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MEASUREMENT OF ACTIVITY CONCENTRATIONS OF ROCK SAMPLES FROM ROCKS- SURROUNDED TOWN IN IGBETI, OYO STATE, NIGERIA

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ABSTRACT

Rocks are known to contain radionuclides that emit radiation continuously. The assessment of activity concentrations of rock samples from Igbeti, Oke-Ogun has been investigated. Twenty (20) rock samples were randomly collected from different rock sites. The rock samples were pulverized at the laboratory of the Department of Geology, University of Ibadan. 200g of each collected sample was allowed to attain secular equilibrium by enclosing it in a plastic container for twenty-eight (28) days. Radiometric analysis of the samples was carried out at the radiation laboratory of the Physics Department of the Federal University of Agriculture, Abeokuta using a thallium doped Sodium Iodide detector. Standard equations were used to estimate the radiological parameters associated with exposure to ionizing radiation from the natural radionuclides in the rock samples. The study revealed that the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K lie between 14 − 487 (Bq/kg), 210 − 3680 (Bq/kg), and 242 − 1580 (Bq/kg) respectively. The absorbed dose rate (nGy/h), annual effective dose equivalent (µSv/y), (radium equivalent (Bq/kg), external and internal indices, activity utilization index and estimated excess lifetime cancer risks lie between from (180 − 2700) nGy/h, (0.10 − 14) , 400 − 6300 (Bq/kg), 1 − 17, 1 − 19, 2 − 41, and 0.6− 9.5 × 10^{-6} respectively. The values of the absorbed dose rates value are greater than the world average of 60 nGy/h while annual effective dose equivalent values are less than the world's average value of 1000 µSv/y respectively. The external and internal indices are greater than the permissible limit of (1) and likewise, the radium equivalent value is also greater than the acceptable limit of 370 Bq/kg. The estimated excess lifetime cancer risk for the study is below the permissible limit of 2.9 × 10^{-4} . Most of the estimated radiological parameters for the study are all greater than the permissible limit. This suggests that further exposure of dwellers to ionizing radiation may be possible and this calls for further investigation.

Keywords: measurement /activity concentrations / rocks-surrounded/rock samples

INTRODUCTION

Natural radioactivity in an environment is a result of the presence of natural radionuclides such as ^{238}U, ^{232}Th, and ^{40}K in the geological formation of the environment (Parakash *et al.,* 2017; Kaleel *et al.,* 2012). The levels of terrestrial environmental radiation is related to the geological composition of the region, and the concentrations of ^{238}U, ^{232}Th, and ^{40}K in rocks (Rangaswamy and Sannappa, 2016; UNSCEAR, 2000). The radioactivity due to natural radionuclides in rocks and soils generates a significant component to the background radiation exposure to the population (Kapanadze *et* *al.,* 2019). Rocks contain naturally occurring radionuclides that emit radiation continuously to their immediate environment (Adewoyin *et al.,* 2018). There are sixteen massive rocks surrounding Igbeti and one of the rocks called Iyamopo occupies over six kilometers of the landmass is as high as forty-seven meters and is known for shelter during attacks (Wikipedia(Igbeti), 2021). Residents are living very close to some of the rocks and this will result in continuous exposure of the villagers to ionizing radiation from the rocks and hence the need to measure the activity concentrations of the rocks surrounding Igbeti. The study aims to measure the activity concentrations of radionuclides in the rock samples and estimate appropriate radiological parameters associated with the exposure of Igbeti dwellers to ionizing radiation from naturally occurring radionuclides in the rock samples. There has been no study on the measurement of activity concentrations of rocks surrounding Igbeti, hence the result of the work will serve as the baseline for further study on the exposure to the ionizing radiation from rock samples in Igbeti. Lastly, the result of the study will contribute to the existing body of knowledge in the field.

