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Natural Radioactivity in Locally Produced Building Materials in Ekiti State, Southwestern Nigeria

K. P. Fasae
Science Technology Department, The Federal Polytechnic, PMB 5354 Ado-Ekiti, Nigeria.
E -mail address: peterkolawole@yahoo.co.uk

Abstract

Building raw materials and processed products can vary greatly in radionuclide contents depending on the character and the geology of the their origin. 160 samples of Brick block and 160 samples of Concrete block for constructing dwellings were collected across the Ekiti State, Nigeria. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the Brick block and Concrete block samples were determined by using gamma-ray spectrometry using a 7.62 cm × 7.62 cm NaI(Tl) detector of dimension, housed in a 6 cm thick lead shield. The results show that the mean activity concentration values of 572.6 ± 175.9 Bq kg^{-1}, 47.9 ± 9.8 Bq kg^{-1} and 63.8 ± 9.4 Bq kg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th respectively in concrete blocks are higher compared to the the mean activity concentration values 351.1 ± 3.1 Bq kg^{-1}18.7 ± 6.2 Bq kg^{-1} and 39.8 ± 3.5 Bq kg^{-1}obtained in brick blocks. The absorbed dose rate, Annual dose equivalent, the external hazard and the qualification coefficients were determined. The radiological assessment values of the brick and concrete block building materials compare well with values found in literatures. However, the use of brick block and cement block materials for constructing buildings for human habitation in the study area may pose a health risk to the population if there is no remediation by the regulatory body in the state

Keywords: Brick-block, Cement, Concrete-block, Building, Radioactivity, Radionuclides, Dose equivalent

1. Introduction

Exposure to natural sources of radiation is often influenced or can be influenced by human activities. Building materials, for instance, cause excess external gamma exposure due solely to their influenced exposure geometry when compared with that of the undisturbed earth's crust. Such excess in exposure is commonly excluded from any system of radiological protection. Construction material can, however, cause substantial radiation exposure if they contain elevated levels of naturally occurring radionuclides.

Man is continuously exposed to ionizing radiation from Naturally Occurring Radioactive Materials (NORM). The origin of these materials is the Earth’s crust, but they find their way into building materials, air, water, food and the human body itself. The worldwide average indoor effective dose due to gamma rays from building materials is estimated to be about 0.4 mSv per year (UNSCEAR 2000).

Natural radioactivity is mainly connected with the presence of potassium K-40 and radioisotopes of uranium U-238 series and thorium Th-232 series. Dose rates from gamma radiation depend mainly on the concentration of the above-mentioned radioisotopes in the soil and building materials. Radon Rn-222, a gaseous product of decay of radium 226, is extremely important in indoor exposure.

All building materials contain various amounts of natural radioactive nuclides. Materials derived from rock and soil contain mainly natural radionuclides of the uranium (^{238}U) and thorium (^{232}Th) series, and the radioactive isotope of potassium (^{40}K). In the uranium series, the decay chain segment starting from radium (^{226}Ra) is radiologically the most important and therefore, reference is often made to radium instead of uranium. The world-wide average concentrations of radium, thorium and potassium in the earth's crust are about 40 Bq kg-1, 40 Bq kg-1 and 400 Bq kg-1, respectively (EU, 1999).

Radiation exposure due to building materials can be divided into external and internal exposure. The external exposure is caused by direct gamma radiation. An inhabitant living in an apartment block made of concrete with average activity concentrations (40 Bq kg-1, 30 Bq kg-1 and 400 Bq kg-1 for radium, thorium and potassium, respectively) receives an annual effective dose of about 0.25 mSv (excess to the dose received outdoors). Enhanced or elevated levels of natural radionuclides in building materials may cause doses in the order of several mSv (EU, 1999).

The internal exposure is caused by the inhalation of radon (^{222}Rn), thoron (^{220}Rn) and their short lived decay products. Radon is part of the radioactive decay series of uranium, which is present in building materials. Because radon is an inert gas, it can move rather freely through porous media such as building materials, although usually only a fraction of that produced in the material reaches the surface and enters the indoor air.

