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Assessment of Terrestrial ^{40}k, ^{238}u And ^{232}th Activities in Soil Within the Basement Complex Terrain of West Central Part of Nigeria

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ABSTRACT

Assessment of natural radioactivity in soil samples have been made within the basement complex terrain of Tanke district of Ilorin in west central part of Nigeria. The work has been carried out keeping in mind the health effects of radio-elements in the environment and evolution of the area as satellite town of the University of Ilorin. The results revealed the presence of potassium, uranium and thorium radio-elements. The activity of the radionuclides range from 252.03 to 494.02 Bq Kg^{-1} for ^{40}K with a mean of 379.30 ± 31.15 Bq Kg^{-1}, 2.08 to 12.87 Bq Kg^{-1} for ^{238}U having a mean of 6.81 ± 2.03 Bq Kg^{-1} and ^{232}Th activity ranges from 6.55 to 11.85 Bq Kg^{-1} with a mean of 9.05 ± 2.95 Bq Kg^{-1}. The derived absorbed dose rate ranges from 20.01 to 30.03 nGy h^{-1} with a mean of 24.89 nGy h^{-1}. Consequently, the annual effective dose received by the population is estimated to range from 0.025 to 0.037 mSv y^{-1} with an average of 0.031 mSv y^{-1}. The radio-activities in soil samples of the area are found to be within global range for average terrestrial ionizing radiation exposure due to radionuclides in the soil.

Key words: Natural Radioactivity, Gamma-ray spectrometer, Dose rate, Soil, Nigeria.

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1. INTRODUCTION

The earth's natural radioactivity can be broadly classified into two categories: high-energy cosmic rays incident on the Earth's atmosphere, commonly termed cosmic radiation; and radioactive nuclides generated during the formation of the Earth and still present in the Earth's crust, commonly termed terrestrial radiation (European Commission, 2015).

Terrestrial radioactivity is mostly produced by Uranium (^{238}U and ^{235}U), and Thorium (^{232}Th) radioactive families together with Potassium (^{40}K), which is a long lived radioactive isotope of the elemental potassium (EC, 2015).

Natural radioactivity is common in rocks, soil, sediments and ground and surface waters, and even in building materials and houses with varying degree of concentrations depending on the geographical conditions and geologic formations (Ravisankar et al., 2015; Huang et al., 2015). Exposure to excessive dose of ionizing radiation poses a threat to humans. The greatest concern stems from its potential to cause malignant diseases in people exposed to it and inherited defects in later generations (International Atomic Energy Agency, 2004). It is one of the causes of the 'dread disease' cancer. As a result, studies have been extended globally to improve analytical techniques, develop diverse ways of detecting and quantifying radionuclides, and assess and monitor the environment (Anagnostakis, 2015; Anagnostakis et al., 2005 ; Bourcier et al., 2014 ; Chao et al., 2014 ; Landsberger et al., 2013; Porto and Walling, 2012 ; Sert et

al., 2012 ; Steinmann et al., 2013 ; Uyttenhove et al., 2002; Zivanovic et al., 2012).

Several researches involving assessment of radioactivity in the environment have been conducted in Nigeria (Avwiri et al., 2007; Ademola, 2008; Ajayi, 2001; Alatise, et al., 2008; Arogunjo et al., 2004; Farai and Ademola, 2005; Farai et al., 2008). Nevertheless, minimal records of studies on terrestrial natural radioactivity exist in Ilorin, a major metropolitan city with about 820,000 people in north-central Nigeria. A background ionizing radiation study carried out within the Asa-dam industrial zone of the city revealed an average level of 1.2 mSv y^{-1} and a subsequent follow-up survey conducted nine years later indicates an increase by 24%, possibly due to the surge in industrial activities in the industrial area (Nwankwo and Akoshile, 2005; Nwankwo et al., 2014). The annual effective dose received by the population as a result of the combined ingestion of ^{226}Ra (a progeny of ^{238}U) and ^{228}Ra (a progeny of ^{235}U) in water obtained from boreholes sited within the main campus of the University of Ilorin was determined and found to range from 0.003 to 1.45 mSv y^{-1} (Nwankwo, 2010), while a similar study in hand dug water wells in Sango district of the metropolis shows an annual effective dose ranging from 0.011 to 1.36 mSv y^{-1} (Nwankwo, 2012). Another study in Tanke district revealed that the annual effective dose received by the population as a result of the combined ingestion of ^{226}Ra and ^{228}Ra in groundwater varies between 0.81 and 1.74 mSv y^{-1} (Nwankwo, 2013). Similarly, an assessment of the natural radioactivity in sachet drinking-water samples sourced from boreholes scattered within Ilorin metropolis revealed that the effective dose received as a result of the combined ingestion of ^{226}Ra and ^{228}Ra ranged from 1.27 to 2.32 mSv y^{-1} (Nwankwo and Balogun, 2014).