Experimental procedure

Study area, sampling, and sample preparation

The study area is a rock-surrounded town located at Igbeti, Oyo State, with Lat.8.77' N and Long. 040 0' E. Igbeti, Oke-Ogun is a town located in the Northern part of Oyo State, Nigeria. It has a landmass area of 967km^2 and an estimated population of 81,000 (NPC, 2006). The study area is situated on the basement complex of granitic rock as shown in Figure 1. The basement complex rocks comprise older gneiss, schist, quartzite, older granite, and amphibolite (Alausa, 2014). This basement complex is rich in ^{226}Ra (^{238}U), ^{232}Th, and 4^{0}K radionuclide (Jibiri *et al.,* 2009) and there is a tendency that the rock from the study area may be high in radioactivity. The people in the area are farmers, miners, civil servants, and petty traders. The temperature typically varies from 63^{o}F to 94^{o}F. The rainy season span from June to October with an average daily of 85°F while the hot season lasts from January to April with an average daily temperature of 92°F (Climate and average weather year-round in Igbeti). The natural vegetation is guinea savanna noted with scanty forest with moderately thick forest along streams path.

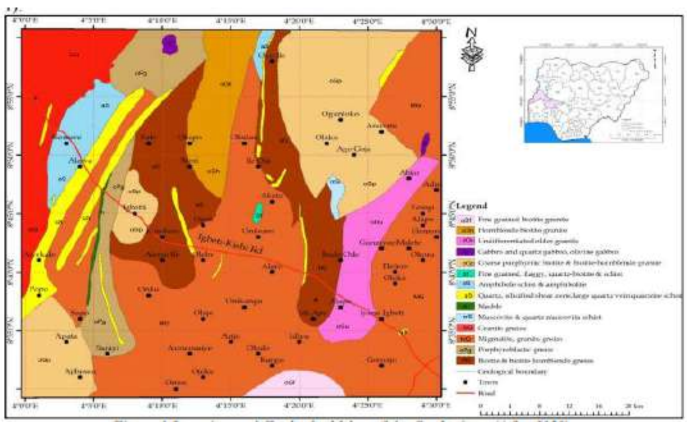

Figure 1: Geological and location map of the study area, (Olasunkanmi *et al.,* 2020)

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A total of twenty (20) rock samples 1.0kg each of twenty rock samples was randomly collected at the sites and packed in a polythene bag which was labeled for identification. The samples were taken to the Geology Department, University of Ibadan, where the rocks samples were crushed and pulverized into powdery form. 200g each of the pulverized samples were weighed and sealed in plastic containers and left for 28 days to attain secular equilibrium. Gamma spectrometry analysis of the samples was done at the radiation laboratory of the Physics department, of the Federal University of Agriculture, Abeokuta, Nigeria using Sodium Iodide spectrometer (NaI) (TI) spectrometer.

Spectrometry analysis of the rock samples in the study

20 rock samples were analyzed for activity concentrations of the radionuclides in the rock samples using thallium activated Canberra vertical high purity 2″×2″ Sodium iodide NaI (TI) detector connected to ORTEC 456 amplifier. The detector was connected to a computer program MAESTRO window that matched gamma energies to a library of possible isotopes. The cylindrical plastic containers for the samples were placed on the NaI (TI) detector with the dimension of 7.6 cm x 7.6 cm. The detector was shielded by 15cm thick lead on all sides and 10cm thick on top and bottom. The energy resolution of 2.0 Kev and relative efficiency of 33% at 1.33Mev was acquired in the system with the counting time of 10,800 seconds to lower the statistical uncertainty. The configuration and geometry were not changed for the period of the analysis, based on the established procedure of the radiation laboratory. The standard International Atomic Energy Agency (IAEA) sources were used for calibration (IAEA, 2003). From the counting spectra lines, the activity concentrations of the radionuclides, ^{238}U, ^{232}Th, and ^{40}K were determined using a computer program. The peak corresponding to 1460 KeV for ^{40}K, 1764.5 KeV (^{214}Bi) for ^{238}U, and 2614.5 keV (^{208}Ti) for ^{232}Th were considered in arriving at the activity levels (Bq kg^{-1}). The background counts were determined by counting an empty container of the same dimension as those containing the samples and subtracting from the gross count. The activity concentrations of the samples were determined using the net area under the photo peaks by the equation (1);

$$A_C = \frac{Cn}{P\gamma \, M \, \varepsilon} \qquad (1)$$

Where A_c is the activity concentrations of the radionuclides (^{238}U, ^{232}Th and ^{40}K) in the sample and unit is Bqkg^{-1}, C_n is the net count rate under the corresponding peak, P_γ is the absolute transition probability of the specific γ-ray, M is the mass of the sample (kg) and ε is the detector efficiency at the specific γ-ray energy. The containers were sealed and airtight to prevent the escape of gaseous ^{220}Rn and ^{222}Rn, incubated for about a month to bring the daughter radionuclide into secular radioactive equilibrium with their respective long-lived parents (Suresh Gandhi *et al*., 2013 and Shittu *et al*., 2015).

