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Radiation hazard in soil from Ajaokuta North-central Nigeria

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► ***Short report***

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ABSTRACT

Background: Measurement of the radiation dose distribution is important in assessing the health risk a population and serve as reference in documenting changes to environmental radioactivity in soil due to man-made activities. ***Materials and Methods***: The activity concentration of ^{238}U, ^{232}Th and ^{40}K in soil samples obtained from different locations in Ajaokuta Local Government area was measured using Hyper Pure germanium Detection System (HPGe). ***Results:*** The calculated average concentration of the radionuclides ranged from 12 ± 1 Bqkg^{-1} to 59 ± 2 Bqkg^{-1} for ^{238}U, 14 ± 1 Bqkg^{-1} to 78 ± 5 Bqkg^{-1} for ^{232}Th and 49 ± 2 Bqkg^{-1} to 1272 ± 23 Bqkg^{-1} for ^{40}K. In order to evaluate the radiological hazards due to natural radionuclides within Ajaokuta, the absorbed dose rate, gamma index, radium equivalent and excess lifetime cancer risk were estimated. According to measured data from the top soil (0-10 cm), the estimated radium equivalent (Ra_{eq}) ranges from 55.7 Bqkg^{-1} at Steel Complex to 253.3 Bqkg^{-1} obtained from Forest samples. ***Conclusion:*** The mean absorbed dose rate, annual effective dose and gamma radiation index evaluated were 66.2 nGyh^{-1}, 81.2 μSvy^{-1} and 1.05 respectively which are higher than the recommended limit for normal background radiation. Thus, we conclude that people living in these locations may be exposed to higher radiation.

Keywords: *Radiation hazard, gamma index, excess lifetime cancer risk, soil, Ajaokuta.*

INTRODUCTION

Natural radioactivity includes the primordial and cosmogenic radionuclides that are common in rocks, soils, water and oceans that make up our planet [1]. It is found also in our building materials constituting main sources of radiation exposure for human beings. Radionuclides are inhaled and ingested every day through breathing and food chain [2, 3]. According to the ALARA principle, "limits" are established by International commissions, but we know well that (especially) stochastic effects have no a threshold. In order to reduce them "as low as (is) reasonably achievable", we must limit exposure to radiation sources. It is therefore pertinent to design mechanisms to monitor the levels of these radionuclides due to their harmful effects [4, 5]. Gamma dose measurements have been conducted in different areas of Nigeria through soil radionuclides. This is the first systematic and extensive study of this kind in the study area. This paper deals with the measurement of decay products of uranium/ thorium series and primordial radionuclide ^{40}K in soil samples taken from various parts of Ajaokuta. Within the framework of this research, radiological parameters that include absorbed dose rate, annual effective dose, gamma index and excess life cancer risk have been estimated

from the activity concentration of ^{238}U, ^{232}Th and ^{40}K. The aim of this study is to assess the health risks associated to the presence of these radionuclides and develops a baseline of natural background radiation levels for the area.

Study area

The area of study is Ajaokuta Local Government area in Kogi state, Nigeria (figure 1). Ajaokuta is located 07°53'94''N and 006° 64'24''E to the left bank of the Niger River; situated within the crystalline basement complex [6]. It is a 1,362 km^2 wide and has a population of 122,321 at the 2006 census, with mean temperature of 26°C and relative humidity of 88% [6]. The crystalline complex rocks (figure 1) are predominantly gneiss, migmatite and older meta-sediment rocks comprising quartzite, marble calc-silicate and the pan Africa granites/ older granites. The geology of the area reveals that rocks are from Pre-cambium crystalline basement complex and the Cretaceous (Campbanian-Maastrichian) sedimentary of the Mid-Niger Basin.

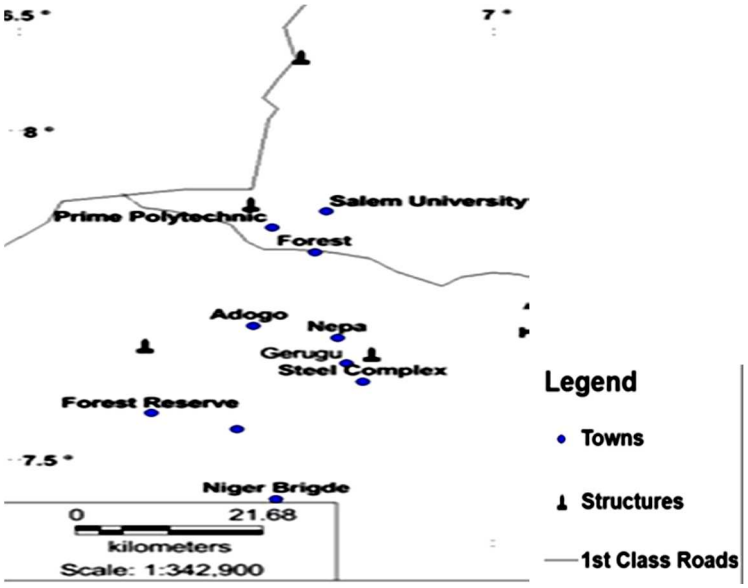

Figure 1. Map showing the sampling locations.