Radon is a noble gas, whose α-radioactive derivatives (Po-218, Pb-214, Bi-214, Po-214) permeate through various levels of the breathing system in a non-bound with aerosols form. Radon easily diffuses from the ground and building materials to indoor air and is the source of exposing bronchus and lungs (UNSCEAR 1988; Stidley C, Samet J 1993; Lubin J.H., Boice J. D, 1989).

Building materials are the most important source of indoor thoron. However, thoron concentrations are usually rather low. Indoor thoron can be an important source of exposure only under some rare conditions where the building materials contain high concentrations of thorium.

In south western Nigeria, most especially the rural areas, the people build houses for human habitation with dung natural earth and locally moulded into brick blocks. The contribution of this building material to indoor exposure in these areas is of interest. The aim of this paper is to determine the activity concentrations of natural radionuclides in building materials and some dose assessment approaches. This is a baseline survey for primordial radionuclide concentrations in brick and concrete block building material of the area in order to establish binding regulations in the country.

2.0 Materials and Method

2.1 Sampling

Samples of dug natural soil moulded into blocks and used for building houses for habitation were collected in the sixteen local governments in Ekiti.

Ekiti State is situated entirely within the tropics. It is located between longitudes 4^0 5^1 and 5^0 45^1 East of the Greenwish meridian and latitudes 7^0 15^1 and 8^0 5^1 north of the Equator. It lies south of Kwara and Kogi State, East of Osun State and bounded by Ondo State in the East and in the south. Ekiti State has 16 Local Government Councils. By 1991 Census, the population of Ekiti State was 1,647,822 while the estimated population upon its creation on October 1st 1996 was put at 1,750,000 with the capital located at Ado-Ekiti.

Mainly an upland zone rising over 250 metres above sea level, Ekiti has a rhythmically undulating surface. The landscape consists of ancient plains broken by steep-sided outcropping dome rocks. These rocks may occur singularly or in groups or ridges and the most notable of these are to be found in Efon-Alaaye, Ikere-Ekiti and Okemesi-Ekiti. The State enjoys a tropical climate with two distinct seasons. These are the rainy season (April - October) and the dry season (November - March). Temperature ranges between 21^0 and 28^0C with high humidity. The south - westerly winds and the North East Trade winds blow in the raining and dry (Harmattan) seasons respectively. Tropical Forest exists in the south, while guinea savanna predominates in the northern peripheries (Fasae and Akinkuade, 2011).

A map of Ekiti State showing the local government head quarters is presented in Fig. 1. The samples were collected from known brick block making areas in the local governments. It was comfirmed that no cement, sand from beds of rivers and any other artificial building materials were added to the natural raw materials used for the mud blocks.

A total of one hundred and sixty (160) brick block samples were collected at 10 samples per local government and a total of one hundred and sixty (160) concrete block samples were collected at 10 samples per local government . The samples collected are representative of brick and concrete blocks used in those rural areas of the State.

2.2 Sample Preparation

The samples were dried at 100 ^{0}C until a constant weight was reached and to eliminate any traces of water. The samples were, pulverized and sieved with a 2-mm mesh sieve to obtain homogenous particle size of the soil samples. About 200 g each of the samples was then transferred to uncontaminated empty cylindrical plastic containers of uniform size (60 mm in height, 65 mm in diameter) and were sealed for a minimum of twenty-eight days. This was done so as to allow for radon and its short-lived progenies to reach secular radioactive equilibrium prior to gamma spectroscopy.

2.3 Measurement technique

A NaI(Tl) detector of dimension, 7.62 cm × 7.62 cm housed in a 6 cm thick lead shield and lined with Cd and Cu sheets was used for the measurement. The IAEA supplied standard isotopic sources (^{60}Co, ^{137}Cs and ^{54}Mn) and reference standard sources RGTh-1, RGU-1 and RGK-1, for ^{232}Th, ^{226}Ra and ^{40}K, respectively (for bulk sample analysis) were used to calibrate for the estimation of concentration levels of the soil samples (Ibeanu, 1999). A computer-based MCA card system MAESTRO programme from Ortec was used for data acquisition and analysis of gamma spectra. In order to estimate the background contribution an empty container was counted using the same geometry as the samples.