In this paper the results of the measurements of ^{40}K, ^{238}U and ^{232}Th concentrations in soil samples collected from Tanke district of Ilorin metropolis in north-central Nigeria are presented. The calculations of the absorbed dose, annual effective dose and external hazard index are also presented and discussed. The main objective of this work was to develop reference data of natural radioactivity in soil and evaluate the radiological consequences in the study area, while keeping in mind the health effects of radio-elements in the environment and evolution of the area as satellite town of the University of Ilorin. Moreover, apart from analysis of radionuclides in water and air, no record of soil or other media exist in Ilorin. Radioactivity measurements in soil samples would, therefore, significantly compliment the available radiometric information and contribute to a better understanding of ionizing radiation exposure in Ilorin city. It is expected that this study would assist environmental policy makers in making informed judgement regarding radiation safety in Nigeria.

1.1 Location and geology of the study area

The area of study, situated at the west of central region of Nigeria, is bounded by latitudes 8.27^{o} and 8.30^{o} North and longitudes 4.36^{o} and 4.39^{o} East. It is positioned at a strategic point between the densely populated south-western and the sparsely populated middle belt of Nigeria (Jimoh, 2003). Ilorin metropolis is located between the deciduous woodland of the south and dry savannah of northern Nigeria (Jimoh, 2003). The area is marked by two distinct climatic conditions namely rainy and dry seasons. The rainy season lasts usually from May to October with a total annual rainfall of 1295 mm. The dry season occurs between November and April while the mean monthly temperatures vary from 25 to 29 ^{o}C (Balogun 2003).

The area lies entirely within the basement rocks of Nigeria (Fig 1). The basement

complex is one of the three major litho-petrological components that make up the geology of Nigeria and has been described at length by several researchers (Oyawoye, 1964; Rahaman, 1973; Oluyide, 1988; Olasehinde *et al.*, 1986; Olasehinde, 1999; Obaje, 2009 etc.). The rocks are mainly banded gneiss, sheared gneiss and augen gneiss intruded by granodiorites and granites at the southeast. The structural fabric is mainly a north-south trending fracture system dominated by a southerly plunging (6^0 - 10^0) anticlinorium with a gentle westerly dipping limb is depicted in the north-central region (Olasehinde, 1999, Olasehinde *et al.*, 1986).

The rocks within the basement complex of Nigeria have been classified into five major groups (Rahaman, 1973):

i. migmatite – Gneiss complex, which comprises gneisses, quartzite, calc silicates rocks, biotite hornblende schist and amphibolites;
ii. slightly migmatised to unmigmatised para-schists and meta-igneous rocks;
iii. charnockitic rocks;
iv. older granites (pan African granitoids); and
v. unmetamorphosed dolerite dykes, which comprises pegmatite, quartz veins and doleritic dykes.

