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Determination of the Distribution of Gamma Emitting Radionuclides in Abeokuta using an In-Situ Gamma Spectrometric System

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ABSTRACT
In all ground formations, naturally occurring radionuclides, such as ^{40}K, ^{226}Ra and ^{232}Th and their decay products exist as trace levels. In this study, in-situ gamma spectrometry, which consists of a NaI(Tl) detector, a portable shield 4 cm thick and 17.5 cm deep which was filled with lead shots and a mobile stand has been used to measure different components of environmental radioactivity around Abeokuta, capital of Ogun State, Southwestern Nigeria. Results from the study shows that ^{40}K, ^{226}Ra and ^{232}Th has a mean of 469.28 ± 4.09, 65.11± 0.27 and 558.93 ± 6.61 Bq/kg correspondingly. Calculated values for absorbed dose rate are as follows: 451.27 nGy/h for the mean, 86.76 nGy/h for the lowest, and 1635.92 nGy/h for the highest. The mean value of the yearly effective dosage is 0.99 mSv/y, with low value of 0.22 mSv/y and high value of 4.22 mSv/y. The minimum value exceeds the maximum value. Based on the findings of this investigation, one may draw the conclusion that the comparatively high activity concentration level of the city can be attributed to the unexpectedly high concentrations that were found at some sites.

INTRODUCTION

There are a lot of different sources of radiation that people are exposed to. According to Hashim et al. (2004), some of these sources originate in nature, while others are man-made. Radiation from the sun, space, and radioactive elements in Earth's crust all contribute to the natural background radiation, as do radioactive elements in the air we breathe or food we consume and store in our bodies. Geographical location and certain human activities determine the size of these natural exposures (Mayeen et al., 2012). The majority of the radiation that people get comes from naturally occurring radionuclides like ^{40}K, ^{232}Th, and ^{238}U, as well as their decay products, which are found in trace amounts in all types of rock (Otwoma *et al.,* 2012).

There are natural and man-made sources; the latter are the product of human endeavors (Hashim et al., 2004). Cosmic radiation, radiation emitted by radionuclides in Earth's crust, and radiation absorbed by man's body via inhalation or ingestion are all examples of radiation that originates in nature. These natural exposures may vary in intensity depending on factors such as geography and certain human actions (Mayeen et al., 2012). Naturally occurring radionuclides, like ^{40}K, ^{232}Th, and ^{238}U, as well as their decay products, are primary external source of radiation dosage to humans. These radionuclides are found in all geological strata at trace quantities. Radiation may enter the human body from a wide variety of sources. Surveys meant for establishing the gamma dose rates baseline in an environment may be carried out using a number of different techniques and methods. Despite the

importance of understanding the distribution of gamma emitting radionuclides in the environment, there is a lack of comprehensive data on the levels and distribution of these radionuclides in Abeokuta in-situ. This knowledge gap may hinder the effective assessment and management of radiation exposure risks to the public and the environment. The aim of this research is to identify and quantify radionuclide present in the study area without taking environmental samples to the laboratory.

Study area

Situated in the southwestern region of Nigeria lies the city of Abeokuta, which serves as the capital of Ogun State. As stated by Moroof and Gabriel (2014), it is located between the longitudes 3°20'E and 3°54'E and between the latitudes 7°9'N and 7°39'N where it is placed. Both Abeokuta North and Abeokuta South are considered to be the two Local Government Areas that make up the majority of this region. The whole area that it encompasses is 1,256 square kilometers.

Geologically speaking, the city is distinguished by the presence of basement complex rocks that lie under it. These rocks are mostly composed of porpyroblastic gneiss, hornblende-biotite gneiss, granite, porphyritic granite, plus pegmatitic intrusions. According to Farai and Vincent (2006), these rocks have significant concentration of radionuclides and a decrease in their capacity to hold water. The Abeokuta formation, is sedimentary and mostly composed of sand with interbeds of sandstone, clay, silt, siltstone, mudstone, and shale (Okeyode and Jibiri, 2013; Moroof and Gabriel, 2014), is what distinguishes the city from other places. The sands have a coarse grain size, are clayey, micaceous, and they are poorly sorted. These characteristics are suggestive of short lengths of transit and may indicate that they originated from granite rocks. The results of the in-situ measurements are shown in Figure 1.