Energy and Efficiency Calibration

An important criterion for the measurement of gamma emitters is the correct identity of photo peaks in a spectrum produced by the detector system. The energy calibration of the detector system is made by measuring mixed standard sources of a known radionuclide with well-defined energies provided by the IAEA Technology. The specific activity concentrations (equation 2) of the samples were determined using the net area under the photo peaks from the energy and efficiency calibration.

$$C\ (BqKg^{-1}) = K\ C_n \qquad (2)$$

Where C (BqKg^{-1}) is the specific activity concentrations of the radionuclide in the sample, C_n is the count rate enclosed by the corresponding peak, $K = 1/P^{\gamma}Ms$, ξ is the detector efficiency at the specific gamma-ray energy, P^{γ} is the absolute transition probability of the specific gamma-ray and M_s is the mass of the sample (Jibiri and Okeyode, 2012).

Estimation of radiological parameters for the study

Annual Effective Dose rate

The annual effective dose *H*e was calculated using equation (3) where H_e is the annual effective dose rate in μSv/y and *D* is the value of absorbed dose rate calculated, T is the occupancy time (T= f × 24 × 365.25h y^{-1}) f is the occupancy factor and F_o is the conversion factor (0.7 $SvGy^{-1}$) UNSCEAR, 1993. Dose conversion factors are used to convert radioactivity taken into the body to radiation dose.

$$H_e = DTF_o \quad (3)$$

Radium Equivalent Activity

The significance of ^{40}K, ^{226}Ra, and ^{232}Th concentrations, to radiation exposure is expressed in terms of radium equivalent activity (Ra_{eq}), which was evaluated using Equation (4), (Beretka and Matthew, 1985). According to OECD, (1979), the maximum value must be less than 370 $Bq.kg^{-1}$ for the radiological effect to be considered negligible.

$$Ra_{eq} = A_{Ra} + 1.43A_{th} + 0.077A_K \quad (4)$$

External Hazard Index

External radiation hazard index (H_{int}) is a widely used hazard index that reflects the external exposure level due to gamma radiation. It is estimated from the relation in equation 5, (UNSCEAR, 2000):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{th}}{259} + \frac{A_k}{4810} \quad (5)$$

Internal Hazard Index

In addition to the internal exposure to radiation is quantified by the internal hazard index (H_{ext}) as defined by UNSCEAR, (2000) in equation (6),

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (6)$$

Activity Utilization Index (AUI)

The samples of rocks and soil samples from the mining sites were also examined to determine whether they satisfied the dose criteria for use as building materials. Activity utilization Index (U) was calculated using the model equation adopted by El-Gamal and El- Taher (2007), (equation 7).

$$AUI = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (7)$$

Where A_U, A_{Th}, and A_K are as previously defined.

Excess Lifetime Cancer Risk (ELCR)

The probability of occurrence of cancer in any given population for a given lifetime exposure is measured by the excess lifetime cancer risk (ELCR). ELCR was calculated from the estimated AEDE using the equation (8),(Qureshi *et al.*, 2014):

$$ELCR = AEDE \times DL \times RF \quad (8)$$

Where DL is the life expectancy of 70 years, and RF is the risk factor given to be $0.05Sv^{-1}$ for stochastic effects (Taskin *et al.*, 2009).

RESULTS AND DISCUSSION

This section presents the results of pictorial representations and discussions. Statistical analysis of the parameters in the study is also presented. Table 1 shows the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the rock samples and their ratio.

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Table 1: Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the rock samples and their ratios.