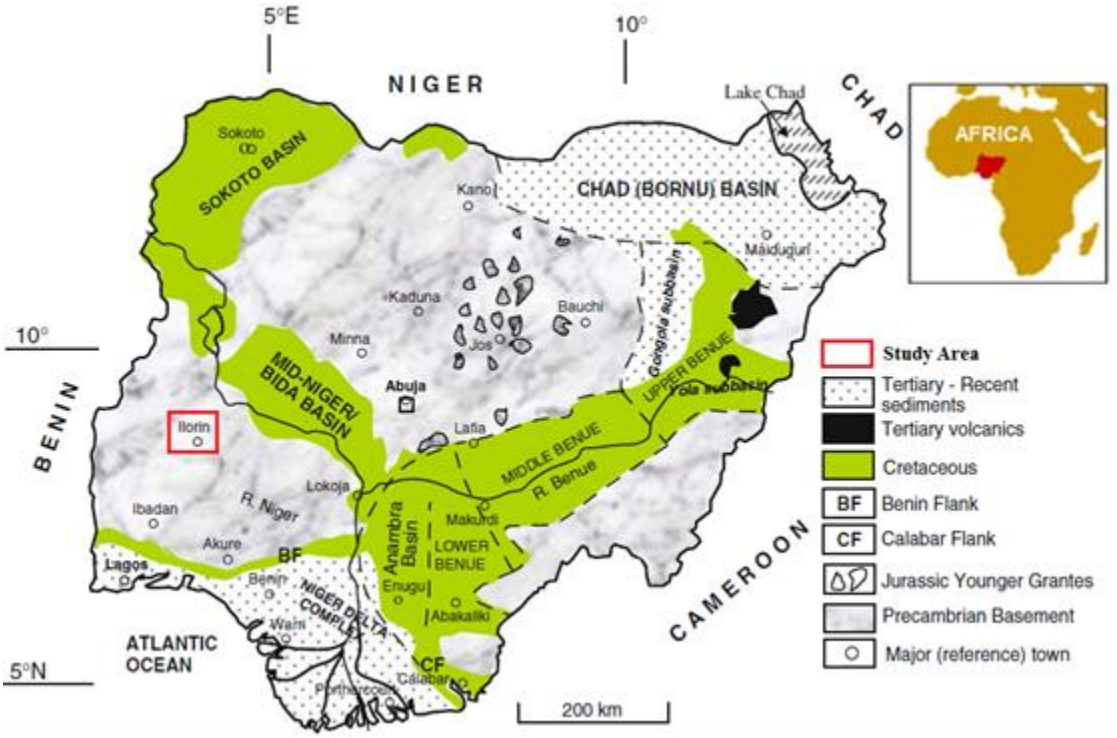
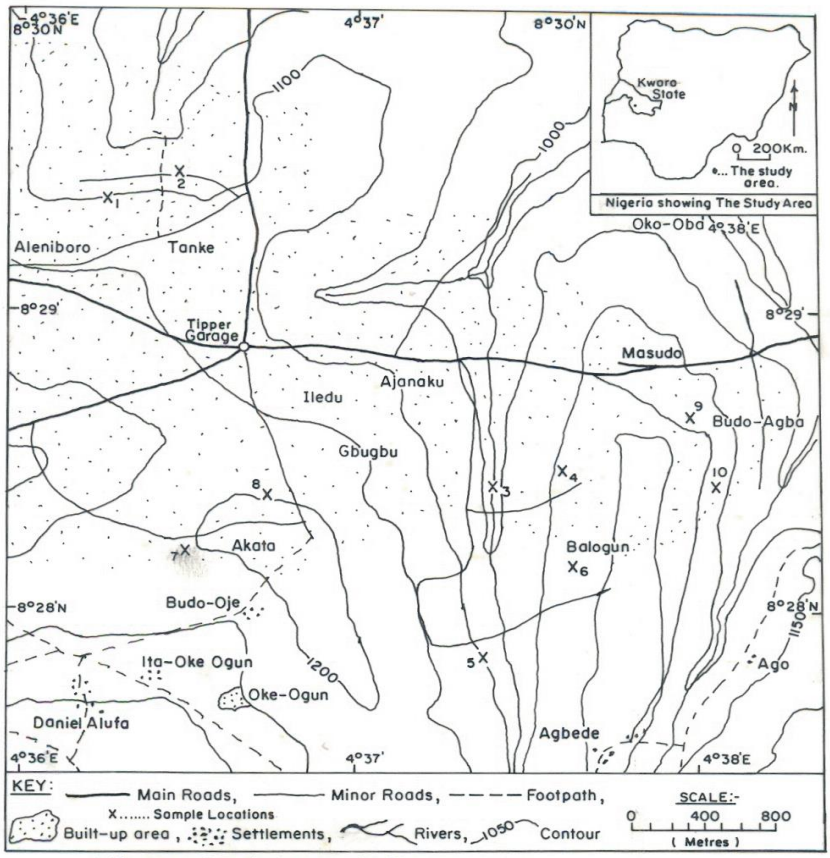


Figure 1. Geological sketch map of Nigeria showing the study area (After Obaje, 2009).