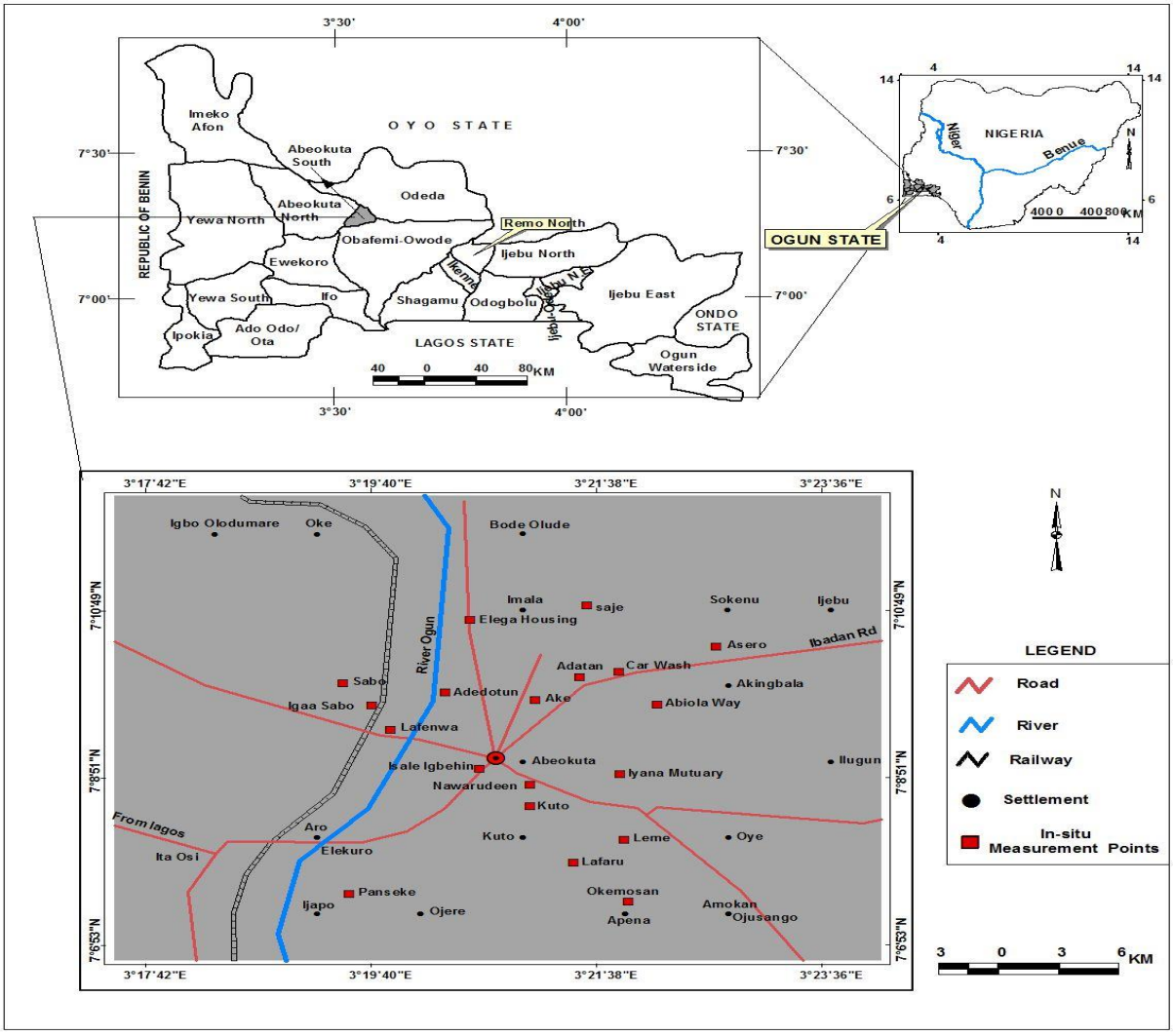

Figure 1: Map of in-situ measurement points

MATERIALS AND METHODS

The spectrometric system used for this work is a mobile in-situ gamma-ray spectrometer that consists of a moveable iron stand for the purpose of mounting the NaI(Tl) detector at each measurement point. The stand has a provision for the detector to face downward, a portable shield 4 cm thick and 17.5 cm deep which was filled with lead shots. The NaI(Tl) detector placed inside the shield is an inorganic scintillator that works on the principle of incoming radiation causing excitation in the crystal. The detector is connected to multichannel analyzer (MCA) that processes the signals from the detector, multichannel buffer (MCB) and the digiBase. The digiBase is also supplied with the MAESTRO-32 MCA Emulation Software and it is connected to the USB port of a computer system that was used.

Before the in-situ measurements were carried out, the detector was calibrated. Two phases were used in order to do the calibration of the detector. Initially, the channel numbers were converted into gamma energy, which was measured in keV. Converting count rates (cps) beneath a photopeak to the soil activity concentration ($BqKg^{-1}$) of radionuclide was the second step in the process.

In-situ specific activity calculations

Analysis of the in-situ gamma ray spectra that were acquired resulted in the determination of the net peak areas for each major photopeak. In order to determine specific activity of the nuclide, which is denoted by SA ($Bqkg^{-1}$), for a single gamma energy, Equation 1 was used (Benke *et al.,* 1997):

$$SA = \frac{\text{Net Peak Area}}{(\text{Count time})(\frac{N_f}{A})} \quad (1)$$

