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Radiological and Geochemical Evaluation of Pegmatite Rocks in some selected States in Nigeria

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ABSTRACT

Natural radioactivity and geochemical evaluation of pegmatite in some selected States in Nigeria has been determined. Five (5) representative rock samples were collected from six states to make a total of 30 samples. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th were counted using a NaI(Tl) detector coupled to a digital-based multi-channel analyzer (MCA) and PerkinElmer AAnalyst 400 AA Spectrometer was used for the geochemical analysis of the samples. The mean gamma absorbed dose rates obtained were 104.1nGyh^{-1} (Oyo) 92.4nGyh^{-1}(Kogi), 81.8nGyh^{-1}(Nasarawa), 93.75nGyh^{-1}(Niger) and 58.9nGyh^{-1}(Osun) with the corresponding mean annual effective dose rates of 0.6, 0.5, 0.5, 0.5, 0.6, 0.7mSv, respectively. The geochemical analysis of major oxides showed that Niger State has SiO_2 concentration of 74.97wt%. Pegmatite samples from Osun and Oyo States have the same SiO_2 concentration of 72wt% while Kogi and Ekiti State also have the same value of 69wt%. Aluminum oxide (AI_2O_3) exhibited the second most abundant concentrations that ranged from 15.11-18.83wt%. Each of the Na_2O and K_2O present in the samples has a value of 2wt% while other major elements including Fe_2O_3, TiO_2, CaO, P_2O_5, MnO and MgO have values of less than 1wt% each.The present study determined the activity concentrations of natural radionuclides and other associated elements in crushed rocks used in building constructions in Nigeria , the values of the radiological hazard indices and geochemical analysis indicated that the rocks pose no radiation hazards, it has provided useful baseline data. However Nigerian Government should encourage obligatory monitoring of the dwellings built with any rock(s) to prevent unnecessary high exposure of human to ionizing radiation.

Keywords:
Radioactivity,
Geochemistry,
Pegmatite rocks,
Hazard indices,
Building construction,
Nigeria

INTRODUCTION

The most fundamental aim of radiation scientists is to ensure radiation protection and safety through scientific research and recommendation, to achieve this goal, the effects of ionizing radiation emanating from different sources must be examined. Rocks host radioactive elements (^{40}K, ^{238}U(^{226}Ra) and ^{232}Th) and other minerals depending on the mode of formation, chemical composition of the parent magma and geological nature of an area (Alausa *et al.,* 2020). Human activities including mining, quarrying, landfills and indiscriminate disposal of radioactive wastes or explosion of radioactive chemicals can elevate the exposure to ionizing radiation (Faanu *et al.,* 2016). Pegmatite is an igneous rock that formed at the last stage of crystallization. Pegmatite hosts many important minerals and precious stones that are not often found in other rocks, and thus makes it very useful in the production of computers (microchips), electronics, aircraft construction, and production of containers,and metal wears (Akintola *et al.,* 2011). Pegmatite rock is used as an architectural stone and hence it may be cut into slabs and polish for building facing, countertops, tile or other decorative stone products. The elemental composition of rocks depends on naturally occurring liquid called magma embedded beneath the earth's crust. About 99% of any magma is made up of elements, including Silicon (Si), Titanium (Ti), Aluminum (Al), Iron (Fe), Magnesium (Mg), Calcium (Ca), Sodium (Na), Potassium (K), Hydrogen (H) and Oxygen (O) (Shams *et al.,* 2012).

There is no doubt that pegmatite is economically viable thus, concerted efforts have been made in searching and mapping the deposit of pegmatite by Nigerian geologists. According to Okunola (2005), there are seven fields of mineralized pegmatite including Kabba-Isanlu, Keffi-Nassarawa, Lema-Ndeji, Oke Ogun, Ibadan-Oshogbo, KushakaBirnin-Gwari and Ijero-Aramoko. In addition, pegmatite was found lying broadly 400km long NE-SW stretching from Wemba, Keffi and Nasarawa area through Isalu-Egbe in central Nigeria to Ijero, Aramoko and Ilesha and Ago-Iwoye. (Akintola *et al.*, 2011)

In recent times, the use of crushed rocks (stones) in building construction is becoming popular in Nigeria. Meanwhile, building contractors and engineers erroneously referred to all forms of rocks as granite. Furthermore, different forms of rocks are now being crushed into smaller sizes or dust and used to produce blocks for wall casting and flooring (Alausa *et al.*, 2019), also, different rocks are used for external and internal decoration, laboratory settings, kitchen countertop, bar and hotel countertops. They are also crushed into different sizes in commercial quantities and processed into other products such as tiles, interlocks, and bricks used for building construction. The building engineers and contractors are usually concerned only with the strength of rocks without due consideration to radiation emission and their health. It is noted that the design and ventilation systems of houses usually influence the indoor levels of the radioactive radon gas and its decay products. These contribute significantly to internal radiation doses through inhalation. The radiological risk to individuals in buildings constructed with crushed rocks (stones) may be high depending on the sources and type of radionuclides in the rocks.