2. MATERIALS AND METHODS

2.1 Sample collection and preparation

Ten soil samples were collected within Tanke district of Ilorin at depth of about 50 cm. The names of the sampling stations are given in Figure 2 and Table 1. Following the procedures of Murty and Karunakara (2008) and Baykara and Dogru (2009), the samples were dried in an oven at about 100 ^{o}C for about 10 hours after removing stones, pebbles and plant materials such as litter, roots, etc. The soil samples were subsequently crushed and passed through a fine mesh sieve of 100 µm to homogenize them. Sieved samples were then sealed in 300 ml plastic containers and stored for 30 days to allow ^{238}U to reach equilibrium with its progeny before gamma ray spectrometry analysis was carried out. Proper sealing was ensured by providing double seal to the lid of the container to prevent the escape of ^{222}Rn.



A Topo Map of Tanke Area showing Sample Locations.

Figure 2. Topographical sketch map of the study area showing sample locations

Table 1. Location of the soil samples in the study area.

S/N	Location of Samples	Code
1.	Tanke Ilewe I	X_1
2.	Tanke Ilewe II	X_2
3.	Tanke Ajanaku I	X_3
4.	Tanke Ajanaku II	X_4
5.	Tanke Bubu I	X_5
6.	Tanke Bubu II	X_6
7.	Akata Tanke I	X_7
8.	Akata Tanke II	X_8
9.	Tanke Oke-Odo I	X_9
10.	Tanke Oke-Odo II	X_{10}

Gamma spectrometer, housed at the Center for Energy Research and Development in Ile-Ife, Nigeria was used in this study. The spectrometer consists of a stream lined vertical gyrostats HpGe semiconductor detector coupled with a Canberra series 10 plus Multichannel Analyzer (MCA) through a pre-amplifier base. The detector counting head is inserted into a circular lead castle of 5 cm wall thickness, which is suitable for limiting the gamma radiation. The transition lines of 1.460 MeV of ^{40}K, 1764.5 KeV of ^{214}Bi and 2614.7KeV of ^{208}Ti were used to determine the concentrations of ^{40}K, ^{238}U and ^{232}Th respectively. Counting was done for 10 hours for each sample, while the spectrum was measured and the area under the photopeaks computed using the algorithm of the MCA. Environmental shielding of the soil was achieved using a Canberra 10cm thick lead castle (Farai and Sanni, 1992).

2.2 Radioactivity measurement and Calculations

The specific activity concentration A_c (i.e. $A_{c(K)}$, $A_{c(U)}$ and $A_{c(Th)}$ for ^{40}K, ^{238}U and ^{232}Th respectively) in soil samples were computed using the relation (Baykara and Dogru, 2006; 2009):

$$A_C = \frac{C}{\varepsilon P_\gamma M_S} \qquad (1)$$

where C is the counting rate of gamma rays (in counts per second), ε is the detectors efficiency of the specific gamma ray, P_y is the absolute transition probability of gamma decay and M_s is the mass of the sample in kg.

The corresponding absorbed dose rates *D* in air due to terrestrial gamma rays at 1 m above the ground were also calculated from ^{40}K, ^{238}U and ^{232}Th concentrations in soil using the equation (UNSCEAR, 1993):

$$D = [0.042A_{c(K)} + 0.429A_{c(U)} + 0.666A_{c(Th)}]nGyh^{-1} \qquad (2)$$

where 0.042, 0.429 and 0.666 are dose conversion factors (nGyh^{-1} per Bqkg^{-1}) and $A_{c(K)}$, $A_{c(U)}$ and $A_{c(Th)}$ are activity concentrations ^{40}K, ^{238}U and ^{232}Th, respectively.