Rocks ID	226-Ra (Bq/kg)	232-Th (Bq/kg)	40-K (Bq/kg)	$\frac{^{232}Th}{^{226}Ra}$	$\frac{^{40}K}{^{226}Ra}$	$\frac{^{40}K}{^{232}Th}$
R1	16.56 ± 2.85	387.85 ± 13.22	1129.18 ± 34.04	23.42	68.20	2.91
R2	14.82 ± 1.38	232.85 ± 14.33	903.879 ± 12.27	15.71	60.98	3.88
R3	57.66 ± 2.07	358.56 ± 11.24	2046.78 ± 27.11	6.21	35.50	5.71
R4	32.19 ± 3.40	332.93 ± 13.44	1088.89 ± 12.06	10.34	33.83	3.27
R5	83.72 ± 1.18	220.65 ± 17.77	296.61 ± 27.17	2.64	3.54	1.34
R6	486.09 ± 1.24	3679.28 ± 14.64	5952.95 ± 47.27	7.57	12.25	1.62
R7	35.66 ± 1.34	395.17 ± 14.74	602.49 ± 22.86	11.08	16.89	1.52
R8	69.24 ± 0.79	210.89 ± 16.05	729.31 ± 25.49	3.05	10.53	3.45
R9	31.61 ± 1.00	464.73 ± 13.16	924.77 ± 27.57	14.70	29.26	1.99
R10	40.29 ± 2.33	509.89 ± 14.06	430.90 ± 15.16	12.65	10.69	0.85
R11	57.66 ± 2.53	574.57 ± 19.00	1579.77 ± 29.21	9.96	27.40	2.75
R12	47.24 ± 2.35	442.76 ± 21.60	1018.77 ± 12.82	9.37	21.56	2.30
R13	44.93 ± 2.50	335.37 ± 11.97	272.75 ± 23.74	7.46	6.07	0.81
R14	72.72 ± 11.25	354.89 ± 11.54	1341.05 ± 10.57	4.88	18.44	3.78
R15	31.98 ± 1.76	3422.9 ± 5.01	791.976 ± 36.66	107.04	24.77	0.23
R16	114.40 ±23.71	407.37 ± 11.34	242.91 ± 24.90	3.56	2.17	0.60
R17	38.56 ± 1.37	442.76 ± 12.06	602.49 ± 12.86	11.48	15.63	1,36
R18	47.24 ± 2.12	407.37 ± 16.91	729.31 ± 15.49	8.62	15.44	1.79
R19	33.35 ± 1.94	440.32 ± 14.06	924.77 ± 17.57	13.20	27.73	2.10
R20	54.77 ± 11.10	562.36 ± 12.75	430.90 ± 15.16	10.27	7.87	0.77
Mean	**355.95 ± 3.91**	**709.17 ± 13.94**	**1102.02 ± 22.50**	**10.05**	**15.62**	**1.55**

The values of the activity concentrations of the radionuclides found in the rock samples vary between 430 −2047 (Bq/kg) for ^{40}K, 1−115 (Bq/kg) for ^{226}Ra, and 273 −5960 (Bq/kg) for ^{232}Th. The values of the activity concentrations of the radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in the study were compared with similar studies in other countries and the world's average, (Table 2). The differences in the activity concentrations values of the radionuclides in the rock samples presented in Table 2, across the countries could be due to the different geological compositions across the countries. The ratios, $\frac{^{232}Th}{^{226}Ra}$, $\frac{^{40}K}{^{226}Ra}$ and $\frac{^{40}K}{^{232}Th}$ reveal the extent of depletion or enrichment of these radioisotopes. The ratio $\frac{^{40}K}{^{226}Ra}$ is greater in value than $\frac{^{232}Th}{^{226}Ra}$ and $\frac{^{232}Th}{^{226}Ra}$ and is greater in value than $\frac{^{40}K}{^{232}Th}$. This shows that ^{232}Th and ^{40}K are the dominant sources of gamma radiation in the area of study as also reported by Alnour *et al.*, 2012 in their study.

Table 2: Comparison of activity concentration values of ^{226}Ra, ^{232}Th and ^{40}K with other countries

Countries	Activity Concentrations Ranges (Bq/kg) ^{226}Ra	^{232}Th	^{40}K	References
Nigeria (Igbeti)	14 – 487	209 – 3680	429 – 5953	Present Study
Coorg	BDL −34.11	16.46−160.84	96.72−933.68	Prakash, *et al.*, 2017
Chika Manguluru	143.9−760.9	45.9−450.7	316.8−985	Manjunatha *et al.*, 1998
Kali river, India	41.0−322.6	BDL−26.1	147.2−2739	Narayana *et al.*, 2007
Cyprus	1−588	1−906	50−160.6	Michalis *et al*, 2003
Pakistan	33	32	57	Iqbal *et al.*, 2000
Sudetes Mountain, Poland	31—122	25−62	320−1200	Malczewski *et al.*, 2004
Wadi Karim area, Egypt.	14.0−227	10.5−183.0	2299−7356	El-Arabi., 2007
Piedmont, Italy	397	211	1265	Lucia *et al.*, 2006
Turkey	15.85	33.8	359	Osmanlioglu, 2006
World Average	35	30	400	UNSCEAR, 1993