Despite the continuous population growth and high demand for crushed rocks for building construction, data on natural radioactivity in different rocks in the Nigerian environment are still very sparse. The use of rocks with high radioactivity in buildings may therefore expose dwellers to enhance background ionizing radiation. Hence, there is a need to measure the radioactivity levels in different rocks to establishing the baseline data on activity concentrations of natural radionuclides in different crushed rocks used for building construction in Nigeria.

The aim of the study therefore, is to characterize the geochemical nature of pegmatite to reveale its mineralization, measure the activity concentration of natural radionuclides (^{40}K ^{238}U and ^{232}Th) in pegmatite and estimate ionizing radiation doses and hazard index levels

MATERIALS AND METHODS

The study area

The Nigerian geological basement complex is located between Latitude 4^{o}N and 15^{o}N and Longitude 3^{o}E and 14^{o}E between the Pan-African mobile belt in-between the West African and Congo Craton (Rahaman, 1989). Nigeria's geology is broadly classified into three major litho-petrological components, which are, the Basement Complex, Younger Granites, and Sedimentary Basins. The basement complex of Southwestern Nigeria lies between latitudes 7^{o}N and 10^{o}N and longitudes 3^{o}E and 6^{o}E. The region is on the crystalline basement rocks comprising the amphibolite, migmatite gneisses, granites and pegmatite. Other important rock units found in the region are the schist comprising biotite schist, quartzite schist, talc-tremolite schist, and the muscovite schist. The study areas in the southwestern Nigeria include, Osun, Oyo, and Ekiti are situated in the basement complex. In terms of lithological setting, Osun and Oyo States belong to crystalline basement complex region, and Ekiti State belongs to post-cretaceous region that comprises shale and sandstone, (Joshua and Alabi, 2012). Three States where pegmatite was obtained include: Niger, Nasarawa and Kogi, the three States belong to North central Nigeria. North Central region of Nigeria lies within a Pan-African remobilized basement complex which consists of intensely multi-deformed high-grade polymetamorphic basement rocks predominantly comprised of migmatitic gneisses, schist, subordinate quartzite, marbles, pegmatite and dolerite dykes which intrude mainly the migmatitic gneisses (Olugbenga and Olubunmi, 2012). Figure 1 shows the geological map of Nigeria showing Oyo, Osun, Ekiti, Kogi, Nasarawa and Niger State where pegmatite samples were obtained.

