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Radiological Evaluation of Quarry Products from Oban Massif, Southeastern Nigeria

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Abstract

A gamma spectrometry analysis using a Thallium-Doped Sodium-Iodide detector has been conducted on rock samples collected from parts of Oban Massif to ascertain the concentration of radionuclide elements: U-(238), Th-(232), and K-(40). The specific objective of this study was to estimate the potential radiological risk associated with the use of rocks from the study area in construction. The estimated radiological hazard indicators showed that the Alpha index ranged from 0.01 to 2.72 Bq/Kg (mean: 0.81 Bq/Kg), and the Gamma index ranged from 0.27 to 5.54 Bq/Kg (mean: 2.35). Internal and external hazard index varied between 0.20 to 5.30 Bq/Kg (mean: 2.20) and 0.19 to 3.82 Bq/Kg (mean: 1.76) respectively, Radium Equivalent ranged from 72.05 to 1406 Bq/Kg (mean: 650 Bq/Kg), Representative Level Index varies from 0.55 to 11.08 Bq/Kg (mean: 4.70 Bq/Kg) and Annual Gonadal Equivalent Dose varied from 248.9 to 5173 μSvy^{-1} (mean: 2070 μSvy^{-1}). The results showed that, of the 18 surveyed locations, only 3 have quarry products suitable for use as building materials. Others showed results that are above permissible limits. Hence, may pose radiological risks when used as building materials It is worth noting that most quarries in the zone are situated in the Akamkpa, an area observed to have radiologically unsafe rocks, and rocks from this region (Akamkpa) are mostly mined for all sorts of construction purposes, which further implies that those buildings and other constructions made from these materials are radiologically unsafe for humans. Further studies are necessary to assess the potential for mitigating these radiations naturally, since it may be impossible to avoid building in those areas due to urban expansion and population growth.

Keywords: Radiological effect; Quarry products; Radionuclides, Radioelements

Introduction

Quarry products such as gravels, rocks, and sands include all crustal rocks (granite, gneiss, diorite, dolerite, granodiorite, and others) with varying mineral compositions, crushed to different sizes (Gbenu et al., 2016). Quarry products are durable and attractive, and thus have been used extensively in Nigeria for flooring and interior decoration in building works.

Crustal rocks from which quarry products are obtained naturally contain radionuclide materials such as Uranium-238, Thorium-232, and Potassium-40. These elements are called lithophile elements

(Gbenu et al., 2016; Essien et al., 2017). The concentration of these radionuclides varies with rock type due to their different mineral composition. In a typical granitic rock, potassium (K) is the dominant constituent element. At the same time, thorium (Th) occurs as a trace element in phosphates, oxides, and silicates as well as a primary rock-forming mineral in materials such as monazite, thorianite, and thorite. Uranium (U) on the other hand is found in different species of rock such as apatite, sphene and zircon and it occurs as a secondary or accessory mineral. Generally, these lithophile materials are more concentrated in felsic rocks than intermediate, mafic and ultra-mafic rocks (Gbenu et al., 2016; Essien et al., 2017; Alnour et al., 2012; Akpan et al., 2016). The presence of lithophile elements in quarry products used as construction materials results in both indoor and outdoor radiation exposure.

Depending on the level of exposure, radiation sickness may occur. (Akpan et al., 2016) reported that lithophile elements have unstable nuclei and thus undergo spontaneous disintegration to produce other progenies. The liberation of particles and electromagnetic radiation usually accompanies the decay process. The actual amount of radiation produced by the primordial radionuclides depends on the mineralogical composition of the rocks. This radiation is known to have potential adverse effects to both the environment and public health. Though the danger of radioactive radiation is contingent on the amount and type of energy emitted by the atoms. Environmental problems associated with lithophile elements occur naturally and spontaneously, more often during quarrying, leaching, handling, storage and transportation processes. During these processes, the radiation emitted is absorbed by man through air inhalation or food intake (Essien et al., 2016; Essiett et al., 2015; Innocent et al., 2013; Jassim et al.; Iwetan et al., 2016).

Recently, there is increase demand for quarry products by individuals, government and non-governmental organization as building and construction materials. Due to the market value and an increased demand for quarry products, the Oban Massif area which is potentially endowed with crustal rocks is experiencing proliferation of quarry sites. The quarry operation which involves blasting and excavation of rocks brings these radionuclides to the surface thereby exposing workers and environment to radiation (Thabayneh & Jazzar, 2012). A very high level of radiation exposure delivered over a short

period of time can cause acute radiation syndrome with symptoms such as nausea and vomiting within hours and can sometimes result in death over the following days or weeks (USEAP, 2011). This has imposed some scientific questions such as, what level of exposure to these radiations can cause acute radiation syndrome. In terms of duration of development of radiation sickness (USEAP, 2011) reported that more than 0.75 gray (75 rad) in a short time span can cause very high radiation exposure to cause acute radiation syndrome. Why do people have records of radiation effects over time in their lifetimes? People may slowly get exposure to low-levels of radiation and this does not cause immediate or acute health effect but can cause a small increase in the risk of cancer over a lifetime. In an attempt to give answers to some of the question, knowledge of radionuclide distribution in rocks of any geological terrain is indispensable for the assessment or evaluation of the hazard due to exposure to radiation associated with the products from such terrain.

Although, (Gbenu et al., 2016; Essien et al., 2017; Essiett et al., 2015; Innocent et al., 2013; Iwetan et al., 2016; Thabayneh & Jazzar, 2012) have conducted research to ascertain radiological effects of rocks in different localities but no detailed study of this sort has been conducted in the study area of this work, which is the major quarry site in Cross River State in particular and Southeastern part of the country in general. It is on this basis that this study was carried out to use a gamma ray spectrometer to investigate the possible radiological impact of quarry products, which have direct impacts on the health condition of the people around the area and away from the area who use these quarry products. (Santos Jr et al., 2010) reported that in recent studies, calc-silicate rocks showing high content of these elements and used for housing constructions are unsafe.

Physiology of the study area

The Oban Massif, is one of the Precambrian basement provinces in Cross River State, southeastern Nigeria. It lies between latitudes $5^{\circ}00' \; and \; 5^{\circ}45'$ North of the Equator and longitudes $8^{\circ}00' \; and \; 8^{\circ}55'$ East of the Greenwich Meridian. It is bounded by the Ikom-Mamfe Embayment in the Northern flank and Calabar Flank in the southern axis. It shares its Eastern border with the Cameroon

Volcanic Line and the Benue Trough in the West. The basement is overlain by Cretaceous to Tertiary sediments.

