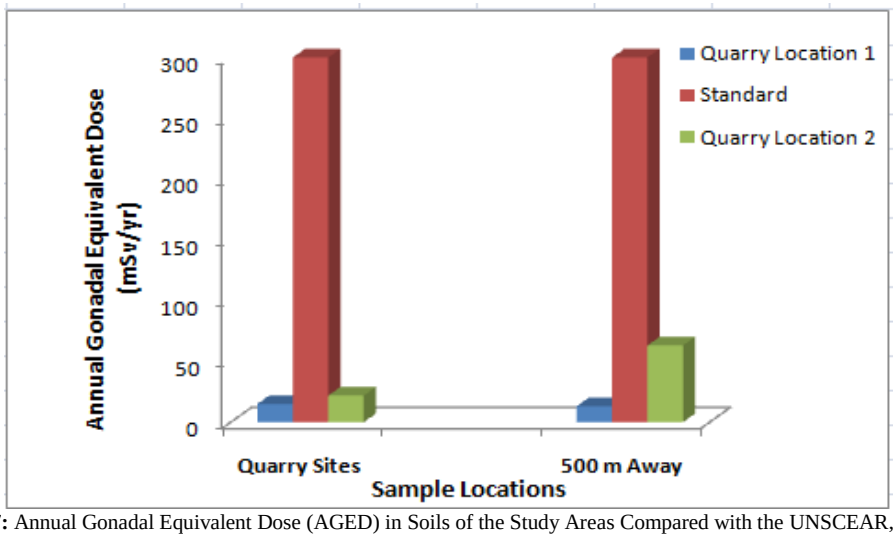


**Fig. 7:** Annual Gonadal Equivalent Dose (AGED) in Soils of the Study Areas Compared with the UNSCEAR, 2000.

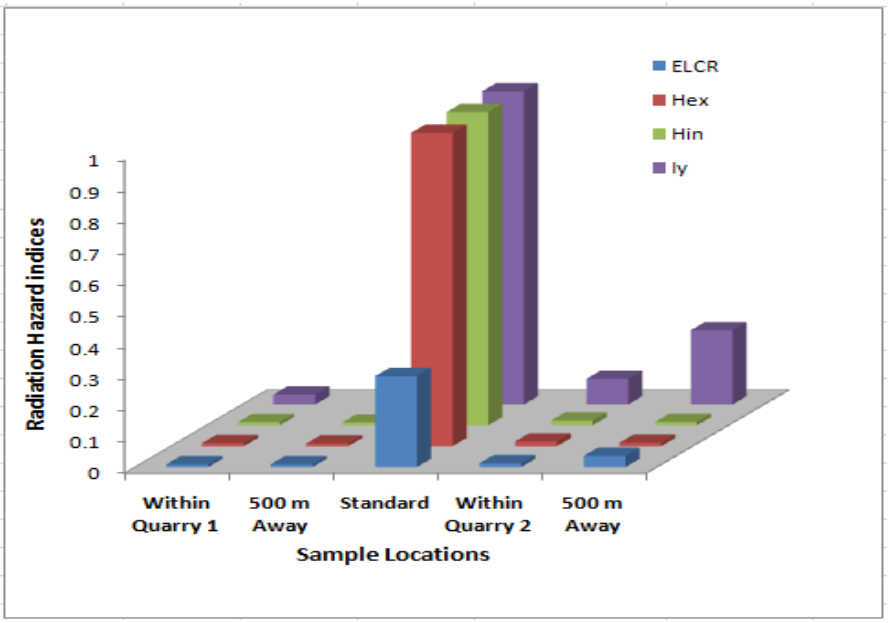


**Fig. 8:** Excess Lifetime Cancer Risk, External Hazard Index, Internal Hazard Index and Gamma Representative Index in Soils of the Study Areas Compared with the UNSCEAR, 2000.

## 5. Conclusion

Quarry activities expose varieties of crystalline rocks to the top surface for the purpose of constructions. This serves as a fast means of human release of natural radionuclides and radiations into various parts of the environments.

The radioactivity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ in soil samples of the two quarry sites showed that there are low level activities in the areas as they were far below their respective world standard values. The measurement showed that $^{40}K$ is the dominant radionuclide in the soils of the study areas. The average dose rates and the annual effective dose equivalent calculated are very low compared to the world standard values for radiological hazard in humans. The other calculated radiation parameters including the excess lifetime cancer risk, radium equivalent, annual gonadal equivalent dose, representative gamma index, external and internal hazard indices for soils of the areas are less than the world permissible value of unity. This indicates that interaction with the soils of the study areas do not expose the workers and the people within and around the areas to any health problem. Nevertheless, continuous radiation monitoring, assessment and control measure is recommended to prevent possible increase in radiation level of the areas due to quarry activities. This will definitely reduce the exposure of workers and people residing around the quarry sites to radionuclide radiations.

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