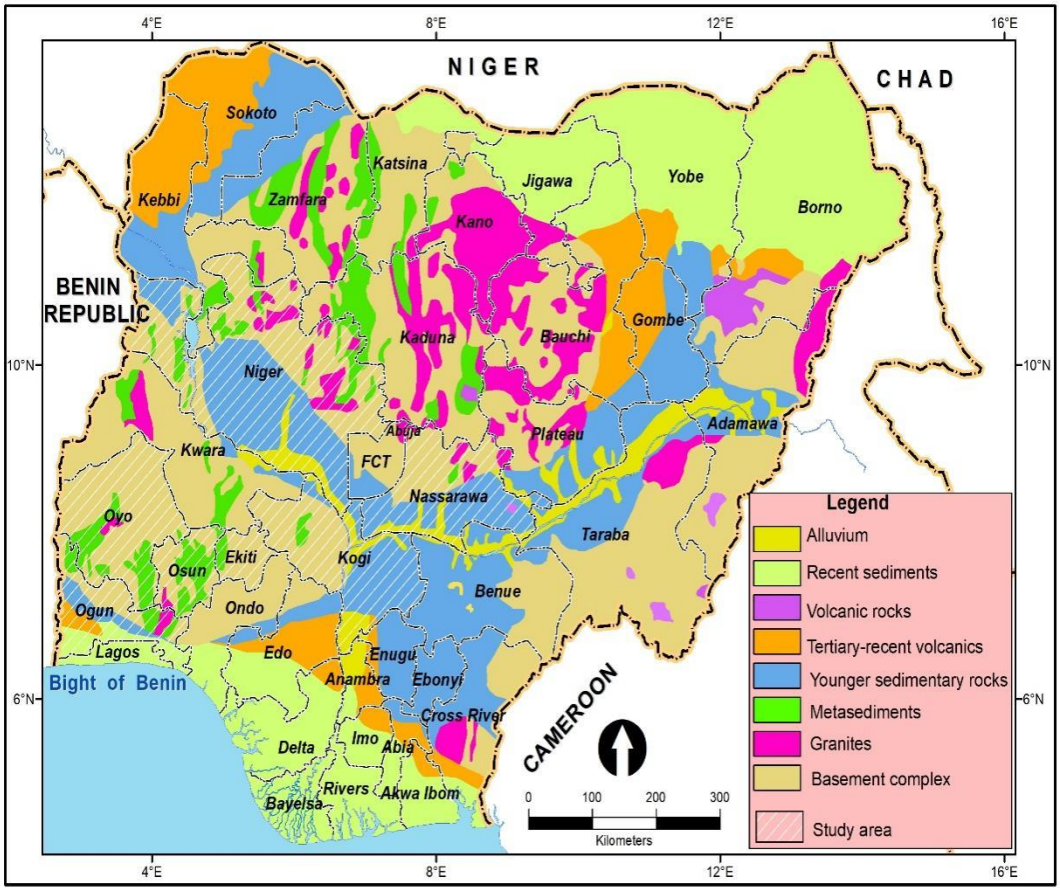

Figure 1: **G**eological map of Nigeria showing the study areas

Sample collection and preparation for gamma spectrometry analysis

The places and locations where pegmatite is outcrop in the selected States in Nigeria were identified. The weathered interface materials on the rocky outcrops at each site were removed with sledgehammer and chisel before the rock samples were cut with a stone cutter and about 2kg of the rock at each location was collected. In each State, five (5) representative rock samples were collected to make a total of 30 samples for present the study. The samples were properly parceled and labeled before being transported to the laboratory where each rock sample was crushed, pulverized and homogenized. The sample was then dried and sieved with a < 0.16mm mesh-size sieve before drying an electric temperature-controlled oven at 110^0C temperature for 4 hours to remove moisture. The 200 g of each of the dried samples was carefully weighed using an electronic balance with a sensitivity of 0.01 mg into a gas-tight radon impermeable, cylindrical polyethylene container of 2 cm uniform base diameter and sealed. The container was substantially fit to sit on the 5 cm x 5 cm NaI(Tl) detector used for the study. The samples in the containers were then kept for 4 weeks to allow for a state of secular radioactive equilibrium between ^{222}Rn and its short-lived decay products (^{214}Pb and ^{214}Bi).

Sample preparation for geochemical analysis

PerkinElmer AAnalyst 400 AA Spectrometer was used for the geochemical analysis of the samples from the study locations. 3g of each pulverized rock sample was set aside for geochemical analysis. 0.2 g was taken with the aid of a weighing machine and digested with 5 ml of concentrated hydrogen fluoride (HF) and a mixture of prepared solution of nitric acid and hydrochloric acid (ratio 3:1). The sample was stirred and heated inside a fume cupboard containing water bath, the water was allowed to boil at 100^0C for two hours so that the sample can become steam. The sample was filtered into another graduated cylinder of 100 ml to have the stock solution for the analysis. Thereafter, the stock solutions of the samples were diluted with distilled water and made up to 50 ml (representing stock solution (x50-dilution factor). The dilution was done to prevent the analyzing machine from being damaged.

Radioactivity measurement

A 5cm × 5cm solid NaI(Tl) gamma-ray spectrometric manufactured by ORTEC and coupled to a Digital-

based multi-channel analyzer (MCA) was used to count the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th. The detector has a poor energy resolution of about 8% at the energy of 0.662 MeV. This is considered adequate to distinguish the gamma energies of interest in the study. In addition, the photons emitted by the samples would sufficiently be discriminated if the emission probability and energy were high enough and the surrounding background continuum was low enough.

However, the activity concentration of ^{214}Bi determined from its 1.76 MeV gamma ray peak was chosen to provide an estimate of ^{226}Ra in the rock samples, while that of the daughter radionuclide ^{208}Tl determined from its 2.61 MeV gamma ray peak was chosen as an indicator of ^{232}Th. The activity concentration of ^{40}K was determined from 1.46 MeV gamma rays emitted during the decay of ^{40}K. The standard reference sample used for efficiency calibration was from Rocketdyne Laboratories California, USA, traceable to a mixed standard gamma source (Ref No 48722-356) by Analytic Inc., Atlanta, GA, USA.

Activity concentration and the count rate under the photo peak of a given gamma-ray spectrometry detector is shown in the equation (1) below (Jibiri and Akomolafe, 2016)

$$C = \frac{C_n}{\varepsilon_p I_\gamma m_s} \quad (1)$$

where C is the activity concentration of the radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in the sample (Bqkg^{-1}), C_n is the count rate under the photo peak, ε_p is the detector efficiency at a specific gamma-ray energy, I_γ is the absolute transition probability of the specific gamma-ray and m_s is the mass of the sample.