The standards and samples were in turn counted for a period of 30,000 seconds per sample in reproducible sample-detector geometry and the count rate in counts per second (cps) obtained for each radionuclide. The gamma ray peak of 1460.0 keV was used in the assessment of ^{40}K, while 1764.0 keV and 2165.0 keV gamma lines of ^{214}Bi were used in the assessment of the activity concentrations of ^{226}Ra and ^{232}Th, respectively.

From the net area of a certain peak, the activity concentrations in the samples were obtained using eq. 1 (Jibiri, et al. 2007).

$$C = \frac{C_n}{\varepsilon P_\gamma M_s} \quad (1)$$

where C is the activity concentration of the radionuclide in the sample given in Bq kg^{-1}, C_n is the count rate under the corresponding peak, P_γ is the absolute transition probability of the specific γ-ray, ε is the detector efficiency at the specific γ-ray, and M_s is the mass of the sample (kg).

Equation 1 can be expressed as (Jibiri, et al. 2007).

$$C = \frac{C_k}{A_k} A \quad (2)$$

where C_k is the activity concentration of the radionuclide in a standard reference sample having the same geometry as the investigated sample (Bq kg^{-1}), A is the net area of the corresponding peak in the sample spetcrum, and A_k is the net area of the peak in the reference sample spectrum.

3.0 Results, Discussion and Conclusion

3.1 Results and Discussion

The activity concentrations of the radionuclides in the brick block building materials in Ekiti State, Nigeria are presented in Table 1 and as shown in Figure 2. ^{40}K exhibits the highest activity concentration value of 499 Bq kg^{-1} in Ijero Ekiti local goverment in the state, while the minimum value of 294 Bq kg^{-1} was obtained in Ido-Osi local goverment of the State. The activity concentration values of ^{226}Ra across the samples in the state varied from 12 Bq Kg^{-1} to 40 Bq Kg^{-1} with the highest mean value of 36 Bq kg^{-1} obtained in Ijero local government. This is in line with the values obtained by Ajayi et al. (1995) , Fasae and Borisade (2012), the area has a relatively higher background radiation compared to other areas in the state, this may be due to the geological formations of the area. The activity concentrations of the ^{232}Th varied from 31 Bq kg^{-1} to 48 Bq kg^{-1} with the highest mean value of 47 Bq kg^{-1} was obtained in Ado- Ekiti, while the minimum activity concentration value of 32 Bq kg^{-1} was obtained in Ikole local goverment of the state. The results also show that the mean activity concentrations value of 39.8 ± 3.5 Bq kg^{-1} for ^{232}Th in the study area is higher than the mean activity concentration value of 18.7 ± 6.2 Bq kg^{-1} for ^{226}Ra.

The mean activity concentrations of the radionuclides in the concrete block building materials in Ekiti State, Nigeria are presented in Table 2 and shown in Figure 3. The results show that the mean activity concentration values of 572.6 ± 3.1 Bq kg^{-1}, 47.9 ± 6.2 Bq kg^{-1} and 39.8 ± 3.5 Bq kg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th

respectively in concrete blocks are higher compared to the the values obtained in brick blocks. This indicate that the gamma emitting radionuclides present in the concrete blocks may elevate the external radiation exposure compared to brick blocks. This in return will enhance the internal radiation exposure due to ^{222}Rn exhaled from the building materials in to the dwellings. Radon exhalation from building materials has been studied and reported as one of the contributors to the indoor radon concentration (Auxier et al, 1974). However, the mean activity concentrations of the primodial radionuclides in the brick and concrete blocks for building in the study area compare well with values obtained in Northeastern Poland as reported by Zalewski et al., (2001).

Two coefficients for qualifying whether building raw material and final material are acceptable for building houses designed for habitation are defined as f_1 and f_2. The coefficient f_1 determines the limit of exposure of the body to gamma radiation and it is defined as (Zalewski et al., 2001):

$$f_1 = 0.00027S_k + 0.0027S_{Ra} + 0.0043S_{Th} \quad (3)$$

where :

S_K, S_{Ra} and S_{Th} are the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in a sample in Bq kg^{-1}.