Table 3: Estimated radiological parameters of rock samples in the study area

Rock ID	Ra_{eq} (Bq/kg)	Hazard Indices External	Internal	Absorbed Dose rates (D) nGy/h	AEDE ($\mu Sv/y$)	AUI	ELCR (10^{-6})
R1	657.56	1.78	1.82	288.76	1.41	4.74	0.62
R2	417.39	1.13	1.17	185.18	0.91	3.03	3.97
R3	727.99	1.97	2.12	328.56	1.61	5.33	7.05
R4	592.12	1.59	1.69	261.37	1.28	4.27	5.61
R5	422.08	1.14	1.37	184.32	0.90	2.96	3.96
R6	6205.83	16.76	18.07	2695.09	13.22	44.00	5.78
R7	647.14	1.75	1.84	280.28	1.37	4.59	6.02
R8	426.97	1.15	1.34	189.78	0.93	3.06	4.08
R9	767.38	2.07	2.16	333.86	1.63	5.47	7.17
R10	1193.22	3.22	4.39	525.02	2.57	8.26	1.13
R11	1000.94	2.70	2.86	439.55	2.15	7.18	9.44
R12	758.84	2.05	2.18	331.74	1.63	5.42	7.12
R13	545.50	1.47	1.59	234.69	1.15	3.83	5.04
R14	683.48	1.85	2.04	303.87	1.49	4.93	6.63
R15	4987.84	13.47	13.55	2115.29	10.37	34.97	4.54
R16	715.64	1.93	2.24	309.03	1.51	4.99	6.64
R17	718.10	1.94	2.04	310.37	1.52	5.08	6.67
R18	885.93	1.85	1.97	298.28	1.46	4.87	6.41
R19	734.22	1.98	2.07	319.92	1.57	5.24	6.87
R20	892.13	2.41	2.56	382.94	1.88	6.28	8.22
Mean	**1199.02**	**4.22**	**3.45**	**515.89**	**2.53**	**8.43**	**5.65**
W.A	**370**	**1**	**1**	**60**	**1000**	**2**	**2.9$\times 10^{-4}$**

Again, Table 3 show that the range of the absorbed dose rates (nGy/h), annual effective dose equivalent (AEDE) (radium equivalent (Bq/kg), hazard indices (external and internal), the activity utilization index, and excess lifetime cancer risks ranged from (184.32− 2695.09) nGy/h, with the mean of 515.89 nGy/h, (0.90 − 13.22) with the mean of 2.53 $\mu Sv/y$, 417.39 – 4987.84 (Bq/kg)

with a mean of 1199.02 Bq/kg, 1.13 − 16.76 with a mean of 3.45 and 3.03 −

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44.00 with a mean of 8.43 and $(0.62 - 9.44) \times 10^{-6}$ with a mean of 5.65×10^{-6} respectively. The values of the absorbed dose rates are greater than the world average of 60 nGy/h while the values of the annual effective dose rates are less than the world average of 1000 μSv/y. The values of the external and internal hazard indices are greater than the permissible limit of one (1). The radium equivalent value is also greater than the acceptable limit of 370 Bq/kg and the activity utilization index is greater than the world's average. The values of these radiological parameters imply that there may be high gamma irradiation externally and internally if the dwellers of Igbeti are exposed to ionizing radiation from the radionuclides in the rocks during the annual festive period they observe at the rocks at Igbeti. However, the mean value of the excess lifetime cancer risk for the study is below the permissible limit of 2.9×10^{-4}, (UNSCEAR, 2000).

