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Measurement of Gamma-emitting Radionuclides in Rocks and Soils of Saunder Quarry Site, Abeokuta, Ogun State, Nigeria

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Abstract: Crystalline rocks have been observed to be rich in Naturally Occurring Radionuclides (NOR) which are the primary terrestrial sources of radiation in the environment. This study determined the activity concentrations of NOR in rocks and soils from Saunder quarry site, Abeokuta North, South-Western, Nigeria. Three rocks were randomly collected and ten soil samples comprising five surface and five sub-surface were collected by pitting to depth of interest in each location and analyzed using NaI (Tl) gamma spectrometer. The average activity concentrations of ^{40}K, ^{238}U and ^{232}Th in rock samples were 603.62±83.29, 39.70±12.57 and 62.64±20.71 Bq kg^{-1}, respectively. The calculated average Absorbed Dose Rate (ADR) and Annual Effective Dose (AED) were 84.01 nGy h^{-1} and 103.03 μSv y^{-1}. While for soils, the mean activity concentration for the two depths were 145.10±12.64 and 236.08±17.34 Bq kg^{-1} for ^{40}K, 13.36±3.53 and 23.99±6.80 Bq kg^{-1} for ^{238}U and 15.09±5.48 and 10.54±5.67 Bq kg^{-1} for ^{232}Th, respectively. Similarly, the corresponding average ADR and AED for soil were 28.99 nGy h^{-1} and 35.56 μSv y^{-1} for surface 33.32 nGy h^{-1} and 40.87 μSv y^{-1} for sub-surface, respectively. The average values for AED of the sampled rock were higher than 70 μSv y^{-1}. Hence, the granite rock used for building and construction purpose from the study area would be rich in NOR. Routine assessment of radionuclide contents of the rocks of the quarry site was recommended.

Key words: Radioactivity hazards, rock and soil, gamma spectrometry, Abeokuta

INTRODUCTION

The naturally occurring radionuclides include the primordial radionuclide such as uranium (^{228}U), thorium (^{232}Th) and potassium (^{40}K) (Carlson *et al*., 2003). Studies of radionuclides distribution in the immediate environment provide vital information on human exposures to natural and man-made source of radiation (Quindos *et al*., 1994; Steinhausler, 1992). Terrestrial sources of radiation contribute for most of man's exposure to radiation and the average annual effective dose arising from natural source of radiation is 2.4 mSv (UNSCEAR, 2000; Okeyode and Akanni, 2009). The interaction of ionizing radiation with living materials will result in the production of ion pair which will affect the fundamental structure of the material (Okedeyi *et al*., 2012).

Quarrying activities can enhance the natural radiation background levels by bringing out large amount of otherwise buried materials containing Naturally Occurring Radionuclides (NOR) on to the surface of the environment (Saleh *et al*., 2007; Karangelos *et al*., 2004). The radiation from rock and the associated exposures of people around the area depends on geographical and geology of the area (Gbadebo, 2011; Olarinoye *et al*., 2010). Similarly, IAEA (2003) revealed that plants grown on the aggregate dust of quarrying and mining activities, which are rich in NOR are environmental pathways. This study determined the distribution and presence of ^{40}K, ^{238}U and ^{232}Th and their potential hazards in rock and soil of Saunder quarry site, Abeokuta South-Western, Nigeria.

MATERIALS AND METHODS

Study area: The geology of the area is a subset of the basement complex geology of south-Western Nigeria fall within latitudes 7°13′N and 7°20′N and longitudes 3°33′E

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and 3°40'E. Three rock samples were collected randomly from the quarry site. Similarly, a total of 10 soil samples which comprised 5 surface (0-25 cm) and 5 subs-surface (25-50 cm) were collected around the quarry site which host some population and agricultural activities. Each soil sample was collected by pitting the soil to depth of interest in each location and then, packed in plastic poly-ethylene bags. The soil samples were air dried at the room temperature to a constant weight and both soil and rock were crushed, sieved with a 2 mm mesh sieve and sealed for at least a month.