The region has an approximate area of $8{,}740\ km^2$ and has few detached hills with estimated maximum vertical distance of roughly 1,200 *m* beyond datum (Ekwere & Edet, 2016). The hills advance steeply creating some recurrent V-shaped valleys which are heavily woodland even to the mountain top. The Massif has a good drainage system that is controlled by joints and fractures with good networks of rivers and streams actively engaged in juvenile stage channel erosion. The area has tropical climatic conditions that are characterized by dry and wet seasons respectively. The rainy season stretches typically from May to October, a period of six months and the dry season spans also for six months from November to April. The average annual temperature and rainfall are $28°C\ and\ 2300\ mm$ respectively (Ekwere et al., 2011).

Geology of the study area

The Oban Massif is part of a massive offshoot that symbolizes the western protraction of the Cameroon Mountain into the Cross River Plains of Southern Nigeria. Extremely distorted Precambrian crystalline basement rocks with height of about 150 *m* rising steadily from Calabar and falling towards the Obudu in Cross River North are found underneath the study area. Moreover, the Oban Massif is an intensely divided plateau in which some places are almost 1,125 *m* above datum (Opera et al., 2014). Lateritic soil type that has resulted from the weathering of granitic rocks overlies the Oban Massif. The prevalent rocks in the Oban Massif are principally migmatites, granites, banded gneisses, schists, phyllites and amphibolite’s. The rocks are intruded by diorites, granodiorites, pegmatites, monzonites, granites and tonalities (Asinya et al., 2016).

The granodiorites shelter around 10% of the region and are the utmost noticeable intrusive rock in the region. They are generally gigantic, weakly foliated and medium-coarse grained (Edet & Okereke, 2015; Akpan et al., 2011; Oden et al., 2017; Asinya et al, 2016; Ekwere & Edet, 2013). Some economic minerals found within the Oban Massif are mica, feldspars, galena, graphite, kaolin, gemstones, gold, quartz, uranium, ilmenite, manganese, rutile and tin (Ekwere & Edet, 2016). Figure. 1 shows the geologic map of the study area.

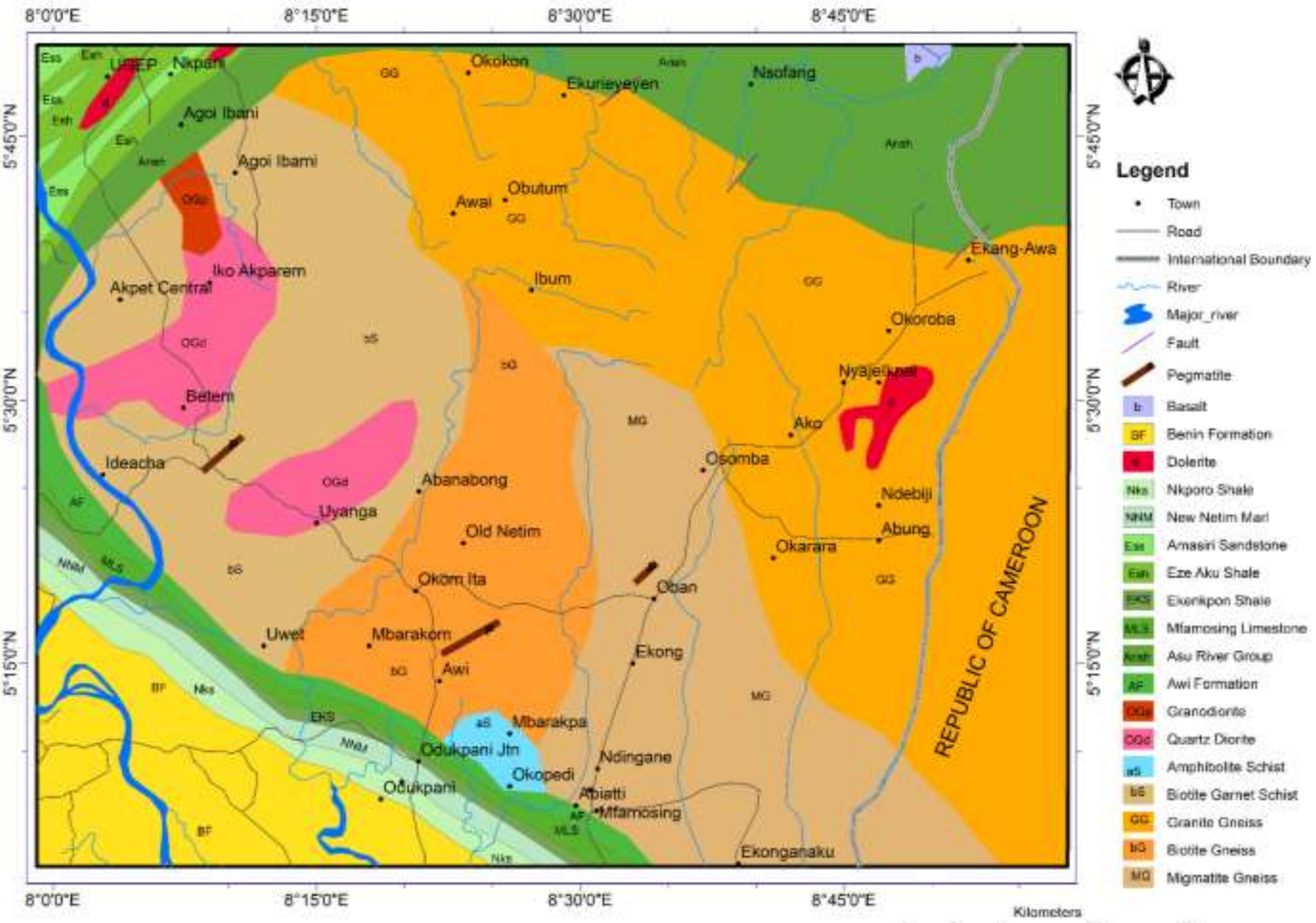

FIG. 1: GEOLOGICAL MAP OF OBAN MASSIF, SOUTHEASTERN NIGERIA

Materials and methods

Sample collection

For the purpose of this study, a total of eighteen rock samples were collected from eighteen (18) locations in the study area. A global positioning system (GPS) receiver was used in measuring the geographic coordinates of the locations where the samples were collected. The samples were labeled accordingly using paper tape and a marker pen. The samples were all packed in black polythene bags and conveyed to the laboratory.