MATERIALS AND METHODS

Sample preparation and measurements

The samples were collected by digging the ground to at least 3cm then taken the soil from there. Five soil samples were taken from different points at each location making a total of fifty samples collected using composite sampling method for better sampling. The samples were then kept in Ziplock bags and labelled accordingly. The samples were dried at 110 ºC in an oven to ensure complete removal of moisture until constant weight was attained. Dried samples were grinded and passed through a 2mm sieve. 100g of each sample were placed in a radon-tight plastic vessel, 9cm in diameter with a total capacity of 300 cm^3. The vessels were weighted and sealed for 30 days to allow equilibrium in the ^{238}U and ^{232}Th with their respective progeny [7].

Gamma ray spectrometric method was used for the radioactivity measurement (model GC8023). The detector was coupled with multi-channel analyser (MCA) through pre amplifier base. The detector is properly shielded with lead to prevent external radiation from environment. An International Atomic Energy Agency (IAEA) standard reference soil sample (MGS6M315) with specific activity was engaged in calibrating the detector. The peak 1.46 MeV was employed for ^{40}K; 2.61 MeV (^{208}Ti) for ^{232}Th and 1.76 MeV (^{214}Bi) for ^{238}U respectively were

used to estimate radionuclide contents of the samples using the Genie 2000 software [8, 9]. Each sample was counted for 36,000 seconds to improve statistics. The specific activity was calculated using equation 2 and the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were estimated using Equation 3. The measured parameters were analysed using Excel spreadsheet and Surfer 11 software

$$\text{Specific activity (Bq kg}^{-1}) = \frac{\text{Net Area - B.G}}{t\varepsilon P_\gamma M} \quad (2)$$

Net Area = Net area under energy peak (count).

B.G= the number of counts for the background spectrum.

t = the counting time

P_γ = the gamma emission probability at energy E

ε = the absolute efficiency of the detector, and M = the weight of the dried sample (kg).

$$Activity\,(Bq) = \frac{CPS \times 100 \times 100}{B.I \times E_{ff}} \pm \frac{CPS_{error} \times 100 \times 100}{B.I \times E_{ff}} \quad (3)$$

Where; *CPS* is the net count rate per second, *B.I* is the branching intensity and *Eff* is the efficiency of the detector.

RESULTS AND DISCUSSION

Table 1 presents the mean concentration of the radionuclides, as well as the corresponding statistical error for five samples each under investigations at the ten locations within the study area. The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K are found to vary from 12 ± 1 Bqkg^{-1}to 59 ± 2 Bqkg^{-1}, 14 ± 1 Bqkg^{-1}to 77 ± 5 Bqkg^{-1}and 49 ± 2 Bqkg^{-1}to 1272 ± 23 Bqkg^{-1} respectively in the soil samples studied in this research. The highest level of ^{238}U (59 Bqkg^{-1}) and ^{40}K (1272 Bqkg^{-1}) are obtained from the soils from Salem University. The highest level of ^{232}Th (78 Bqkg^{-1}) was obtained from soil samples collected from Forest. The measured concentration of ^{40}K is found to be higher than that of ^{232}Th and ^{238}U in all the locations studied. It varied from below detection limit (BDL) and 1272 Bq kg^{-1} having a mean value of 712 Bq kg^{-1}. High activity concentration level of ^{40}K in this location may be probably due to application of inorganic phosphate rich fertilizer used for agricultural activities.