Measurement and techniques: The counting system consists of a 7.6×7.6 cm NaI (Tl) scintillation detector (Model Bircom) encapsulated in a 5 cm tick lead shield and couple to a set of electronic made up of Preamplifier, amplifier, Analog-to-Digital Converter (ADC) that bring an output through a Canberra S100 Multi-Channel Analyzer (MCA) using a spectrum analysis program SAMPO 90, also from Canberra. The detector was quoted at 25% efficiency and calibration was achieved using an IAEA-375 Reference soil supply by the International Atomic Energy Agency. A mass of 200 g of each sample sealed and put in the container were kept for twenty-eight days for attainment of secular equilibrium after which each of the container was placed directly on top of the detector for counting. The same container geometry was used for each sample background (which consists of an empty) and standard with a counting time of 36,000 sec. For quality assurance the gamma ray spectroscopy analysis adopted in this work was used by several researchers (Olomo *et al*., 1994; Ajayi and Ajayi, 1999; Jibiri *et al*., 1999; Tchokossa *et al*., 2011; Iqbal *et al*., 2000). The radionuclides identified with reliable regularity belong to the series one headed by ^{238}U and ^{232}Th, as well as the non-series ^{40}K.

The photopeak used to identify ^{40}K was at 1,461 keV, while those for ^{238}U were ^{214}Bi at 1,764 and 609.3 keV and for ^{232}Th, ^{228}Ac and ^{208}Tl at 911.0 and 583.5 keV, respectively. These photopeaks were also contains in the standard. The mean specific activity was computed as follows:

$$A_c = \frac{A_{net}}{M_S . t_C . p_\gamma . \xi}$$

Where:

A_c: Activity concentration of radionuclide i
A_{net}: Net area under the peak of radionuclide i
M_s: Mass of the sample (kg)
t_c: Counting time (sec)
P_γ: Emission probability
ξ: Detector efficiency

Since, the sample mass was measured to be the same as that of the standard, the mean specific activity per kilogram of dried mass of the samples (rock and soil) was cross checked using Okedeyi *et al*. (2012) as follows:

$$\frac{A_s}{A_{st}} = \frac{N_s}{N_{st}}$$

$$A_s = A_{st}\left(\frac{N_s}{N_{st}}\right)$$

Where:

A_S: Specific activity concentration of radionuclides (Bq kg^{-1}) in unknown sample
A_{st}: Specific activity concentration of radionuclides (Bq kg^{-1}) in reference Material
N_s: Net count rate under region of interest for unknown sample
N_{st}: Net count rate under region of interest (same as N_s) for reference material

RESULTS AND DISCUSSION

The activity concentrations of the naturally occurring radionuclides in the sampled rock and soil are shown in Table 1-3. The results revealed that ^{40}K, ^{238}U and ^{232}Th mean activity were 603.62±83.29, 39.70±12.57 and 62.64±20.71 Bq kg^{-1} in rock (Table 1), 145.10±12.64, 13.36±5.53 and 15.10±5.48 Bq kg^{-1} in surface soil (Table 2) and finally 236.08±17.34, 23.99±6.80 and 10.54±5.67 Bq kg^{-1} in sub-surface soil (Table 3), respectively.

The results show that, the mean activity concentrations of the Naturally Occurring Radionuclides (NOR) were higher in the rocks compared to the soil. This is not surprising in the sense that radionuclides can be easily washed in soil through underground water. The finding revealed that the concentration of the radionuclides in soil samples were higher than

Table 1: Radioactivity concentration, absorbed dose rate and annual effective dose in rock sample

	Conc. (Bq kg^{-1})				
Sample	^{40}K	^{238}U (^{226}Ra)	^{232}Th (^{228}Ra)	Absorbed dose rate (nGy h^{-1})	Annual effective dose (μSv y^{-1})
1	392.32±78.81	16.71±6.74	46.81±20.71	54.64	67.01
2	1353.82±157.17	30.18±8.21	61.22±9.78	110.55	135.59
3	64.72±13.90	72.20±22.75	79.90±31.65	86.83	106.49
Mean	603.62± 83.29	39.70±12.57	62.64±20.71	84.01	103.03

Table 2: Radioactivity concentration, absorbed dose rate and annual effective dose in soil depth 1; 0-25 cm

Sample	Conc. (Bq kg^{-1}) ^{40}K	^{238}U (^{226}Ra)	^{232}Th (^{228}Ra)	Absorbed dose rate (nGy h^{-1})	Annual effective dose (μSv y^{-1})
1	629.80±44.09	19.59±5.85	27.74±8.97	53.31	65.38
2	6.48±2.04	7.85±2.03	7.54±2.05	8.65	10.61
3	29.40±4.98	6.25±12.08	5.69±5.54	43.33	53.14
4	52.93±9.98	12.75±3.45	11.98±3.87	15.66	19.20
5	6.90±2.11	20.37±4.25	22.54±6.95	24.02	29.46
Mean	145.10±12.64	13.36±5.53	15.10±5.48	28.99	35.56