Sample preparation and analyses

Prior to analysis, the samples were first sun dried for a week to eliminate all moisture content, then crushed into powder before being loaded into a black polythene bag and coded for easy identification and tracking. They were then sent to National Institute for Radiation Protection and Research (NIRPR), University of Ibadan Campus, Ibadan, Nigeria for analyses. At NIRPR, the pulverized samples were dried in an oven programmed to a fixed temperature of 110 ^{o}C for over 24 hours to ensure complete moisture-free samples and to obtain a constant dry weight as well as to reduce self-absorption and to obtain homogeneity (Alabi et al., 2007). The rock samples were carefully packed in a 39.1 g sealable, non-radioactive plastic container and labelled. They were left for a month to allow the short-lived gaseous members of the Uranium and Thorium decay series to reach secular equilibrium prior to the gamma spectroscopy (Asaduzzaman et al., 2015). Thereafter, the activity concentrations of Uranium, Thorium, and Potassium were analyzed using a gamma ray spectrometer. The results of the analysis are presented in Table 1.

Radiological hazard indices

Alpha index

The alpha or internal index (I_α) is a tool developed for weighing the excess α-radiation exposure due to the breathing in Radon released from crustal rock used for building materials. According to Asaduzzaman et al. (2015), it can be estimated using equation 1.

$$I_\alpha = \frac{C_u}{200\ Bqkg^{-1}} \quad (1)$$

Where I_α, C_u and 200 are the alpha index, activity concentration of the alpha particle emitter (Uranium-238) in the material and the recommended level respectively. The recommended exemption level and upper level for the Radium-226 activity concentration in building materials are $100\ Bqkg^{-1}$ and $200\ Bqkg^{-1}$ respectively (Ademola et al., 2014).

Gamma index

Gamma index is also known as the external index. It is an index designed as a selection tool for the categorization of construction materials. This is carried out to reduce the surplus gamma rays liberated from building materials. The gamma index for a usual building material can be valued using equation 2 according to (Asaduzzaman et al., 2015).

$$I_\gamma = \frac{C_u}{300\ Bqkg^{-1}} + \frac{C_{Th}}{200\ Bqkg^{-1}} + \frac{C_K}{3000\ Bqkg^{-1}} \quad (2)$$

Where I_γ, C_u, C_{Th} and C_k are the gamma index, activity concentrations of Uranium, Thorium, and Potassium, respectively. The assumption here is that the activity concentrations of $300\ Bqkg^{-1}$ of Uranium-238, $200\ Bqkg^{-1}$ of Thorium-232 and $3000\ Bqkg^{-1}$ of Potassium-40 each gives off the same gamma dose rate (Ademola et al., 2014).

Internal hazard index

The internal exposure caused by the breathing in of α particle emanated from the short-lived radio-isotope such as Radon in the decay series of Uranium are hazardous to the respiratory organ. So, it is quantified or controlled by the internal hazard index (H_{in}) which can be estimated using equation 3 according to (Asaduzzaman et al., 2015).

$$H_{in} = \frac{C_u}{185\ Bqkg^{-1}} + \frac{C_{Th}}{259\ Bqkg^{-1}} + \frac{C_K}{4810\ Bqkg^{-1}} \quad (3)$$

Where H_{in}, C_{Ra}, C_{Th} and C_k are the internal hazard index and the activity concentrations of Uranium, Thorium and Potassium respectively. (Ademola et al., 2014)., the recommended safety level of the internal hazard index (H_{in}) is less than or equal to unity.

External hazard index

The external radiation hazard is one of the widely used hazard index to value the radiological suitability of building construction materials and also to determine the external dose delivered to an individual in the environment. The external hazard is defined according to Ademola et al., 2014, as in equation 4

$$H_{ex} = \frac{C_u}{370\ Bqkg^{-1}} + \frac{C_{Th}}{259\ Bqkg^{-1}} + \frac{C_K}{4810\ Bqkg^{-1}} \quad (4)$$

Where H_{ex}, C_u, C_{Th} and C_k are the external hazard index and the activity concentrations of Uranium, Thorium and Potassium respectively. Considering an individual in an ideal house modeled with standard windows and doors which cause proper air circulation in the rooms thereby decreasing the radiation exposure of the occupants leading to the reduction in the doses. The external hazard defined by Isinkaye et al. (2015) is presented in equation 5.

$$H_{ex} = \frac{C_{Ra}}{740\ Bqkg^{-1}} + \frac{C_{Th}}{518\ Bqkg^{-1}} + \frac{C_K}{9620\ Bqkg^{-1}} \quad (5)$$

Isinkaye et al., (2015) reported that, for materials to be considered safe, the external hazard index must be less than or equal to unity.

Radium equivalent

The radium equivalent is another commonly used radiological parameter in defining exposure due to gamma radiation associated with the primordial radioelements. It is usually regarded as the weighted sum of the activities of the specified radionuclide established on the approximation that $370\ Bqkg^{-1}$ of Radium, $259\ Bqkg^{-1}$ of Thorium and $4810\ Bqkg^{-1}$ of Potassium produces identical gamma ray dose rates (Isinkaye et al., 2015). The maximum allowable bounds of any usable material by humans must have Radium equivalent activity less than $370\ Bqkg^{-1}$for it to pass the radiological health safety assessment. Asaduzzaman et al. (2015) report that the Radium equivalent can be valued using equation 6.

$$Ra_{eq} = 370\ Bqkg^{-1}\left(\frac{C_u}{370\ Bqkg^{-1}} + \frac{C_{Th}}{259\ Bqkg^{-1}} + \frac{C_K}{4810\ Bqkg^{-1}}\right) \quad (6)$$

Where Ra_{eq}, C_u, C_{Th} and C_k are the radium equivalent and the activity concentrations of Uranium, Thorium, and Potassium, respectively.