where $\frac{N_f}{A}$ is photopeak count rate at the gamma energy per unit activity concentration of radionuclide in soil ($\frac{cps}{Bqkg^{-1}}$)

In-situ absorbed dose rate

In-situ absorbed dose rate, D was calculated by means of Equation 2 (UNSCEAR, 2000)

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

where, D is total absorbed dose rate in nGy h^{-1}, A_K, A_{Ra} and A_{Th} is activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in Bq kg^{-1} respectively.

Effective Dose Rate Calculation

The formula was used to obtain the yearly effective dose rates, denoted as H_E(mSv/y), expected to be received within the locations under investigation (Okeyode et al, 2013).

$$H_E(mSv/yr) = D\ (nGy/hr) \times 8760\ (hr/yr) \times 0.4 \times 0.7\ (Sv/Gy) \times 10^{-6} \quad (3)$$

In this equation, the variable D represents total absorbed dose in air, whereas variable 8760 is number of hours per year (24 × 365). 0.7 represents the conversion factor from absorbed dose in air to effective dose in tissues. This study makes use of a measure called the occupancy factor (Outdoor), which is equal to 0.4 hours. This represents the percentage of time that individuals in these places spend outside.

RESULTS AND DISCUSSION

A presentation of the findings about the in-situ activity concentration may be seen in table 1. In the region under investigation, the frequency distributions of each individual radionuclide are shown in Figures 2, 3, and 4, respectively. A presentation of absorbed dose rates and yearly effective dose rates that correlate to them may be found in table 2.

Table 1: Activity concentration of naturally occurring radionuclides in soil from in-situ gamma spectrometry