World average concentrations are 33 Bqkg^{-1}and 45 Bqkg^{-1}for ^{238}U and ^{232}Th respectively; and typical ranges are 16 - 36 Bqkg^{-1}for ^{238}U and 7 – 50 Bqkg^{-1} for ^{232}Th. Similarly, the world average concentration for ^{40}K is 420 Bqkg^{-1}, and typical range is 100 - 700 Bqkg^{-1} for ^{40}K [10]. It is evident from Table 1 that the concentration of Uranium (^{238}U) is higher than the world standard at Salem University, Forest, Nepa, and Niger Bridge; whereas, the activity concentration of Thorium (^{232}Th) is greater than that of the world standard obtained at Salem University and Forest. The natural radionuclides measured in this study is comparable with that obtained in other countries such as, Jordan (49, 27, 291 Bqkg^{-1}), Turkey (37, 40, 667 Bqkg^{-1}) and Yemen (44, 58, 823 Bqkg^{-1}) for ^{238}U, ^{232}Th and ^{40}K concertation respectively [11, 12, 13]. The elevated concentrations of ^{238}U and ^{232}Th measured in these locations may be attributed to the geology and geographical conditions of these locations, from the geology point of view these locations belong to basement complex which is associated with igneous rock. This corroborates the report by [10] and [14] that igneous rocks such as granite are associated with a higher level of radiation when compared with sedimentary rock.

Estimation of radiological parameters

Radium equivalent activity is calculated in order to compare the activity concentration of samples containing varying amounts of ^{238}U, ^{232}Th, and ^{40}K with respect to radiation exposure. It is estimated using Equation 4 [15]:

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

Where C_U, C_{Th} and C_K are the concentrations (Bqkg^{-1}) of ^{238}U, ^{232}Th, and ^{40}K, respectively in the soil samples. The range of the radium equivalent activity within the study area varies from 55.74 Bqkg^{-1}at Steel Complex to 253.27 Bqkg^{-1}at Forest.

In order to estimate the absorbed and

effective dose according to [10], the measured activity of ^{238}U, ^{232}Th, and ^{40}K were converted into dose ($nGyh^{-1}$) by applying the dose factors 0.462, 0.604, and 0.0417 for uranium, thorium and potassium respectively [16]. The factors were applied to calculate the total absorbed gamma dose rate in air at 1m above the ground level using equation 5.

Table 1. Activity concentration measured in Ajaokuta LGA

Location	No	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
Salem University	5	59 ± 2	63 ± 5	1272 ± 23
Prime Polythecnic	5	15 ± 1	27 ± 2	701 ± 14
Forest	5	46 ± 3	78 ± 5	1242 ± 23
Steel Complex	5	30 ± 1	15 ± 1	49 ± 2
Ajaokuta	5	12 ± 1	14 ± 1	553 ± 11
Nepa	5	44 ± 3	33 ± 3	1090 ± 20
Adogo	5	23 ± 1	17 ± 1	870 ± 16
Forest Reserve	5	21 ± 1	37 ± 3	BDL
Gerugu	5	26 ± 2	35 ± 3	649 ± 13
Niger Bridge	5	34 ± 3	42 ± 3	692 ±13
Minimum		12 ± 1	14 ± 1	49 ± 2
Maximum		59 ± 2	78 ± 5	1242 ± 23
Mean ± SD		31 ± 2	36 ± 3	712 ± 13

Absorbed dose (D) ($nGyh^{-1}$) =
$0.462C_U+0.604C_{Th}+0.0417C_K$ (5)

where C_U, C_{Th} and C_K are the activity (Bq kg^{-1}) of uranium, thorium and potassium in the soil samples. The annual effective doses were estimated putting into consideration the conversion coefficient from the absorbed dose in the air to effective dose, this involves using the conversion factor of 0.7 $SvGy^{-1}$ to convert the absorbed rate to annual effective dose with and outdoor occupancy of 20%. This is calculated using the Equation 6.

Outdoor annual effective dose = (Absorbed dose) $nGyh^{-1}$×8760 h×0.2×0.7 $SvGy^{-1}$ (6)

The absorbed dose rate and annual effective dose rate from the soil samples were calculated and presented on table 2. It showed that the minimum and maximum annual dose was obtained in steel complex and Forest respectively.

Calculation of external indices includes that of gamma index (I_γ) for a typical material, according to [17], the gamma index determined as given by equation 7.

$$I_\gamma = \sum_x \frac{C_x}{A_x} \quad (7)$$

Where C_x (Bq kg^{-1}) is the measured activity of each nuclide in the building material, A_x (Bq kg^{-1}) is the activity concentration of each nuclide in the material and it is assumed to produce the same gamma dose rate, i.e. 300, 200, and 3000 $Bqkg^{-1}$ for ^{238}U, ^{232}Th, and ^{40}K respectively. Based on the dose criterion of $1mSvy^{-1}$ for public exposure, the estimated gamma index (I_γ) for soil samples is presented in table 2. Figure 2 is the image map of gamma index. It is obvious that I_γ is greater than unity in soil samples from Salem University, Forest, Nepa and Niger Bridge within the study area. The soil samples with values greater than unity failed to satisfy the safety criterion from radiation point of view hence, these soils within the areas may not be good for building and construction purposes.