Representative level index

The representative level index is another radiological parameter used in computing levels of gamma radioactivity associated with different concentrations of certain specified radionuclides. Khandaker et al. (2012) define the estimation tool to be (equation 7).

$$RLI = \left(\frac{C_u}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500}\right) \quad (7)$$

Where RLI, C_u, C_{Th} and C_k are the representative level index and the activity concentrations of Uranium, Thorium and Potassium respectively. The representative level index must be less than or equal to one for a building construction material to be considered safe (Darwish et al., 2015).

Annual gonadal dose equivalent

The annual gonadal dose equivalent is a parameter that values the degree of the genetic implication of the annual gamma ray doses absorbed by rapidly dividing cells found in organs such as the active bone marrow, gonads and the bone surface. The annual gonadal dose equivalent (AGDE) obtained from certain activities of some specified radionuclides can be estimated using the equation 8 according to Isinkaye et al. (2015)

$$AGDE\ (\mu Svy^{-1}) = 3.09\ C_u + 4.18\ C_{Th} + 0.314\ C_K \qquad (8)$$

Where $AGDE$, C_u, C_{Th} and C_k are the annual gonadal dose equivalent and the activity concentrations of Uranium, Thorium and Potassium respectively. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) recommended world average limit is 300 $\mu Svyr^{-1}$.

Results and discussion

The activity concentration of the three natural radionuclides (U-238, Th-234, and K-40) in rocks of the study area is presented in Table 1.

Radionuclide concentrations in rock samples

The activity concentrations presented in Table 1 show that Potassium-40 ranges from 82.27±4.25 to 2119.79±18.72 Bq/kg, with the highest activity found in Ekang 2 (sample I) and the lowest in Ekong 1. Uranium-238 ranges from 2.01±0.38 to 545.61±97.46 Bq/kg, with the highest concentration in a sample from Mfamosing and the lowest in a sample from Akor. Thorium-232 concentrations range from 27.13±2.70 to 661.51±65.78 Bq/kg, with the highest in a sample from Betem and the lowest in one from Akor. Potassium-40 contributes the most to the specific activities in the rock samples from the study area.

The mean activity concentration of Potassium-40 in the region (998.07 Bq/kg) is 60% higher than the world average of 400 Bq/kg reported by Santos Jr et al. (2010). Similarly, the mean activity concentrations of Uranium-238 (157.48 Bq/kg) and Thorium-232 (260.76 Bq/kg) for the region are 81% and 87% higher than the global averages of 30 Bq/kg and 35 Bq/kg, respectively, as recommended by UNSCEAR (2000). The high potassium concentration can be attributed to the significant abundance of alkali feldspar in the rocks, indicating the influence of geological composition on radionuclide concentrations in the area. The variation in activity concentration of natural radionuclide elements is presented in Figure 2.

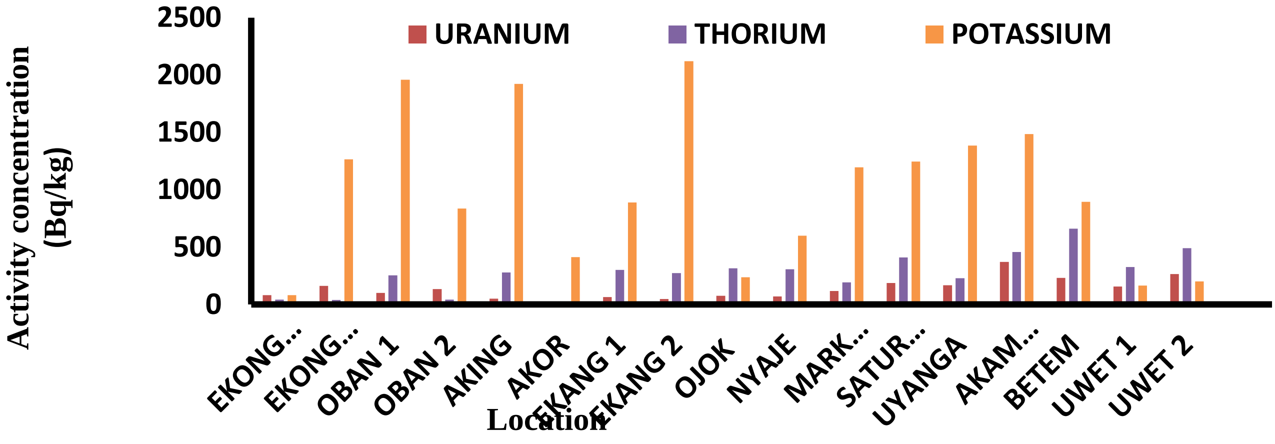

Figure 2: Multiple bar chart showing concentrations of U-238, Th-232 and K-40 radionuclides in rocks in the study area

Radiological hazard indices in rocks in the study area

Alpha index

To evaluate the level of alpha-particle radiation exposure from radon gas released by rocks in the area, the alpha index tool was used. The results show that the alpha index ranges from 0.01 to 2.73 Bq/kg, with an average of 0.81 Bq/kg. The mean value exceeds the UNSCEAR (2000) exemption limit of 0.5 Bq/kg. Figure 3 visually demonstrates that rock samples from the study area are radiologically unsafe for use as building materials, except for those from eight communities within the Oban Massif: Ekong 1, Oban 1, Aking, Akor, Ekang 1, Ekang 2, Ojok, and Nyaje. However, with these safe limits, our findings reveal that regulations of construction materials are necessary in these areas, especially those areas with a higher level of radon concentrations, in order to mitigate the health risks associated with this exposure index.