S/N	LOCATION	$^{40}K(Bqkg^{-1})$	$^{226}Ra(Bqkg^{-1})$	$^{232}Th(Bqkg^{-1})$
1	AKE	232.71±2.61	67.69±0.76	234.32±2.62
2	ABIOLA WAY	218.94±2.45	63.52±0.71	418.69±4.69
3	ADATAN	597.92±6.69	79.15±0.88	724.94±8.12
4	ADEDOTUN	1147.20±12.84	63.52±0.71	634.32±7.10
5	ASERO	346.47±3.88	54.15±0.60	353.07±3.95
6	CAR WASH	402.27±4.51	46.86±0.52	221.82±2.48
7	ELEGA HOUSING	202.27±2.27	82.27±0.92	625.98±7.01
8	IGAASABO	187.78±2.10	35.40±0.39	185.36±2.08
9	IYANAMUTARY	187.78±2.10	41.65±0.47	185.36±2.08
10	ISALEIGBEHIN	281.26±3.15	31.23±0.35	1030.15±11.54
11	KUTO	937.05±10.49	99.98±1.12	2362.40±2/65
12	LAFARU	896.47±10.04	89.57±1.00	2578.07±28.87
13	LAFENWA	168.94±1.89	36.44±0.41	104.11±1.17
14	LEME	1312.42±14.69	120.82±1.35	1320.78±14.79
15	NAWARUDEEN	292.85±3.27	73.94±0.83	466.61±5.22
16	OKEMOSAN	103.72±1.16	56.23±0.63	199.94±2.24

17	PANSEKE	315.31±3.53	64.57±0.72	153.07±1.71
18	SABO	291.40±3.26	44.77±0.50	190.57±2.13
19	SAJE	793.57±8.88	85.40±0.96	756.19±8.47
	MEAN	**469.28±4.09**	**65.11±0.27**	**558.93±6.61**
	MIN	**103.72±1.16**	**31.23±0.35**	**104.11±1.17**
	MAX	**1312.42±14.69**	**120.82±1.35**	**2578.07±28.87**

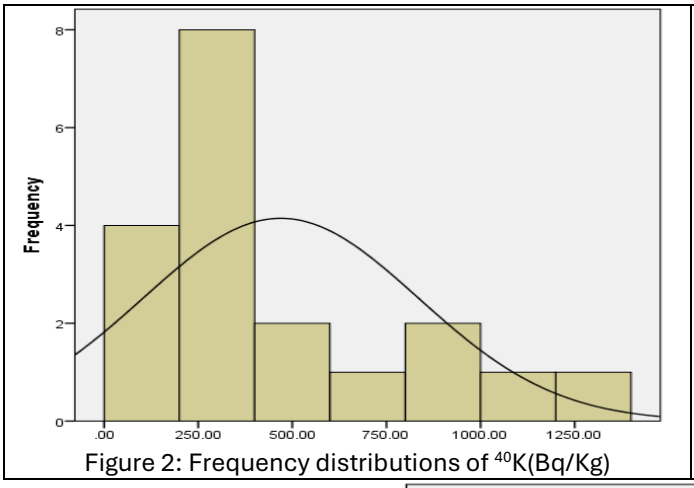

Figure 2: Frequency distributions of ^{40}K(Bq/Kg)

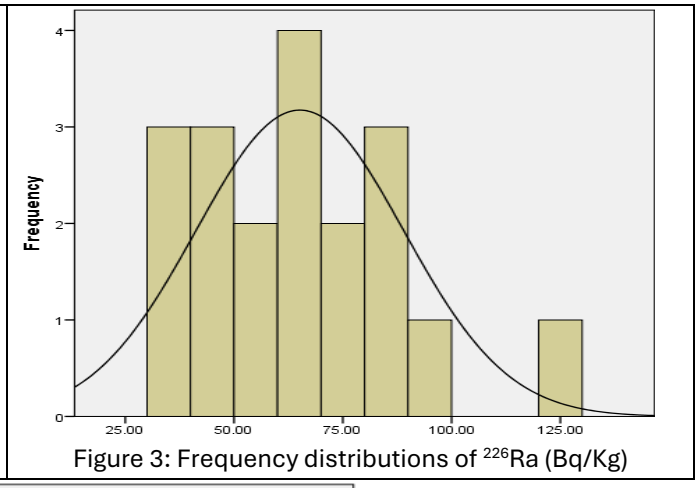

Figure 3: Frequency distributions of ^{226}Ra (Bq/Kg)