Table 4: Comparison of estimated radiological parameters for the study with other countries

Countries	**Ra_{eq} (Bq/kg)**	**H_{ext}**	**H_{int}**	**Dose (D) nGy/h**	**AEDE ($\mu Sv/y$)**	**ELCR ($\times 10^{-6}$)**	**References**
Present Study	1199.0	4.22	3.45	515.89	0.63	5.65	Present study
Egypt	56.00	0.15	0.18	28.60	40	-	El-Arabi, 2006
China	190.0	0.51	0.59	-	0.65	-	Xinwei *et al.*, 2006
Turkey	-	-	-	44	0.30	-	Wafaa, 2004
Turkey				43.2			Ahmet, 2006
Cyprus	-	-		1209	2970	-	Michalis *et al.*, 2003

Table 4 presents the comparison of the estimated radiological parameters associated with the exposure due to ionizing radiation from the radionuclides in rock samples for the study with similar studies from other countries.

Table 5: Statistical analysis of the Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K

Statistical Parameters	**^{226}Ra**	**^{232}Th**	**^{40}K**
Minimum	14.82	210.8	242.91
Maximum	5766.0	3679.28	5952.95
Mean	355.95	709.17	1102.02
Standard Deviation	1277.35	977.17	1228.34
Skewness	4.43	2.84	3.55
Kurtosis	19.71	6.97	14.12
Frequency	leptokurtic distribution	platykurtic distribution	leptokurtic distribution

The statistical analysis of the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are presented in Table 4. SPSS 17 software was used for the analysis. The curves showing the frequency distributions for ^{226}Ra, ^{232}Th, and ^{40}K (Figs. 2 − 4) concentrations are normal. Skewness is a measure of the asymmetry of the probability distribution of a real-valued random variable around its mean. Knowledge of the Skewness of a data set indicates whether deviations from the mean are going to be positive or negative. The mean and the standard deviation of the activity concentrations of ^{40}K are close compared to that of ^{226}Ra and ^{232}Th. The measure of skewness of 4.43, 2.84, and 3.35 for ^{226}Ra, ^{232}Th, and ^{40}K concentrations show that the distributions of the three radionuclides are fairly symmetrical. Kurtosis is a measure of probability of data being peaked or flat relative to a normal distribution. Data sets with high kurtosis tend to have a distinct peak near the mean and decrease and forming heavy tails (leptokurtic distribution). Data sets with low kurtosis tend to have a flat top (Figure 3) and small tails (platykurtic distribution) (Figs. 2 and 3). Positive kurtosis indicates a peaked distribution and negative kurtosis indicates a flat distribution of the activity concentrations. The positive kurtosis values of 19.71, 6.97, and 14.12 for ^{226}Ra, ^{232}Th, and ^{40}K concentrations show that most of the samples have either very low values or very high values. The radionuclides in the rock samples for the study exhibit some degree of non-multi-modality. Multi-modal characteristics of the radioactive elements show the complexity of minerals in soil samples.