An empty container of the same geometry as the sample container was counted for the same time to take care of the background radiation count and determination of the radionuclide detection limits. The detection limits (DLs) which describes the operating capability of the detector without the influence of any sample were determined using Kitto et al., (2006) model.

The detection limits (DLs) obtained in the present study were 0.12, 0.14 and 0.40 Bqkg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th respectively. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th less than the corresponding values of the DLs is referred to as below detection limit (BDL). One-half of each DL is considered for calculating the mean activity concentrations of the radionuclides and the radiological parameters (Alausa and Odusote, 2013)

Outdoor gamma and effective dose rates

The quantity of absorbed dose is the amount of energy per unit mass absorbed by irradiated object and absorbed dose is the energy responsible for damage in living organism. The gamma dose rate at 1 m above the ground (nGyh^{-1}) is calculated using the expression given by UNSCEAR (2000)

$$D_R = 0.462A_{Ra} + 0.604A_{Ra} + 0.0417A_K \quad (2)$$

where D_R is the absorbed dose rate in nGyh^{-1}, A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

However, annual effective dose is used to assess potential long term effects that might occur in future due to ionizing radiation exposure of the general public. The annual effective dose E_D (mSvy^{-1}) to the public due to absorbed dose rate in air can be calculated using UNSCEAR, (2000).

$$E_D = D_R \times 8760 \times 0.2 \times 0.7 \quad (3)$$

where E_D is the effective dose in mSvy^{-1}, D_R (nGyh^{-1}) is the dose rate in air, 8760 is the time in hours for one year, 0.2 is the outdoor occupancy factor and 0.7 is the conversion factor (UNSCEAR, 2008)

Radium equivalent activity (Ra_{eq})

The radium equivalent activity (Ra_{eq}) is used as a common index to compare the specific activities of samples. It provides a useful guideline in regulating the safety standards on radiation protection of the general public and is obtained as the sum of the weighted activities of ^{226}Ra, ^{232}Th and ^{40}K based on the estimation for which 10 Bqkg^{-1} of ^{226}Ra, 7 Bqkg^{-1} of ^{232}Th and 130 Bqkg^{-1} of ^{40}K will deliver the same gamma dose rate (Alnour *et al.*, 2012). The radium equivalent was calculated using (Jibiri *et al.*, 2016)

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (4)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations (Bqkg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

External Radiation Hazard Index (H_{ex})

The external hazard index (H_{ex}) is used to measure the external hazard due to the emitted natural gamma radiation. The external hazard index, H_{ex} estimates the potential radiological hazard posed by the different rock samples for the external gamma dose of materials to 1.5 mGy/y. It is another criterion to assess the suitability of a building material for the construction of a dwelling. A safety criterion for materials used for building construction is $Hex \leq 1$ (UNSCEAR, 2016). The external hazard index is also calculated using (Jibiri *et al.*, 2016)

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (5)$$

Where C_{Ra}, C_{Th}, C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively.

Internal Radiation Hazard Index (H_{in})

In addition to the external hazard index, there is also a threat to the respiratory organs due to ^{222}Rn, the gaseous short-lived decay product of ^{226}Ra. The internal hazard index (H_{in}) is defined generally to reduce the maximum permissible concentration of ^{226}Ra to half the value appropriated for external exposure alone (Shiva *et al.*, 2008). Internal exposure to radon and its progeny

products is quantified by estimating the internal hazard index using the model by Xinwei (2005):

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

where C_{Ra}, C_{Th}, C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. If the maximum concentration of ^{226}Ra is one-half that of the normal acceptable limit, then H_{in} will be less than one. For safety precautions in the use of materials in the construction of dwellings, the criterion demands that $H_{in} \leq 1$.

Gamma activity index (I_γ)

The gamma activity index (I_γ) is used as a screening tool for identifying materials that might be a threat to human health. The representative gamma index (Iγ) was used to estimate the level of γ-radiation hazard associated with the natural radionuclides in specific investigated samples.

It has been recommended that controls should be based on the dose range of 0.3-1 mSvy^{-1}, which is the excess gamma dose received outdoors. While $I_{\gamma v} \leq 1$ corresponds to an effective dose less than or equal to 1 mSvy^{-1}, $I_\gamma \leq 0.5$ corresponds to an effective dose less than or equal to 0.3 mSvy^{-1} for the material (pegmatite) used in bulk quantity (Sharma et al., 2015).

The index is calculated using Sharma et al., (2015)

$$I_\gamma = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000} \quad (7)$$

Where C_{Ra}, C_{Th} and $C_{K,}$ are the activity concentrations (Bqkg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}k respectively.