Coefficient f_2 determines the limitof the concentration of ^{226}Ra in a building material with reference to emanation of ^{222}Rn from the walls. The coefficient f_2 is defined as:

$$f_2 = S_{Ra} \quad (4)$$

The coefficient f_1 must not be higher than 1 while the coefficient f_2 must not be higher than 185 Bq kg^{-1}. Only when both conditions are realized is the assessment positive and the material may be used in buildings designed for human habitation (Zalewski et al., 2001).

The calculated values of the coefficients f_1 and f_2 using equations 3 and 4 are presented in Table 3 and Table 4, for brick and concrete blocks respectively. The values of the coefficient f_1

varied from 0.28 to 0.41 with a mean value of 0.32 ± 0.04 and 0.30 to 0.68 with a mean value of 0.56 ± 0.1 for brick blocks and concrete blocks respectively. The values of the coefficient f_2 varied from 14 to 36 with a mean value of 18.7 ± 6.2 and 36.7 to 59 with a mean value of 47.9 ± 9.8 for brick blocks and concrete blocks respectively in the study area. The mean calculated values of f_1 are less than unity and the mean calculated values of f_2 is less than 185 Bq kg^{-1}, hence, the assessment is positive. This is an indication that the materials, subject to further radiological investigation may be used in constructing buidings for human habitation.

The exposition rate dose absorbed in the air, expressed in nGy/h was estimated using the equation (3):

$$D = 0.043 S_K + 0.43 S_{Ra} + 0.66 S_{Th} \quad (3)$$

where: S_K , S_{Ra} and S_{Th} are concentrations of ^{40}K, ^{226}Ra and ^{232}Th (Bq/kg) respectively. Using the equation 3 and taking the mean activity concentration values of radioactive radium, thorium and potassium of the raw brick block building material in the study area, the absorbed dose rate were estimated.

The absorbed dose rate in air due to the brick block in the study area which covers the entire state ranged from 42.7 nGy/h to 64.0 nGy/h with a mean of 49.4 nGy/h as presented in Table 3. The absorbed dose rate in air due to the concrete block ranged from 47.1nGy h^{-1} to 105.6 nGy h^{-1} with a mean value of 87.4 ± 0.08 nGy h^{-1}. The calculated absorbed dose rate values compare well with reported values by Zalewki et al, (2001) and the estimated average global terrestrial radiation of 55 nGy h^{-1} in the range (28 – 120 nGy h^{-1}) by UNSCEAR, (2000).

Values of dose rates absorbed in the air can be used in estimating the annual dose equivalent (H) expressed in mSv/year according to the equation 4 (Zalewski et. Al, 2001):

$$H = 0.69 * 7008 * D \quad (4)$$

where: 0.69 is the coefficient of transfer dose absorbed in the air dose equivalent. 7008 is the number of hours spent indoors in the year (80% of the year). The estimated values of the annual dose equivalent are presented in Table 3 and Table 4. The annual dose equivalent estimated ranged between 0.21mSv y^{-1} to 0.31 mSv y^{-1} with a mean value of 0.24 ± 0.03 mSv y^{-1} and 0.23 mSv y^{-1} to 0.51 mSv y^{-1} with a mean value of 0.42 ± 0.07 mSv y^{-1}. The annual dose equivalent estimated for concrete blocks in the study area is higher than the annual dose equivalent estimated for brick blocks, this may be attributed to granites, pegmatites and sandstone and minerals such as uranite, canotite etc. that are rich in Uranium (Cothern et al., 1983). The presence of these radioactive elements are therefore, reflected in soil (such as clay used in cement manufacture) which had been formed as a result of weathering of these rocks. It is then natural that Uranium and its decay progenies together with thorium and Potassium -40 will find their way into cement (Tufail et al., 1991). The calculated annual effective dose values ; 0.24 ± 0.03 mSv y^{-1} and 0.42 ± 0.07 mSv y^{-1} for brick block and cement block respectively, due to gamma rays from the building materials are within the world average indoor effective dose value of 0.4 mSv (UNSCEAR, 2000).