Table 3: Radioactivity concentration, absorbed dose rate and annual effective dose in soil depth 2; 25-50 cm

Sample	Conc. (Bq kg^{-1}) ^{40}K	^{238}U (^{226}Ra)	^{232}Th (^{228}Ra)	Absorbed dose rate (nGy h^{-1})	Annual effective dose (μSv y^{-1})
1	421.67±39.08	16.75±4.25	14.63±5.20	34.62	42.46
2	29.40±4.98	6.25±2.08	14.63±5.20	7.69	9.44
3	693.13±32.67	74.71±21.67	5.69±1.87	101.44	124.41
4	28.10±6.65	6.90±2.03	4.74±1.76	7.29	8.94
5	8.09±3.31	15.32±3.97	13.03±14.31	15.57	19.10
Mean	236.08±17.34	23.99±6.80	10.54±5.67	33.32	40.87

previous works by Arogunjo *et al.* (2004), Huy and Loyen (2006) and Nrayang *et al.* (2001). However, the results is similar to previous work on abandoned quarry sites in Abeokuta by Gbadebo (2011) and in disagreement with earlier finding by Okedeyi *et al.* (2012). It was equally observed that, all values of the activity per unit mass are in the ranges of the corresponding typical world values (UNSCEAR, 2000), which are 50, 50 and 500 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively with exception of ^{238}U in some rock and soil samples. The finding also revealed that, the mean activity concentration of NOR in the soil were samples lower than 39, 41 and 578 Bq kg^{-1} reported by Quindos *et al.* (1994).

The total air absorbed dose rate: The absorbed dose at 1 m above soil or rock containing the naturally occurring radionuclide is calculated from the following expression (UNSCEAR, 2000):

$$D(nGyh^{-1}) = 0.604C_{th} + 0.462C_{u} + 0.042C_{k}$$

where, C_{th}, C_{u}, C_{k} are the activity concentrations (Bq kg^{-1}) of ^{232}Th, ^{238}U and ^{40}K, respectively in the soil/rock sample, and 0.604, 0.462 and 0.042 (nGy h^{-1} per Bq kg^{-1}) are the activity concentration-to-dose conversion factors. The annual effective dose resulting from the absorbed dose is also obtained from UNSCEAR (2000) as:

$$AED\ (\mu Sv\ y^{-1}) = D\ (nGy\ h^{-1}) \times (8760\ h\ y^{-1}) \times 0.2 \times 0.7\ (Sv\ Gy^{-1})$$

where, D (nGy h^{-1}) is the dose rate in air from outdoor terrestrial gamma radiation, 0.7 (Sv Gy^{-1}) is the dose conversion factor and 0.2 is the outdoor occupancy factor.

The average gamma Absorbed Dose Rate (ADR) in air and Annual Effective Dose (AED) of the rock sample were calculated as 84.01 nGy h^{-1} and 103.03 μSv y^{-1} (Table 1) in rock; 28.99 nGy h^{-1} and 35.56 μSv y^{-1} in surface soil (Table 2), and finally 33.32 nGy h^{-1} and 40.87 μSv y^{-1} in sub-surface soil (Table 3), respectively. These values are similar to 77.40 nGy h^{-1} and 88.70 μSv y^{-1} earlier reported by Kurnaz *et al.* (2007), 71 nGy h^{-1} reported by Mehra (2007) as well as 124.00 nGy h^{-1} and 152.00 μSv y^{-1} reported by Yang *et al.* (2005). But the result is lower than 219 nGy h^{-1} and 269 μSv y^{-1} reported by Merdanoglu and Alitinsoy (2006). However, the average annual effective doses recorded at the two depths of the sampled soil of this study were lower than the worldwide average value (70 μSv y^{-1}) recommended by UNSCEAR (2000).

CONCLUSIONS

This study determined the distribution and presence of NOR in rock and soil of Saunder quarry site, Abeokuta, south-western Nigeria. The results not only confirmed the presence of ^{40}K, ^{238}U and ^{232}Th in appreciable amount in the rock as well as in the soils samples, but also indicate a slight increase in the concentration of those radionuclides when compared with other areas with the state. Hence, the quarry activities had been implicated in the concentration of these naturally occurring radionuclides in the surroundings. There is a wide distribution of radionuclides within the samples, even among samples of the same kind. The activity concentrations of natural radionuclides and dose rate were observed to be higher in the rock analyzed than the worldwide average value of 70 μSv y^{-1}, which put the end users of the aggregate rocks and people around the area on a radiological hazard.

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