Table 1: The Activity Concentration of Radionuclides in Rock Samples

S/N	Sample code	Location	K-40 (*Bq/Kg*)	U-238 (Bq/kg)	Th-234 (Bq/kg)
1	Sample A	Mfamosing	1068.51±98.01	545.61±97.46	40.45±4.03
2	Sample B	Ekong 1	82.27±4.25	80.99±9.20	42.36±2.51
3	Sample C	Ekong 2	1266.04±89.35	163.39±17.53	39.35±4.74
4	Sample D	Oban 1	1957.87±136.98	100.28±18.65	253.66±25.25
5	Sample E	Oban 2	835.7±42.58	133.44±14.93	42.14±4.74
6	Sample F	Aking	1924.29±134.63	50.00±7.67	278.88±27.79
7	Sample G	Akor	411.87±29.10	2.01±0.38	27.13±2.70
8	Sample H	Ekang 1	888.27±62.57	66.05±15.08	301.95±41.49
9	Sample I	Ekang 2	2119.79±18.76	46.97±15.09	274.53±41.49
10	Sample J	Ojok	238.53±20.30	76.13±15.08	316.42±41.49
11	Sample K	Nyaje	598.96±42.35	70.54±12.99	308.39±30.81
12	Sample R	Mark Sino Quarry	1195.42±83.97	117.36±21.48	194.17±19.32
13	Sample S	Saturn Quarry	1247.25±87.55	188.10±34.36	409.28±40.79
14	Sample T	Uyanga	1385.03±97.22	168.41±30.87	228.44±22.75
15	Sample U	Akamkpa	1486.19±74.81	372.78±37.35	457.82±27.06
16	Sample V	Betem	894.88±62.89	231.51±42.04	661.51±65.78
17	Sample O	Uwet 1	164.22±11.68	156.95±29.39	325.75±87.25
18	Sample P	Uwet 2	200.22±14.22	264.24±150.7	491.61±48.90
Minimum			82.27±4.25	2.01±0.38	27.13±2.70
Maximum			2119.79±148.76	545.61±97.46	661.51±65.78
Average			998.0728±345.63	157.4867±201.27	260.7689±158.79

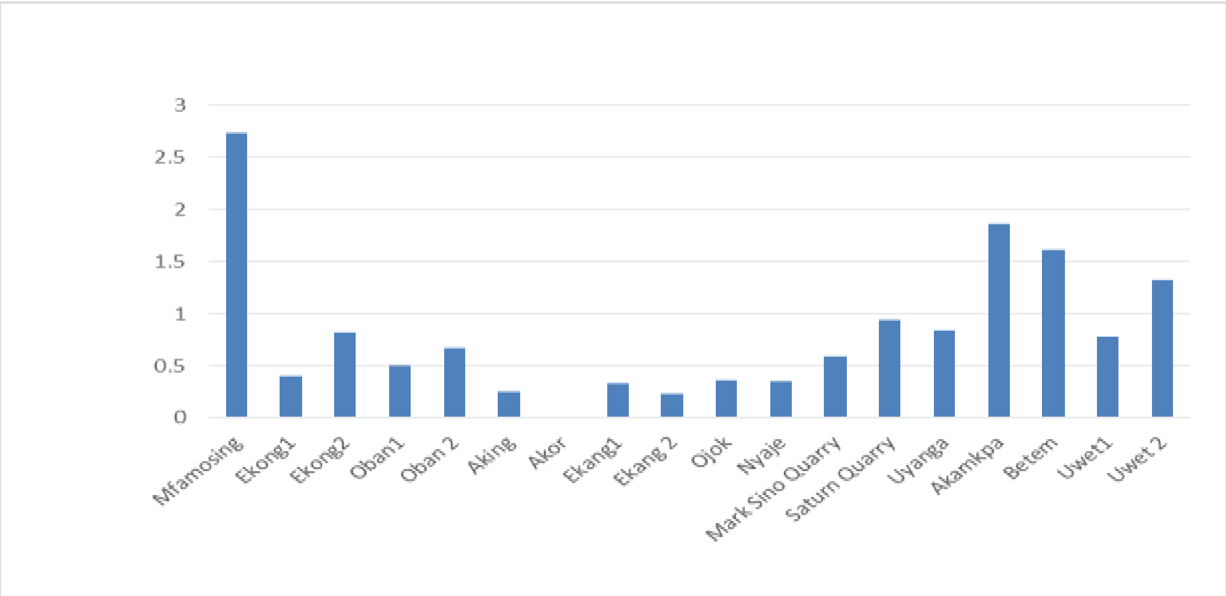

Figure 3: A bar chart showing the computed alpha index

Gamma index

The computed gamma index (Table 2) ranges from 0.28 to 5.54 Bq/kg, with a mean of 2.35 *Bq/kg*. The average value exceeds the recommended safe limit of 1 *Bq/kg*. Based on this result, Figure 4 shows that only samples from Ekong1, Oban 2, and Akor are radiologically safe for building purposes. These results have indicated an urgent need to assess gamma radiation levels in the construction materials for public safety to be ensured.

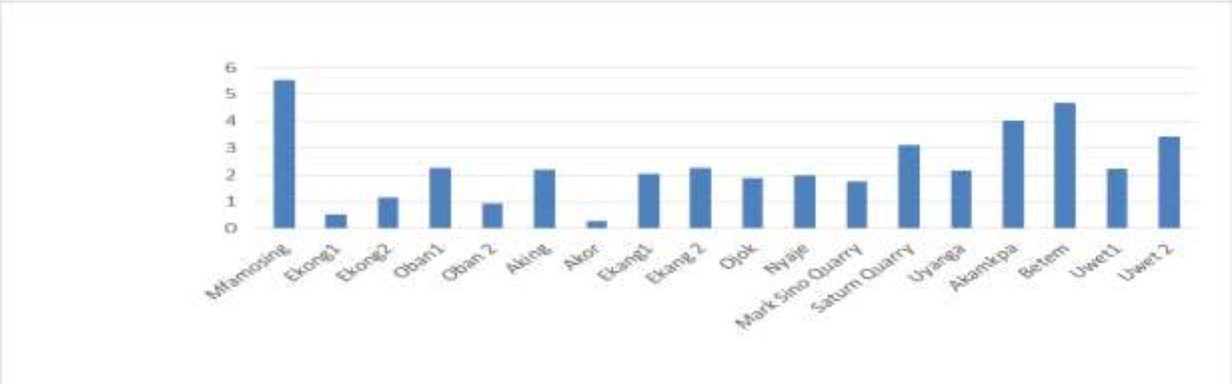

Figure 4: A bar chart showing the computed gamma index

Internal index

Determination of internal gamma radiation exposure level produced by analyzed samples presented in Table 2 reveals that the parameter ranges from 0.20 to 5.30 *Bq/kg* (mean: 2.20 *Bq/kg*). In the study area, the mean value exceeds the upper permissible limit of 1 *Bq/Kg* recommended by UNSCEAR (2000). Therefore, rendering this building material radiologically unsafe except, for materials from only two communities- namely: Ekong 2 and Ako communitiesr. Figure 5 shows the variation of the internal index in the study area.