In order to estimate the annual effective dose rates, one has to take into account the conversion coefficient from the absorbed dose in air to the effective dose received by adults (ie. 0.7 SvGy^{-1}) and the outdoor occupancy factor (0.2), which implies that people spend 20% of their time outdoors, on the average (UNSCEAR, 2000; Ravisankar

et al. 2015). Therefore the annual effective dose *AED* to the population due to the soil radioactivity was similarly estimated using the relation (UNSCEAR, 2000; Faheem et al., 2008; Ravisankar et al. 2015):

$$\mathrm{AED} = [\mathrm{D\ x\ T\ x\ Q\ x\ O_f\ x 10^{-6}}]mSvy^{-1} \quad (3)$$

where D is the absorbed dose rate defined in equation 2, T is time in hours in one year, i.e., 8760h, Q is dose conversion coefficient of 0.7 $SvGy^{-1}y^{-1}$ for environmental exposure to gamma ray of moderate energy, and O_f is the occupancy factor of 0.2).

Consequently, *AED* can be simplified as:

$$\mathrm{AED} = [\mathrm{D\ x\ 0.00123}]mSvy^{-1} \quad (4)$$

Again, the external hazard index H_{ex} was calculated as defined as (Jankovic et al., 2008):

$$\mathrm{H_{ex}} = \frac{\mathrm{A_{c(K)}}}{4810} + \frac{\mathrm{A_{c(U)}}}{370} + \frac{\mathrm{A_{c(Th)}}}{259} \quad (5)$$

The value of H_{ex} must be less than unity in order to keep the radiation hazard insignificant (Jankovic et al., 2008).

3. RESULTS AND DISCUSSION

The radionuclides identified in the soil samples and quantified from the gamma ray spectra belong to the decay daughter products of naturally occurring radioactive elements ^{238}U and ^{232}Th and the singly-occurring radionuclide ^{40}K. The activity of naturally occurring radionuclides for the 10 different locations is shown in Table 2, while the total absorbed dose rates, estimated annual effective dose and the external hazard index are presented in Table 3. The activity of ^{40}K range from 252.03 to 494.02 Bq kg^{-1} with an average of 379.37±31.15 Bq kg^{-1}; ^{238}U activity range from 2.08 to 12.87 Bq kg^{-1} with an average of 6.81±2.03 Bq kg^{-1} and ^{232}Th range between 6.55 and 11.85 Bq kg^{-1} with an average of 9.05±2.95 Bq kg^{-1} for the soil samples.

Table 3 shows that the absorbed dose rate varies between 20.01 and 30.03 nGy h^{-1} with a mean of 24.89 nGy h^{-1}. The absorbed dose rate itself does not give an indication of possible biological effects until it is converted to the effective dose equivalent, which is measured in Sieverts (Sv). Therefore, the annual effective dose rates calculated vary from 0.025 to 0.037 mSv y^{-1} with a mean of 0.031 mSv y^{-1}. The results revealed that the soil samples X_6 (Tanke Bubu II) has the lowest dose rate of 20.01 nGy h^{-1} (0.025 mSv y^{-1}) while sample X_4 (Tanke Ajanaku II) has the highest dose rates of 30.03 nGy h^{-1} (0.037 $mSvyr^{-1}$). Nevertheless, the mean annual effective dose calculated for the area are within the permissive dose limit of 1 mSv y^{-1} for average terrestrial gamma rays exposure due to radionuclides in the soil (International Commission on Radiological Protection, 2012). More so the calculated external hazard indices, whose primary objective is to limit the radiation dose to the permissible dose equivalent of 1 mSv y^{-1}, was found to vary between 0.11 and 0.16 with an average index of 0.13. The index obtained for all the soil samples is less than unity showing that the radiation hazard due to soil in the study area is insignificant.

For comparison, the reported and average values for natural radionuclides in soil from some other countries are given in Table 4. It is evident from the table that the concentrations observed in soils of the study area are comparable to those reported for worldwide range and average values (UNSCEAR, 2000) and also the values reported for African, American, Asian and European countries (Murty and Karunakara, 2008). For example, it could be deduced from Table 4 that the global range for ^{238}U, ^{232}Th and ^{40}K are 1 – 1520, 2 – 276, and 12 – 6590 respectively. The values obtained in this work fall within the ranges but are far below the global average values. In addition, the results obtained are the world average of 0.48 mSv y^{-1} (UNSCEAR, 2000). Therefore, the concentrations of

observed soil radio-elements in the study area may not pose any serious detrimental health side-effects to the public.