The excess lifetime cancer risk (E_L) and percentage risk were estimated in order to obtain the probability of developing cancer over a lifetime at a given exposure level using [18] equation. Figure 3 is the correlation of the excess lifetime cancer risk and annual effective dose rate with a trend line was drawn between

the points using regression analysis technique. The correlation between the excess lifetime cancer risk and annual effective dose rate was very high (1). The high correlation obtained may be due to the retaining capability of the soil of these radionuclides under different atmospheric conditions. The estimated average excess lifetime cancer risk ranged between 0.16×10^{-3} and 0.52×10^{-3} μSvy^{-1} with percentage risk between -62.67 **%** and 78.48 **%.** Although the mean excess lifetime cancer estimated for all the locations is 0.28×10^{-3} μSvy^{-1}**,** which is slightly less than the standard0.29×10^{-3} μSvy^{-1}, the soils from Salem University, Forest, Nepa and Niger Bridge remain above this limit. Therefore, people living or working in these areas may be exposed to high radiation from natural radionuclides.

Table 2. Estimated Radiological Parameters for Ajaokuta LGA.

Location	D ($nGy\ h^{-1}$)	H_E (μSvy^{-1})	I_γ	E_L (μSvy^{-1})	%Risk
Salem University	119.13	146.1	1.88	0.511	76.33
Prime Polytechnic	52.58	64.48	0.84	0.226	-22.18
Forest	120.58	147.88	1.91	0.518	78.48
Steel Complex	25.22	30.98	0.39	0.108	-62.67
Ajaokuta	37.34	45.79	0.59	0.16	-44.74
Nepa	86.19	105.7	1.35	0.37	25.57
Adogo	57.65	70.7	0.91	0.247	-14.67
Forest Reserve	32.35	39.67	0.51	0.139	-52.12
Gerugu	60.61	74.33	0.96	0.26	-10.29
Niger Bridge	70.24	86.14	1.11	0.301	3.96
Mean	66.19	81.18	1.05	0.28	-2.23

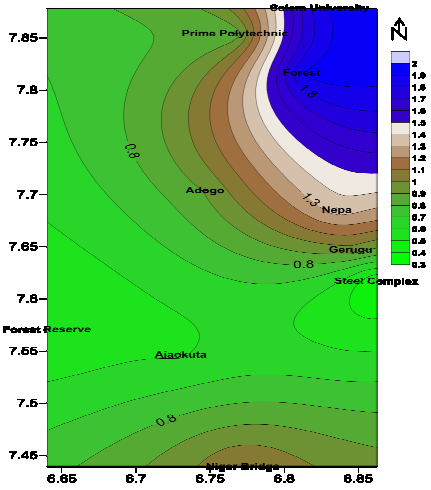

Figure 2. Map showing estimated Gamma Index within the study area.

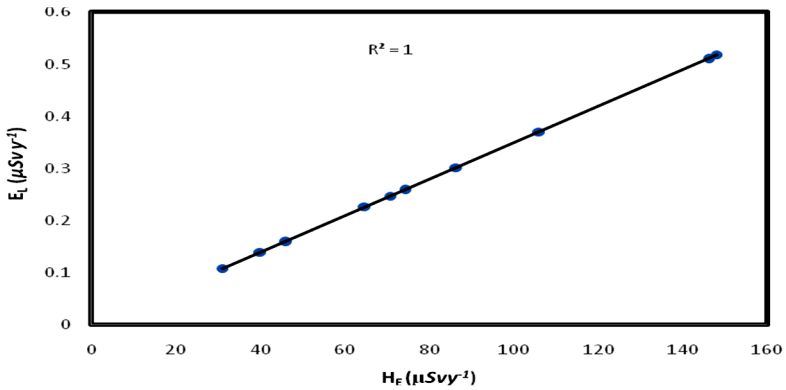

Figure 3. Correlation of excess lifetime cancer risk and annual effective dose rate.

CONCLUSION

The estimated activity concentration for ^{238}U, ^{232}Th, and ^{40}K in soils samples from different sampling locations in Ajaokuta Local Government of Kogi State, Nigeria is found to vary from one location to another. The highest level of ^{238}U and ^{40}K are observed within Salem University. The highest level of ^{232}Th was detected from soil samples obtained from Forest. Radiological parameters estimated were found to be relatively higher in Salem University, Forest, Nepa and Niger Bridge. The soils from these areas may put the users of the soils and people around these areas on a radiological hazard.

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***Conflicts of interest*: Declared none.**

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