External index

Estimation of external gamma radiation exposure levels produced by analyzed samples presented in Table 2 reveals that the external index ranges from 0.20 to 3.83 *Bq/kg* (mean: 1.76 *Bq/kg*). Figure 6 shows that only samples from Ekong 1 and 2, Oban 2, and Akor have external index values below the upper bound limit of 1 *Bq/Kg* recommended by UNSCEAR (2000). Hence, rocks from these locations are safe for building works, while other samples are radiologically unsafe for building works.

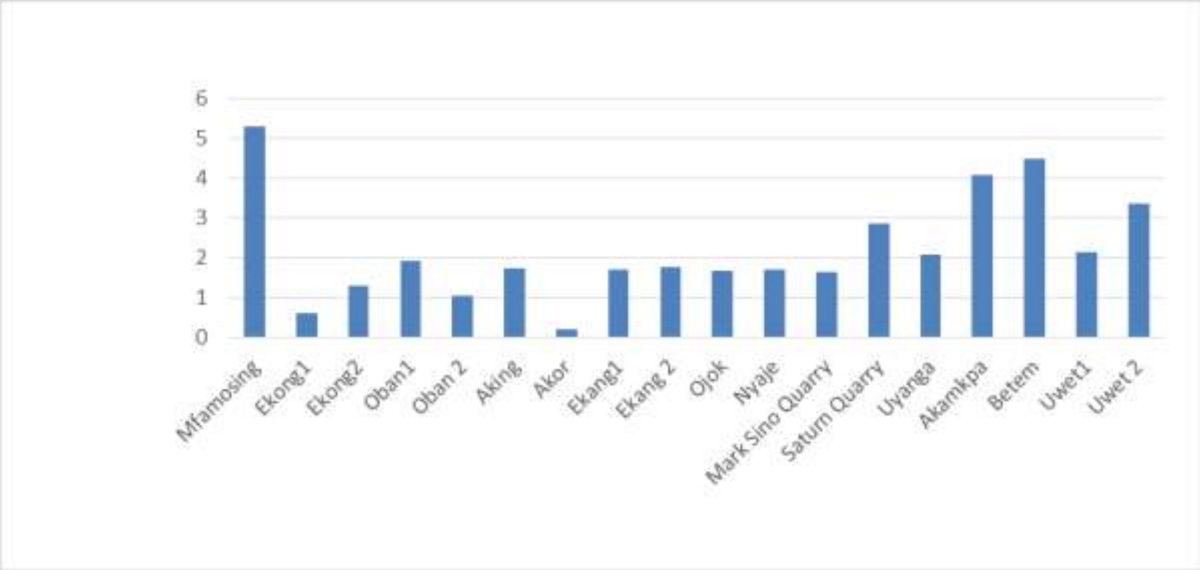

Figure 5: A bar chart showing the computed internal hazard index

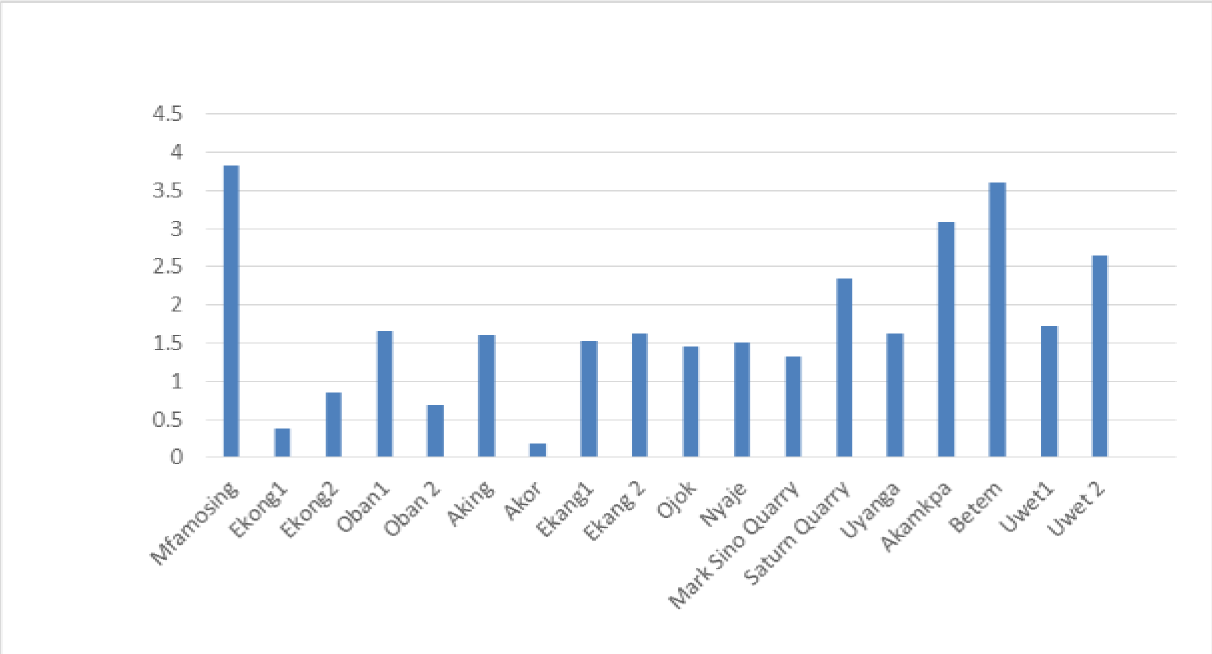

Figure 6: A bar chart showing the computed external hazard index

Radium equivalent index

The computed values of the radium equivalent of rocks in the study area are presented in Table 2. Results observed range from 72.05 to 1406.58 Bq/kg, yielding an average of 650.56

Bq/kg, which exceeds the UNSCEAR (2000) maximum acceptable limit of 370 Bq/kg. Figure 7 indicates that only samples from Ekong1, Ekong2, Oban 2, and Akor are radiologically suitable for building construction, while others are not. Prolonged exposure to this index's emissions at other locations can pose health risks, particularly cancer, Leukemia, and bone, organ and tissue damage.