Table 2. The activity of the soil samples collected from the study sites.

Sample Code	^{40}K (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
X_1	410.28±36.81	11.14±3.87	11.85±4.14
X_2	334.87±32.96	12.87±3.47	5.95±2.23
X_3	252.03±21.12	9.67±2.37	10.87±3.51
X_4	494.02±40.84	6.30±1.24	9.88±2.98
X_5	378.25±27.90	3.43±1.22	6.55±1.74
X_6	304.44±27.19	4.16±1.37	8.16±3.04
X_7	349.60±26.17	9.16±2.37	10.82±3.09
X_8	399.48±30.84	6.39±3.02	7.41±1.96
X_9	476.48±39.76	2.94±1.04	9.42±3.21
X_{10}	394.25±27.86	2.08±0.32	9.63±3.63
Mean	379.37±31.15	6.81±2.03	9.05±2.95

Table 3. The absorbed dose rates and dose equivalents of the soil samples collected from the study sites.

Sample Code	Absorbed dose rate (nGy h^{-1})	Annual effective dose (mSvyr^{-1})	External hazard index
X_1	29.90	0.037	0.16
X_2	23.55	0.029	0.13
X_3	21.97	0.027	0.12
X_4	30.03	0.037	0.16
X_5	21.72	0.027	0.11
X_6	20.01	0.025	0.11
X_7	25.82	0.032	0.14
X_8	24.45	0.030	0.13
X_9	27.55	0.034	0.14
X_{10}	23.86	0.029	0.13
Mean	24.89	0.031	0.13

Table 4. Comparison of ^{40}K, ^{238}U and ^{232}Th activity of soil samples obtained in this study with that of other countries (Murty and Karunakara, 2008).

Country	^{238}U (^{226}Ra) (Bq kg^{-1})	^{232}Th (^{228}Ra) (Bq kg^{-1})	^{40}K (Bq kg^{-1})
Present Study	2.1 – 12.9 (6.8)	6.6 – 11.9 (9.1)	252 – 494 (379)
Botswana	6.1 – 74.4 (34.8)	7.4 – 110.0 (41.8)	33.5 – 1085.7 (432.7)
India	7.8 – 1520 (31)	17.5 – 158.3 (63)	43 – 766 (394)
Greece	1.0 – 238 (25)	1.0 – 193 (21)	12 – 1570 (360)
Spain	13 – 165 (46)	7 – 204 (49)	48 – 1586 (650)
Japan	6 – 98 (33)	2 – 88 (28)	15 – 990 (310)
Ireland	10 – 200 (60)	3 – 60 (26)	40 – 800 (350)
USA	8 – 160 (40)	4 – 130 (35)	100 – 700 (370)
Turkey	82.3 – 166.99 (115)	151.9 – 275.6 (192)	1015.5 – 1484.9 (1207)
Namibia	45 – 48 (46)	3 – 38 (32)	42 – 1100 (480)
Egypt	5 – 64 (17)	2 – 96 (18)	29 – 6590 (320)
Taiwan	36	14.8 – 44.4	148 – 814
China	40.2 – 442 (112)	32.6 – 88.1 (71.5)	440 – 913 (672)
World Average	8 – 160 (32)	4 – 130 (40)	100 – 700 (420)

Values given in parenthesis are mean values

4. CONCLUSION

The study of the radioactivity of soil in Tanke district of Ilorin, Nigeria has been carried out. The mean value has been taken as the estimated value for the area. The estimated value for the absorbed dose rate for the soil samples range from 20.01 to 30.03 nGy h^{-1}with a mean of 24.89 nGy h^{-1},while the resulting effective dose equivalent range from 0.025 to 0.037 mSv y^{-1} with a mean of 0.031 mSv y^{-1}.

The acknowledged mean for the doses are within global tolerable limit. Since measurements of natural radioactivity in soil is performed mostly for assessment of the doses and risk, exposure to ionizing radiation resulting from soil in the area may not pose any serious detrimental health side-effects to the public.

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