The external hazard index H_{ex} was estimated using the equation 5 (Beretka and Mathew, 1985):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K.

The external hazard index values are presented in Table 3 and Table 4 for brick blocks and cement blocks respectively. The mean external hazard index ranged from 0.24 – 0.36 with a mean value of 0.28 ± 03 for brick blocks while the values range from 0.27 – 0.60 with a mean value of 0.50 ± 0.08. The results show that the value of external hazard index is less than unity, in this case the concentrations of ^{226}Ra, ^{232}Th and ^{40}K satisfy the criterion eqation 5 for which to limit the radiation dose rate from building materials. The activity concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in other materials of building ; wood, glass and ceramic tiles were not considered in this study. The activity concentrations of the radionuclides in other building materials may also contribute to the environmental exposure. The results and the radiological assessments show that the use of brick block and cement block materials for constructing buildings for human habitation in the study area may pose a health risk to the population if there is no remediation by the regulatory body in the state.

3.2 Conclusion

The activity concentrations of the naturally occuring radionuclides ^{226}Ra, ^{232}Th and ^{40}K brick block and cement block material used for constructing dwellings in Ekiti have been determined. Concrete blocks were found to have higher Mean activitiy concentration values of the radionuclide. The ehnanced activity concentration values may be attributed to the presence of the radionuclides in the cement, water and sand used for the production of the concrete blocks. The radiological assessment values of the brick and concrete block building materials compare well with values found in literatures. The calculated annual effective dose values ; 0.24 ± 0.03 mSv y^{-1} and 0.42 ± 0.07 mSv y^{-1} for brick block and cement block respectively, due to gamma rays from the building materials are within the world average indoor effective dose value of 0.4 mSv (UNSCEAR, 2000). However, the use of brick block and cement block materials for constructing buildings for human habitation in the study area may pose a health risk to the population if there is no remediation by the regulatory body in the state. The regulatory body consider this for establishing a binding regulations.

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Table 1: The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in brick block building material in Ekiti State, Nigeria

S/N	No of Samples	Local Govt. Area	^{40}K (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
1	10	Oye –Ekiti	298 (278 - 310)*	15 (12-16)	39 (36 - 41)
2	10	Ado –Ekiti	351 (348 - 353)	15 (14 -16)	47 (46 - 48)
3	10	Efon Alaaye	396 (380 – 420)	19 (17 – 20)	39 (34 – 46)
4	10	Otun – Ekiti	276 (265 - 332)	15 (14 – 16)	40 (38 – 42)
5	10	Emure-Ekiti	315 (291 -390)	16 (15 – 17)	40 (37 - 45)
6	10	Ido/Osi	294 (279 -305)	16 (15 – 17)	41 (39 – 43)
7	10	Irepodun/Ife	300 (290 – 305)	14 (13 – 16)	36 (34 – 38)
8	10	Ijero – Ekiti	499 (439 – 456)	36 (33 – 40)	41 (37 – 46)
9	10	Ikere – Ekiti	399 (389 – 406)	31 (29 – 33)	41 (38 – 45)
10	10	Ikole – Ekiti	341 (339 - 342)	17 (15 – 18)	32 (30 – 33)
11	10	Ekiti South	381 (369 – 390)	17 (16 – 18)	39 (38 – 40)
12	10	Ise – Ekiti	333 (317 – 332)	15 (14 – 17)	35 (31 – 39)
13	10	Ilejemeje	361 (356 – 366)	21 (19 – 22)	40 (37 – 42)
14	10	Ode – Ekiti	371 (367 – 372)	15 (14 – 16)	41 (40 – 42)
15	10	Omuo – Ekiti	353 (339 – 361)	20 (18 – 23)	41 (39 – 43)
16	10	Aramoko-Ekiti	350 (343 – 352)	17 (16 – 18)	45 (42 – 47)
Mean			351.1 ± 3.1	18.7 ± 6.2	39.8 ± 3.5
Range			276 - 499	14 - 36	32 - 47

* The parentheses gives the range of the concentration values.