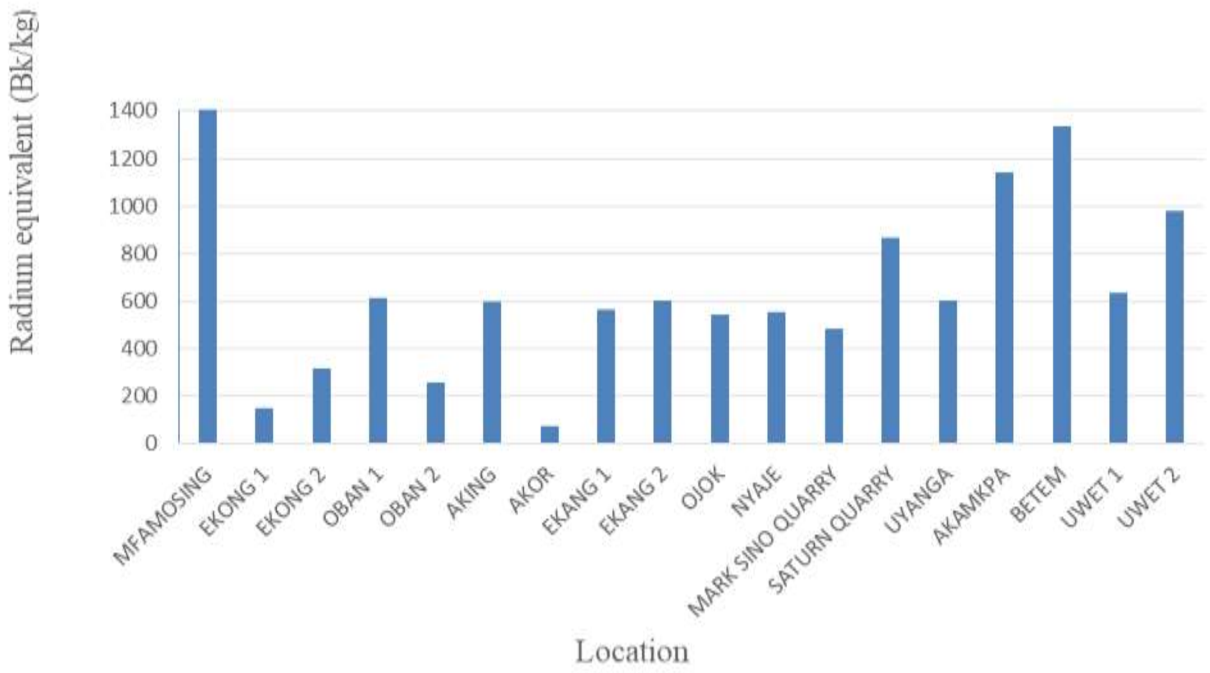

Figure 7: A bar chart showing computed radium equivalence

Representative level index

This index was employed to estimate the levels of gamma radiation that will be generated from weathered rock particles (sand). From Table 2, the minimum (in Akor) and maximum (in Mfamosing) values of representative level index obtained from the study sample are 0.56 and 11.09 Bq/kg, with an average of 4.71 *Bq/kg*. The range of values is relatively large and exceeds the permissible limit of 1 *Bq/kg*. This presents the studied samples as liberating high gamma radiation level thus radiologically unsafe for construction. Figure 8 shows the result of the representative level index for the various rock samples obtained from some of the communities in Oban Massif.

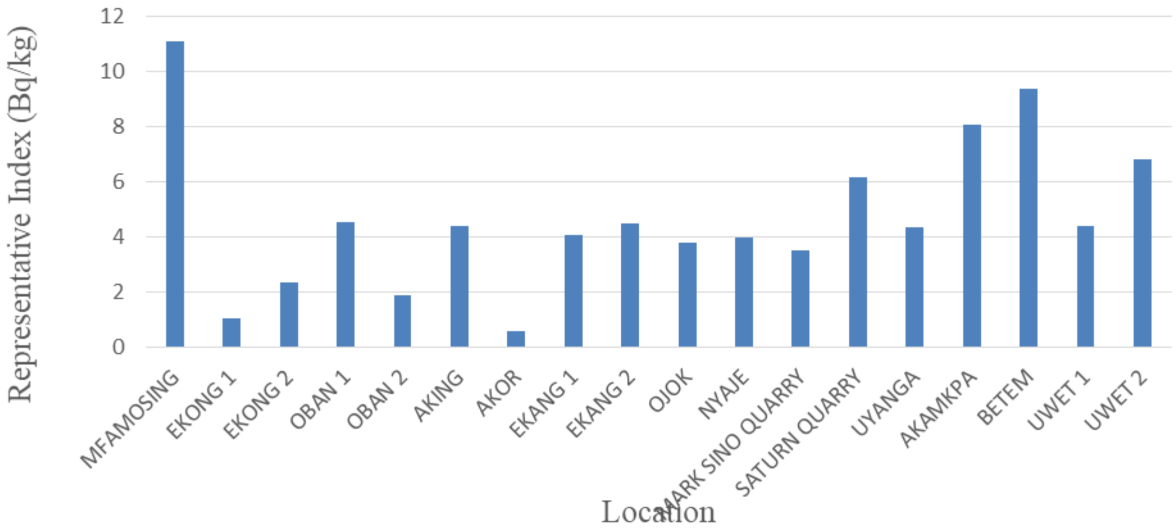

Figure 8: A bar chart showing the results of the computed representative level index

Annual gonadal equivalent dose

The Annual gonadal equivalent dose (AGED) was used to estimate the annual genetic implications of gamma radiation doses absorbed by the reproductive systems of individuals and by other organs with rapidly dividing cells. The range of the AGED is between 248.94 and 5173.53 $\mu Svyr^{-1}$ with an average value of 1552.79 $\mu Svyr^{-1}$. The average value exceeds the world average permissible criterion of 300 $\mu Svyr^{-1}$ as recommended by UNSCEAR (2000). Thus, the rocks here are unsafe for building works. Figure 9 shows the distribution of the annual gonadal-equivalent dose index across the study locations. Our results suggest that people living within buildings constructed with these rocks are likely exposed to higher levels of this radiation, above the global acceptable level, which poses potential health challenges.