RESULTS AND DISCUSSION

Activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in pegmatite from the study areas

The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Thin pegmatite have been measured and the results are presented in Table 1. As observed from the table, the mean activity concentration of ^{40}K measured in pegmatite from all the study areas (Table 1) was1490.5 Bqkg^{-1} (Osun), 1161.3 Bqkg^{-1} (Nasarawa), 1091.9 Bqkg^{-1} (Niger), 1087.4 Bqkg^{-1} (Oyo), 1043.2 Bqkg^{-1} (Kogi) and 143.4 Bqkg^{-1} (Ekiti). Pegmatite is an extreme igneous rock with a similar composition to granite with abundant quartzite, mica and feldspar. However, the high concentrations of ^{40}K and other radionuclides are attributed to their similar composition to granite. Pegmatite is a source of valuable mineras that may enhance the concentration of natural radionuclides in the rock. The highest value of ^{226}R in pegmatite was found in Oyo, and the least value was found in pegmatite rock samples from Osun state with mean value of 23.3±4.1 Bqkg^{-1}. As Mentioned earlier the reason for the lowest value of ^{226}Ra in Osun state is because Osun State is on schist belt formation which is not too granitic. ^{232}Th radionuclide exhibited 73.9±1.6 Bqkg^{-1}, 73.8±1.1 Bqkg^{-1}, 56.2±14.1 Bqkg^{-1}, 54.0±1.1 Bqkg^{-1}, 47.6±1.8 Bqkg^{-1} and 23.9±1.2 Bqkg^{-1} for Kogi, Ekiti, Niger, Nasarawa, Osun and Oyo States respectively. All the mean values obtained for ^{232}Th were higher than the world average value of 35 Bqkg^{-1}.

Gamma absorbed and effective doses in pegmatite from the study areas

The average absorbed and effective dose rates were 104.1 nGyh^{-1} and 0.6 mSvyr^{-1} for Oyo, 92.4 nGyh^{-1} and 0.5 mSvy^{-1} for Kogi, 81.8 nGyh^{-1} and 0.5 mSvy^{-1} for Nasarawa State, 93.75 nGyh^{-1} and 0.5 mSvy^{-1} for Niger State, 101.6 nGyh^{-1} and 0.6 mSvy^{-1} for Ekiti State. The maximum value of the annual effective dose obtained in pegmatite from the study areas in the present study is lower than the permitted value of 1 mSvy^{-1}, although, values of absorbed doses obtained in all the pegmatite samples are higher than the maximum permissible limit value of 59 nGyh^{-1} (Table 2)

Radium equivalent and hazard indices in pegmatite from the study areas

The radium equivalent dose calculated for pegmatite from the study areas ranged from 154.2 to 220.6 Bqkg^{-1}. The highest value of radium equivalent was obtained in pegmatite from Kogi State while the least was obtained in pegmatite from Ekiti State. Other values of radium equivalent dose obtained for pegmatite in the present study were 206.1 Bqkg^{-1} for Osun State, 191.3 Bqkg^{-1} for Nasarawa and 167.7Bqkg^{-1} for Niger State. It can be seen that the emission of gamma radiation in pegmatite from Kogi and Osun State was higher compared to Nasarawa and Niger which recorded about one-half of the maximum recommended value of radium equivalent dose for building materials. Pegmatite from Ekiti State emits the least gamma radiation with a mean value of 154.2 Bqkg^{-1}, this value is less than half of 370Bqkg^{-1} recommended by UNSCEAR (2000). In addition, external and internal in granites from the study areas are presented in Table 1 as well, all the values obtained for external and internal hazard indices were less than unity; this showed that radiation hazard associated with the pegmatite from the study areas is not significant. Hence, radium equivalent in pegmatite rocks from the study areas was ypically low, reflecting low external hazard and internal hazard exposure of gamma radiation from pegmatite obtained for this study.

Geochemistry of Major elements in Pegmatite from the study areas

Pegmatite samples from the study areas were analyzed for the major elements where the sample from Niger State has SiO_2 contents of 74.97 wt%. Pegmatite samples from Osun and Oyo State have the same SiO_2 content of 72 wt% while Kogi and Ekiti State also have the same value of 69 wt%. Aluminum oxide (AI_2O_3) is the second most abundant element in pegmatite samples

in the present study with a range of 15.11-18.83 wt%. In addition, sodium oxide (Na_2O) and potassium oxide (K_2O) present has a value of 2 wt% while other major elements including Fe_2O_3, TiO_2, CaO, P_2O_5, MnO and MgO present less than 1wt%. Figure 2 shows the distribution of the major element oxides in pegmatite from the study areas