Table 2: The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in Concrete block building material in Ekiti State, Nigeria

S/N	No of Samples	Local Govt. Area	^{40}K (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
1	10	Oye –Ekiti	185.4 (100 – 195)	20.6 (15 – 30)	45.8 (37 – 47)
2	10	Ado –Ekiti	379.2 (200 – 453)	53.7 (43 – 58)	65.3 (60 – 67)
3	10	Efon Alaaye	450.7 (205 – 460)	54.9 (45 – 60)	70.2 (58 – 74)
4	10	Otun – Ekiti	587.5 (356 – 594)	43.4 (35 – 52)	52.7 (50 – 61)
5	10	Emure-Ekiti	705.3 (654 – 730)	59.0 (50 – 68)	62.9 (50 – 76)
6	10	Ido/Osi	473.5 (367 – 683)	41.8 (39 – 56)	59.5 (46 – 69)
7	10	Irepodun/Ife	289.6 (204 – 562)	46.7 (36 – 53)	48.8 (43 – 65)
8	10	Ijero – Ekiti	677.5 (548 – 758)	58.9 (48 – 62)	77.5 (61 – 83)
9	10	Ikere – Ekiti	730.8 (601 – 740)	40.8 (35 – 59)	71.5 (54 – 78)
10	10	Ikole – Ekiti	740.2 (633 – 750)	36.7 (32 – 56)	68.4 (51 – 75)
11	10	Ekiti South	469.1(485 – 678)	56.2 (51 – 68)	58.4 (46 – 62)
12	10	Ise – Ekiti	712.4 (673 – 734)	50.6 (47 – 55)	63.6 (58 – 72)
13	10	Ilejemeje	658.3 (521 – 703)	54.5 (41 – 57)	59.7 (52 – 64)
14	10	Ode – Ekiti	672.4 (465 – 682)	51.6 (42 – 61)	76.4 (62 – 74)
15	10	Omuo – Ekiti	745.7 (662 – 762)	48.9 (36 – 55)	73.5 (61 – 77)
16	10	Aramoko-Ekiti	684.5 (572 – 720)	48.2 (35 – 63)	67.1 (53 – 71)
Mean			572.6 ± 175.9	47.9 ± 9.8	63.8 ± 9.4
Range			185 - 745	36.7 – 59.0	45.8 – 77.5

* The parentheses gives the range of the concentration values.

Table 3: The mean activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in brick block building material in Ekiti State, Nigeria

Local Govt. Area	**^{40}K (Bq kg^{-1})**	**^{226}Ra (Bq kg^{-1}) f_2**	**^{232}Th (Bq kg^{-1})**	**f_1**	**Dose rate (D) (nGyh^{-1})**	**Annual dose rate (H) (mSv y^{-1})**	**H_{ex}**
Oye –Ekiti	298	15	39	0.29	45.0	0.22	0.25
Ado –Ekiti	351	15	47	0.34	52.6	0.25	0.29
Efon Alaaye	396	19	39	0.33	50.9	0.25	0.28
Otun – Ekiti	276	15	40	0.29	44.7	0.22	0.25
Emure-Ekiti	315	16	40	0.30	46.8	0.23	0.26
Ido/Osi	294	16	41	0.30	46.6	0.23	0.26
Irepodun/Ife	300	14	36	0.27	42.7	0.21	0.24
Ijero – Ekiti	499	36	41	0.41	64.0	0.31	0.36
Ikere – Ekiti	399	31	41	0.37	57.6	0.28	0.33
Ikole – Ekiti	341	17	32	0.28	43.1	0.21	0.24
Ekiti South	381	17	39	0.32	49.4	0.24	0.28
Ise – Ekiti	333	15	35	0.28	43.9	0.21	0.25
Ilejemeje	361	21	40	0.33	51.0	0.25	0.29
Ode – Ekiti	371	15	41	0.32	49.5	0.24	0.28
Omuo – Ekiti	353	20	41	0.33	50.9	0.25	0.29
Aramoko-Ekiti	350	17	45	0.33	52.1	0.25	0.29
Mean	351.1 ± 3.1	18.7 ± 6.2	39.8 ± 3.5	0.32±0.04	49.4±5.6	0.24±0.03	0.28±0.03
Range	276 - 499	14 - 36	32 - 47	0.28-0.41	42.7-64.0	0.21-0.31	0.24-0.36