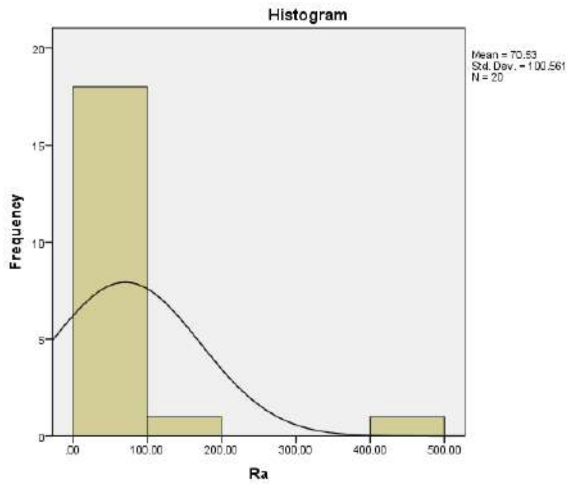

Figure 2: Frequency distribution curve for ^{226}Ra

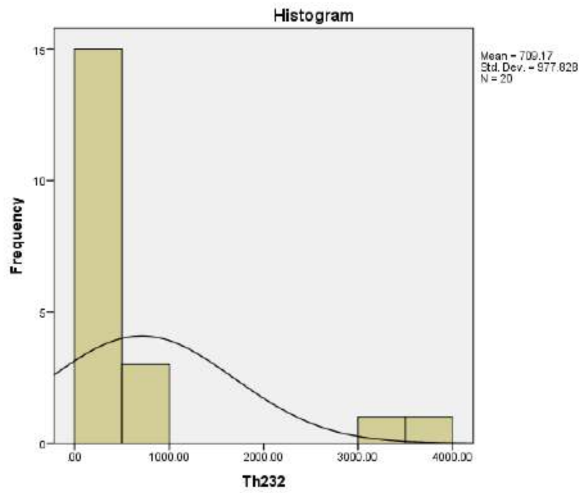

Figure 2: Frequency distribution curve for ^{232}Th

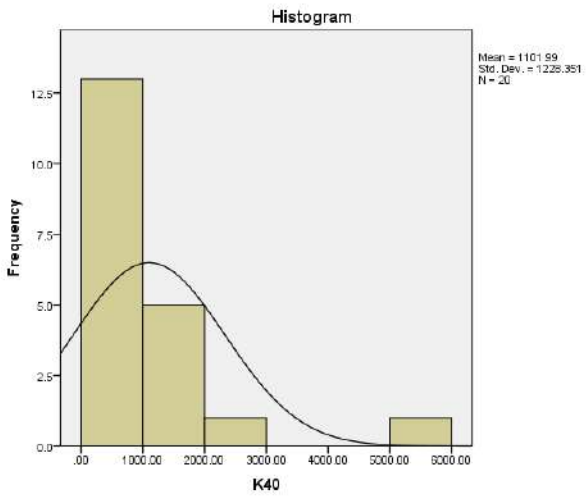

Figure 3: Frequency distribution curve for ^{40}K

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Table 6: Pearson correlation coefficient matrix for estimated radiological parameters of the study

Radiological Parameters	^{226}Ra	^{232}Th	^{40}K	Ext_{ind}	Int_{ind}	Ra_{eq}	Absorbed Dose rates(D) (nGy/h)	AEDE (µSv/y)	AUI	ELCR
^{226}Ra	1.00									
^{232}Th	0.67	1.00								
^{40}K	0.52	0.66	1.0							
Ext_{ind}	0.75	0.62	0.73	1.0						
Int_{ind}	0.73	0.99	0.72	0.62	1.0					
Ra_{equ}	0.73	0.99	0.73	0.63	0.99	1.0				
Dose(D) (nGy/h)	0.73	0.99	0.73	0.63	0.99	0.99	1.0			
AEDE(µSv/y)	0.73	0.99	0.73	0.62	0.99	1.00	1.0	1.0		
AUI	0.09	-0.02	0.16	-0.15	-0.05	-0.28	-0.03	-0.03	1.0	
ELCR	0.69	0.93	0.51	0.54	0.84	0.91	0.90	0.90	-0.23	1.0

Pearson correlation coefficient was used to establish the degree of relationship that exists between the radiological parameters in the study and the result is as presented in Table 6. There are strong correlations between all the radionuclides with the highest being 0.99. This implies that the levels of exposure of the dwellers of Igbeti to these natural radionuclides are close in range. This trend was also observed in the positive correlation that exists between the other estimated radiological parameters viz a viz; external and internal gamma indices, dose rates, annual dose rates, and excess lifetime cancer risks. This again explains the fact that quantifying the level of exposure of the dwellers of Igbeti to radionuclides in the rock surrounding the area concerning the estimated radiological parameters gives close-range values. Fusun *et al.*, 2020, Ajetunmobi, 2018, and Ghada and Arafat, 2018 reported the same trend of positive correlation between estimated radiological parameters in their study. However, there seems to be a negative and very low correlation between the activity utilization index and other radiological parameters for the study. This may be interpreted that the activity utilization index values (though greater than the world) do not hinder the use of the rocks as building materials. This is due to the low values of the activity concentrations of all the radionuclides in the rock samples. Unlike the work of Lasun *et al.*, 2019, which reported positive correlations between the activity utilization index and ^{226}Ra (0.99), ^{232}Th (0.57), external and internal indices (0.98, 0.99), and radium equivalent (0.99).

CONCLUSION

The activity concentrations of natural radionuclides in the rock samples from Igbeti and the associated radiological parameters have been investigated to estimate the number of exposures of the dwellers. The estimated radiological parameters for the study are all greater than the permissible limit with the exceptions of excess lifetime cancer risks and the annual effective dose rates. This shows that the rocks surrounding the dwellers of Igbeti town enhance natural radionuclides exposure. Further and regular radiological i nvestigations/measurements should be advised and encouraged in the areas studied and different pathways for exposure to ionizing radiation should be considered.

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