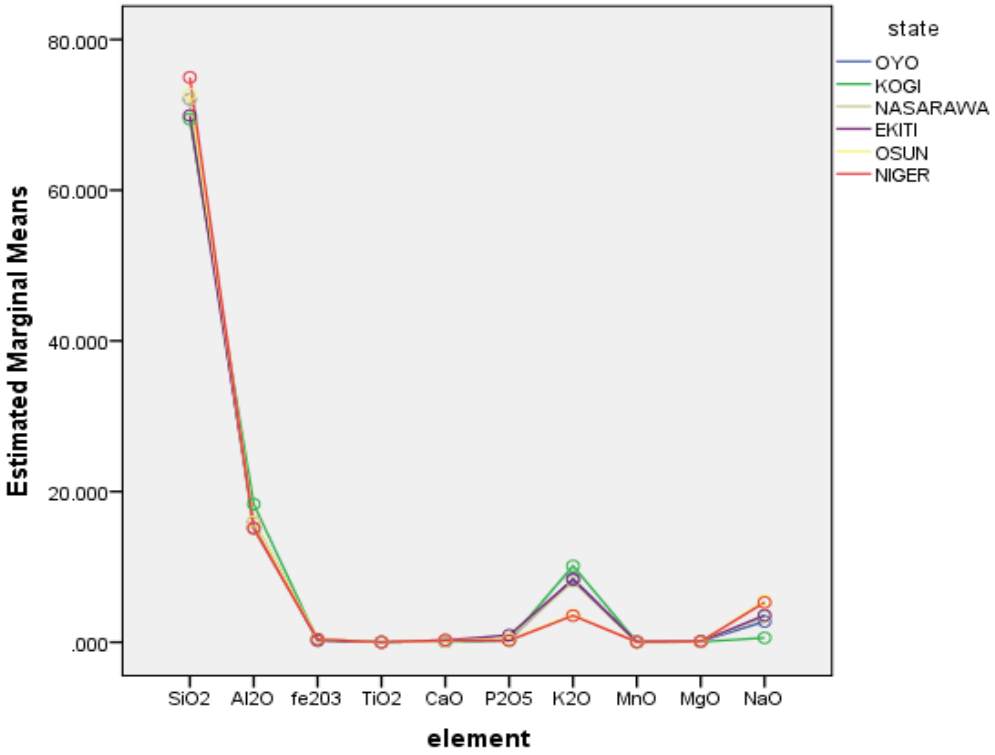

Figure 2: Marginal means of major oxides in pegmatite

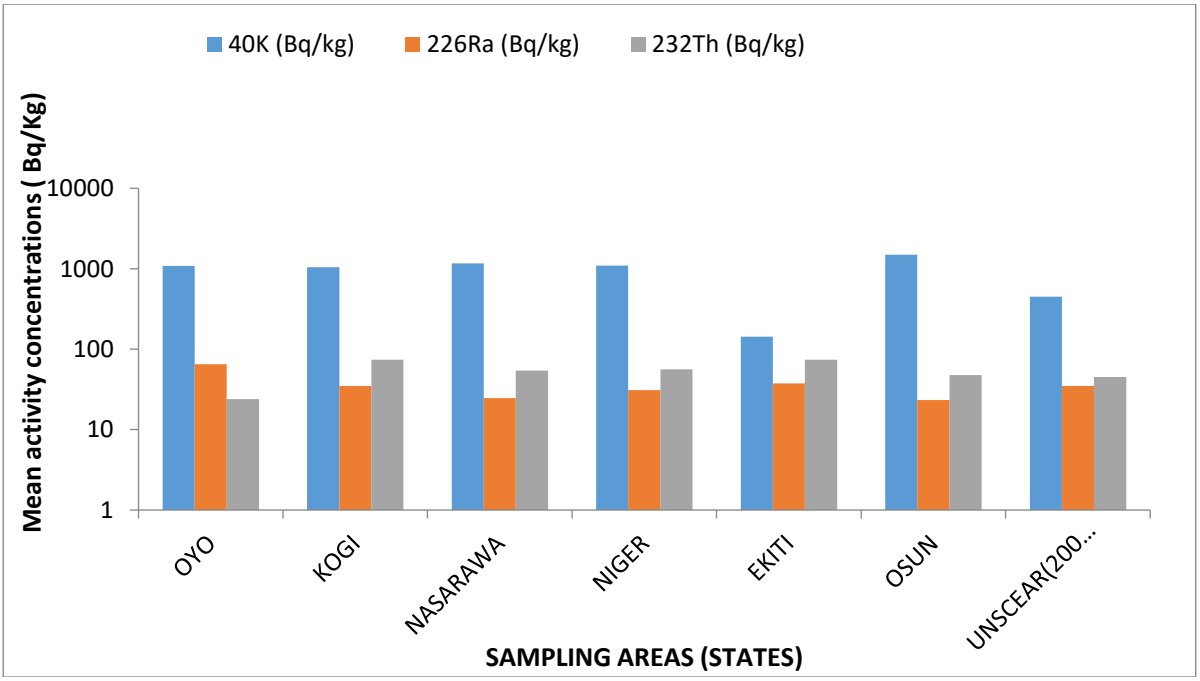

Figure 3: Mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th radionuclides in pegmatite