Table 4: The mean activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in Concrete block building material in Ekiti State, Nigeria

Local Govt. Area	**^{40}K (Bq kg^{-1})**	**^{226}Ra (Bq kg^{-1}) f_2**	**^{232}Th (Bq kg^{-1})**	f_1	**Dose rate (nGyh^{-1})**	**Annual dose rate (mSv y^{-1})**	**H_{ex}**
Oye –Ekiti	185.4	20.6	45.8	0.30	47.1	0.23	0.27
Ado –Ekiti	379.2	53.7	65.3	0.53	82.5	0.40	0.48
Efon Alaaye	450.7	54.9	70.2	0.57	89.3	0.43	0.51
Otun – Ekiti	587.5	43.4	52.7	0.50	78.7	0.38	0.44
Emure-Ekiti	705.3	59.0	62.9	0.62	97.2	0.47	0.55
Ido/Osi	473.5	41.8	59.5	0.50	77.6	0.38	0.44
Irepodun/Ife	289.6	46.7	48.8	0.41	64.7	0.31	0.37
Ijero – Ekiti	677.5	58.9	77.5	0.68	105.6	0.51	0.60
Ikere – Ekiti	730.8	40.8	71.5	0.62	96.2	0.46	0.54
Ikole – Ekiti	740.2	36.7	68.4	0.59	92.8	0.45	0.54
Ekiti South	469.1	56.2	58.4	0.53	82.9	0.40	0.47
Ise – Ekiti	712.4	50.6	63.6	0.60	94.4	0.46	0.53
Ilejemeje	658.3	54.5	59.7	0.58	91.1	0.44	0.51
Ode – Ekiti	672.4	51.6	76.4	0.65	101.5	0.49	0.57
Omuo – Ekiti	745.7	48.9	73.5	0.65	101.6	0.49	0.57
Aramoko-Ekiti	684.5	48.2	67.1	0.60	94.4	0.46	0.53
Mean	572.6 ±175.9	47.9 ± 9.8	63.8 ± 9.4	0.56±0.1	87.4±0.08	0.42±0.07	0.50±0.08
Range	185 - 745	36.7 –59.0	45.8 – 77.5	0.30-0.68	47.1-105.6	0.23-0.51	0.27-0.60