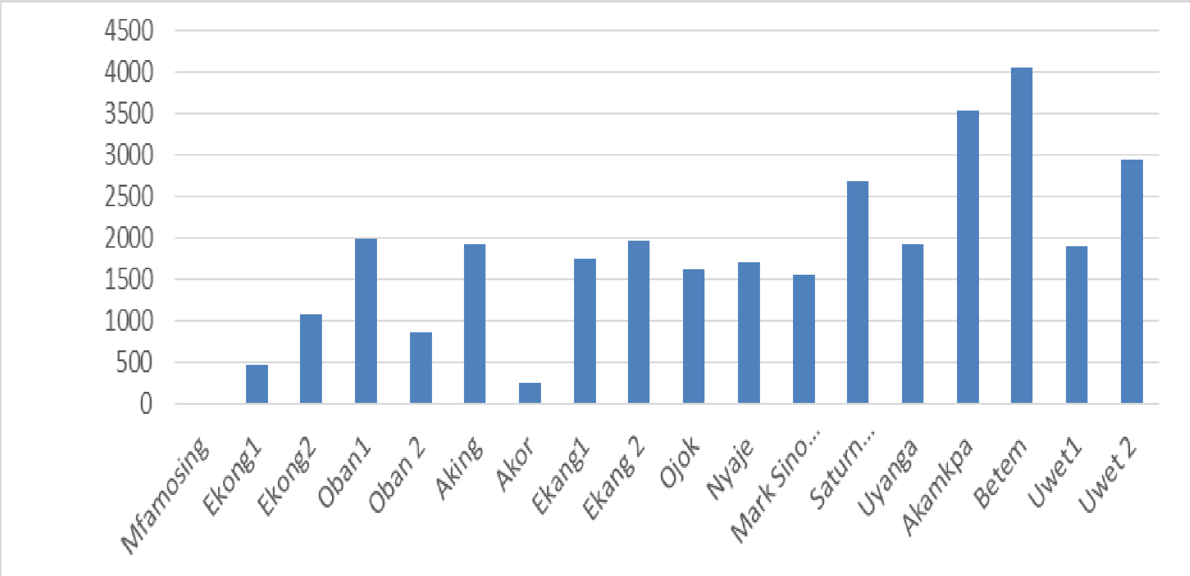

Figure 9: A bar chart showing results of the computed annual gonadal equivalent dose

Table 2: Computed radiological hazard indices for the study area

Community	I_α (Bq/Kg)	I_Y (Bq/Kg)	H_{in} (Bq/Kg)	H_{ex} (Bq/Kg)	Ra_{eq} (Bq/Kg)	RLI (Bq/kg)	AGED (µSvyr-1)
Mfamosing	2.73	5.54	5.3	3.83	1406.58	11.09	
Ekong 1	0.4	0.51	0.62	0.39	147.64	1.02	452.86
Ekong 2	0.82	1.16	1.29	0.86	315.8	2.33	1066.89
Oban 1	0.5	2.26	1.93	1.66	611.3	4.51	1984.94
Oban 2	0.67	0.93	1.06	0.69	257.13	1.87	850.88
Aking	0.25	2.2	1.74	1.61	594.49	4.4	1924.45
Akor	0.01	0.28	0.2	0.19	72.05	0.56	248.94
Ekang 1	0.33	2.03	1.7	1.53	564.79	4.05	1745.29
Ekang 2	0.23	2.24	1.75	1.63	600.08	4.47	1958.22
Ojok	0.36	1.89	1.66	1.46	541.08	3.79	1617.25
Nyaje	0.35	1.98	1.69	1.51	556.44	3.95	1695.11
Mark Sino Quarry	0.59	1.76	1.63	1.32	485.49	3.52	1549.64
Saturn Quarry	0.94	3.09	2.86	2.35	867.65	6.18	2684.61
Uyanga	0.84	2.17	2.08	1.63	599.88	4.33	1910.17
Akamkpa	1.86	4.03	4.09	3.08	1139.49	8.05	3532.24
Betem	1.61	4.68	4.48	3.61	1334.16	9.36	4039.57
Uwet 1	0.78	2.21	2.14	1.72	634.6	4.41	1898.18
Uwet 2	1.32	3.41	3.37	2.65	981.48	6.81	2934.3
Minimum	0.01	0.28	0.2	0.19	72.05	0.55	248.94
Maximum	2.73	5.54	5.3	3.83	1406.58	11.09	5173.53
Average	0.81	2.35	2.2	1.76	650.56	4.71	2070.39

Conclusion

Building materials (rocks) from the Oban Massif were assessed for the various activity concentrations of the naturally occurring radioelements (U-238, Th-232, K-40) in them. The measured activity concentration was carried out using a NaI thallium-doped gamma-ray spectrometer. The overall results of activity concentrations revealed that these primordial radioelements are not homogenously distributed but vary from location to location. The results for the radiological hazard indices show that the rock samples from Ekong1, Oban2, and Akor are radiologically safe for building works.

Reports from previous studies have consistently indicated that these radioelements are unevenly distributed across the formations. Results from studies done in other regions (e.g Santos Jr et al., 2010) have shown same variability in the natural radioactivity and have corroborated the results of our findings in the Oban Massif. This has confirmed that the local geology can play a significant role in the determination of the levels of radiation in rock formations. Also, the identification of Ekong1, Oban2, and Akor specifically as radiologically safe locations is in line with the previous studies, which stated that certain materials are safe for building construction based on the level of radioactivity metrics (Essien et al., 2016; Essiett et al., 2015; Thabayneh & Jazzar, 2012).

In contrast, rocks from other locations in the study area are radiologically unsuitable for construction purposes because they exhibit a high mean U-238, Th-234, and K-40 activity concentration, which aligns with studies by Thabayneh & Jazzar, 2012. It is worth noting that most quarries in the zone are situated in the Akamkpa, an area observed to have radiologically unsafe rocks, and rocks from this region are mostly mined for all sorts of construction purposes, which further implies that those buildings and other constructions made from these materials are radiologically unsafe for humans.

The urbanization of the area has imposed challenges which have been documented in the reports, which emphasized the need for regulatory measures (USEAP, 2011). Further studies are necessary to assess the potential for mitigating the effects of these radiations naturally, since it may be impossible to avoid building in those areas due to urban expansion and population growth. Landscaping and ventilation improvement techniques are necessary to mitigate the effects of naturally occurring radioelements in the area.

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