Correlation of Activity Concentrations with Major Oxides in Pegmatite

The results of the correlation of activity concentration and major oxides in pegmatite showed a negative correlation between major oxides Al_2O_3, Fe_2O_3, MgO, CaO, TiO_2, MnO, PO, MgO, NaO and ^{40}K, ^{226}Ra, ^{232}Th radionuclides except for SiO_2 that is moderately correlated with ^{226}Ra, ^{232}Th. CaO showed a strong positive correlation with Al_2O_3, Fe_2O_3 and TiO but had a negative correlation with SiO_2. Similarly, MgO displayed a strong positive correlation with Al_2O_3, Fe_2O_3, TiO and CaO but correlate negatively with SiO_2. Major oxides Al_2O_3, $Fe_2O_3$and TiO also showed a negative correlation with SiO_2.

CONCLUSION

The activity concentrations of ^{40}K, ^{238}U and ^{232}Th have been determined in pegmatite rock samples collected from Oyo State, Kogi State, Nasarawa State, Niger State, Ekiti State and Osun State, all in Nigeria, using a NaI(Tl) detector. The highest activity concentrations of ^{40}K,^{238}U (^{226}Ra) and^{232}Th were 1490.5 $Bqkg^{-1}$ (Osun), 65.1 (Oyo), 73.9±1.6 $Bqkg^{-1}$(Kogi) respectively. The radiological hazards due to the radioactivity levels in rock samples indicated that the radium equivalent activity, external and internal hazard indices, and the annual effective indoor dose rate are all lower than the world-recommended values for materials to be used in the construction of dwellings. It can, therefore, be concluded that the use of Pegmatite rocks from the study areas is safe and will not pose any serious radiological risk to the occupants of buildings constructed with these rocks. As a matter of necessity, the Nigerian Government should encourage obligatory monitoring of the dwellings built with any rock(s) to prevent unnecessary high exposure of humans to ionizing radiation.

Table 1: Activity concentrations (Bq/kg), absorbed dose and annual effective dose of primordial radionuclides

Location	^{40}K ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	^{226}Ra($Bqkg^{-1}$)	Outdoor absorbed ($nGyh^{-1}$)	Outdoor effective dose ($mSvy^{-1}$)
Oyo	1086.6±24	BDL	BDL	94.4	0.01
	1090.2±32	23.1±0.2	65.2±0.2	83.9	0.12
	1087.2±21	23.8±0.3	67.2±0.6	76.6	0.11
	1085.7±41	24.7±0.2	62.8±0.8	73.0	0.14
	1087.4±31	23.9±0.4	65.1±0.4	108.1	0.09
Mean ±σ	1087.4±32	23.9±0.5	65.1±0.2	87.2±13	0.08±0.03
Kogi	909.9±51	68.7±.04	32.6±0.4	58.7	0.04
	1094.4±23	76.8±0.6	36.4±0.7	89.7	0.09
	1056.0±22	73.2±0.1	35.1±0.4	61.1	0.07
	1112.3±13	76.7±0.3	34.7±0.8	66.4	0.06
	1043.2±24	73.9±0.6	34.7±0.3	64.8	0.09
Mean ±σ	1043.2±55	73.9±0.3	34.7±0.4	68.1±09	0.07±0.01
Nasarawa	1164.3±22	50.0±0.1	23.7±0.3	81.2	0.04
	1160.1±21	52.8±0.3	23.6±0.2	67.4	0.02
	1164.5±23	53.8±0.4	24.6±0.5	88.0	0.03
	1156.4±24	59.4±0.4	26.7±0.6	75.5	0.08
	1161.3±23	54.0±0.1	24.7±0.4	64.6	0.05
Mean ±σ	1161.3±19	54.0±0.5	24.7±0.2	75.3±03	0.04±0.01
Ekiti	141.0±19	71.1±0.5	33.7±0.2	91.7	0.02
	142.2±20	73.4±0.6	33.6±0.7	79.2	0.05
	150.8±26	77.3±0.8	41.1±0.8	62.4	0.06
	139.4±27	73.4±0.9	42.1±0.2	83.5	0.07
	143.4±28	73.8±0.4	37.6±0.2	81.0	0.03
Mean ±σ	143.4±34	73.8±0.2	37.6±0.3	79.6±16	0.05±0.01
Niger	1094.4±23	51.6±0.6	24.4±0.2	64.3	0.05
	1083.7±24	BDL	BDL	50.9	0.04
	1089.5±23	55.2±0.5	33.2±0.6	52.9	0.05
	1099.8±41	61.8±0.7	35.2±0.4	70.9	0.06
	1091.9±34	56.2±0.5	30.9±0.2	71.9	0.05
Mean ±σ	1091.9±31.1	56.2±0.8	30.9±0.6	62.2±0.1	0.05±0.2
Osun	1490.5±50	49.1±0.7	23.3±0.5	84.3	0.7
	1489.2±43	44.8±0.5	23.8±0.3	54.5	0.7