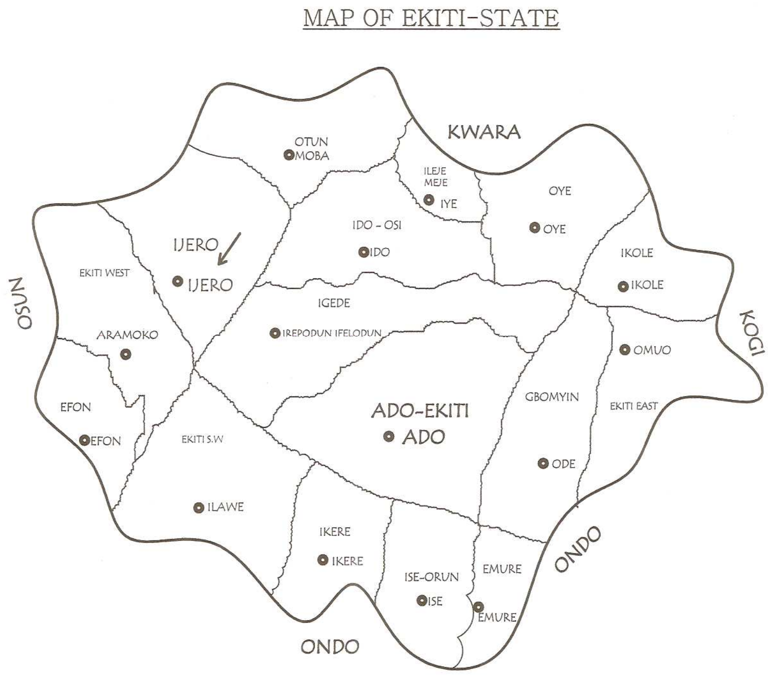

Fig. 1: Map of Ekiti State showing Ijero the location of the study area

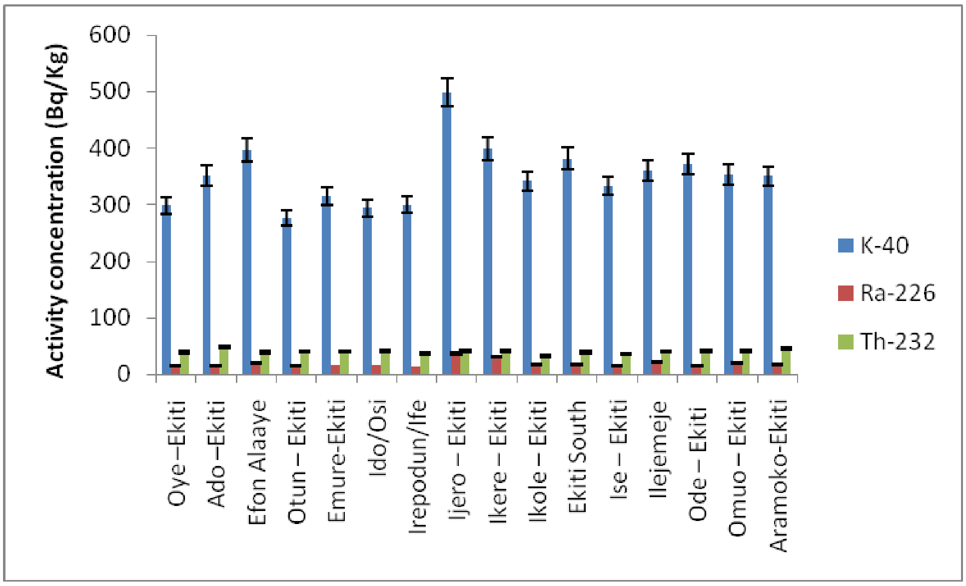

Fig. 2: The activity concentration of the radionuclides in the brick block building material across Ekiti State, Nigeria.

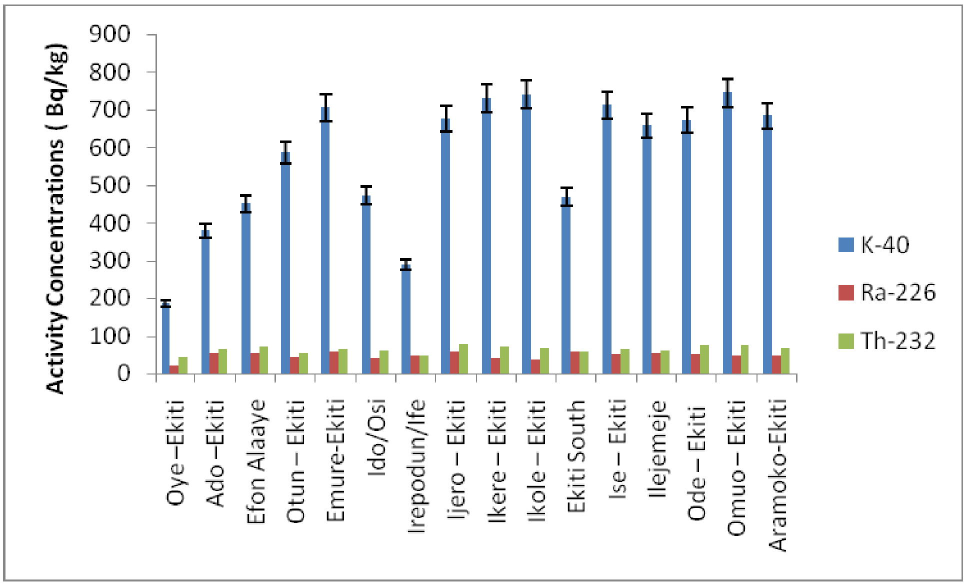

Fig. 3: The activity concentration of the radionuclides in the Concrete block building material across Ekiti State, Nigeria.