	1492.5±32	48.6±0.3	22.5±0.2	66.3	0.4
	1489.8±32	47.8±0.3	23.5±0.6	71.2	0.5
	1490.5±34	47.6±0.5	23.3±0.6	67.4	0.3
Mean ±σ	1476.5±20.4	47.6±0.3	22.7±0.1	58.9±11.2	0.7±0.1

Table 2: Radium equivalent, internal, external hazard and gamma representative indices

Location		Ra_{eq} (Bq/kg)	H_{in}	H_{ex}	I_{γ}
	Range	162.3-199.5	0.18-0.71	0.17-0.54	0.54-1.48
Oyo	Mean	180.9	0.445	0.355	1.106
	Std	5.784	0.265	0.185	0.375
	Range	200.9-230.4	0.5-0.57	0.35-0.38	0.95-1.03
Kogi	Mean	215.65	0.535	0.365	0.99
	Std	15.4	0.035	0.05	0.16
	Range	188.4-200.6	0.17-0.54	0.12-0.38	0.14-0.43
Nasarawa	Mean	184.4	0.355	0.25	0.285
	Std	64.79	0.74	0.52	0.57
	Range	176.2-201.3	0.10-0.36	0.11-0.30	0.35-0.83
Ekiti	Mean	186.9	0.25	0.205	0.590
	Std	57.57	0.43	1.09	0.95
	Range	184.1-208.2	0.30-0.35	0.22-0.24	0.63-0.67
Niger	Mean	196.15	0.325	0.230	0.650
	Std	48.18	0.09	0.04	0.08
	Range	202.5-208.2	0.13-0.18	0.11-0.13	0.31-0.37
Osun	Mean	205.35	0.155	0.120	0.340
	Std	11.39	0.09	0.04	0.11

Std= Standard deviation,

Table 3: Comparison of gamma dose rate of pegmatite rock in the present study with rock types from some part of the world

Country	Rock types	Gamma dose rate ($nGy.h^{-1}$)	References
Brazil	Mafic Igneous	21.3 ± 4.6	Rodrigo et al., (2009)
Turkey	Limestone	26.7+1.9	Turhan,, et al.,(2008)
India	Migmatite gneiss	131.8± 11.3	Abdu Hamoudet al., (2017)
Nigeria	Granite	110.5 ± 14.8	Okedeyi et al., 2012
Cameron	Gneiss	51.37± 0.1	Ngachi et al., 2006
Egypt	Limestone	59.1± 0.6	Shams et al., 2012
Oyo	Pegmatite	87.2±13	Present study
Kogi	Pegmatite	68.1±09	Present study
Nasarawa	Pegmatite	75.3±03	Present study
Ekiti	Pegmatite	79.6±16	Present study
Niger	Pegmatite	62.2±0.1	Present study
Osun	Pegmatite	58.9±11.2	Present study
ICRP		59±0.1	ICRP (2005).

Table 4: Pearson correlation matrix of activity concentrations and major oxides in pegmatite

	^{40}K	^{226}Ra	^{232}Th	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	P_2O_5	KO	MnO	MgO	Na_2O
^{40}K	1												
^{226}Ra	-.215	1											
^{232}Th	-.516	-.563	1										
SiO_2	-.717	.523	.242	1									
Al_2O_3	.671	-.528	-.319	-.913*	1								
Fe_2O_3	.520	-.387	-.197	-.945**	.822*	1							
TiO_2	.531	-.401	-.200	-.952**	.833*	1.000**	1						
CaO	.502	-.391	-.201	-.944**	.815*	.998**	.998**	1					
P_2O_5	.139	.024	-.114	.117	-.285	-.278	-.266	-.232	1				
KO	.051	-.249	.319	.436	-.307	-.682	-.668	-.692	.324	1			
MnO	-.218	-.245	.726	.220	-.521	-.199	-.205	-.197	.347	.281	1		
MgO	.509	-.421	-.162	-.947**	.817*	.999**	.999**	.998**	-.257	-.668	-.168	1	
Na_2O	-.636	.801	-.134	.643	-.749	-.435	-.451	-.412	.201	-.324	.112	-.446	1

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