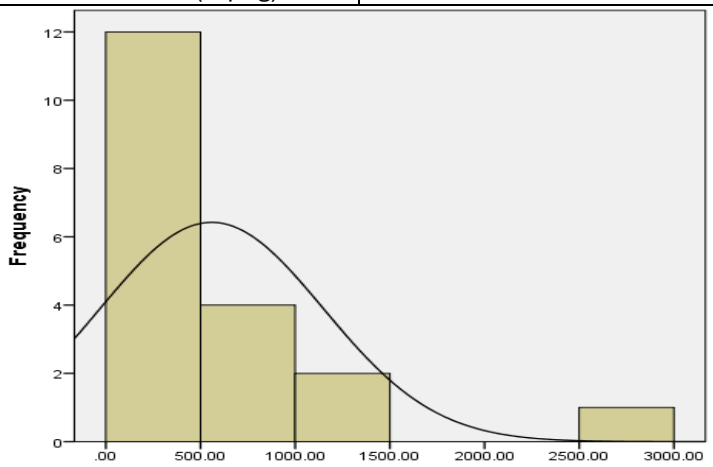

Figure 4: Frequency distributions of ^{232}Th (Bq/Kg)

Table 2: Absorbed dose rate in air and annual effective dose from in-situ Measurement

S/N	LOCATION	D(nGy/hr)	AED(mSv/y)
1	AKE	182.50	0.47
2	ABIOLA WAY	291.37	0.75
3	ADATAN	499.37	1.29
4	ADEDOTUN	460.31	1.19
5	ASERO	252.72	0.65
6	CAR WASH	172.40	0.44
7	ELEGA OUSING	424.54	1.09
8	IGAASABO	136.14	0.35
9	IYANAMUTARY	139.03	0.36
10	ISALEIGBEHIN	648.37	1.67
11	KUTO	228.05	0.59
12	LAFARU	1635.92	4.22
13	LAFENWA	86.76	0.22
14	LEME	908.29	2.34

15	NAWARUDEEN	328.20	0.85
16	OKEMOSAN	151.07	0.39
17	PANSEKE	135.43	0.35
18	SABO	147.94	0.38
19	SAJE	529.29	1.36
	MEAN	**451.27**	**0.99**
	MIN	**86.76**	**0.22**
	MAX	**1635.92**	**4.22**

Discussion

Table 1 displays activity concentrations of naturally occurring radionuclides measured by in-situ gamma spectrometry. With a mean value of 469.28 ± 4.09 Bq/kg, the results for ^{40}K varied from 103.72 ± 1.16 Bq/kg to 1312.42 ± 14.69 Bq/kg. ^{232}Th readings varied from 104.11 ± 1.17 Bq/kg to 2578.07±28.87 Bq/kg, with an average of 558.93 ± 6.61 Bq/kg, and ^{226}Ra values varied from 31.23 ± 0.35 Bq/kg to 120.82 ± 1.35 Bq/kg, with a mean of 65.11± 0.27 Bq/kg. All mean values of the naturally occurring radionuclides in the study area are higher than the world average values of 400 Bq/kg, 30 Bq/kg and 35 Bq/kg for ^{40}K, ^{232}Th and ^{226}Ra respectively (UNSCEAR, 2000). Radionuclide activity concentration frequency distributions reveal a leftward skew for ^{40}K and ^{232}Th and a near-normal distribution for ^{226}Ra. This shows non-homogenous distribution of radionuclide in the study area. Table 2 shows total absorbed dose rates and the annual effective dose. Mean, minimum and maximum values of absorbed dose rate are 451.27, 86.76 and 1635.92. nGy/h respectively. With a mean value of 0.99 mSv/y, yearly effective dosage ranges from a low of 0.22 mSv/y to a high of 4.22 mSv/y. Additionally, the results demonstrate that the average absorption rates in the research region exceed the global average absorption rates of 59 nGy/h (UNSCEAR, 2000).

CONCLUSION

This research reported the findings of an in-situ activity concentration measurement, absorbed dose rates, and yearly effective dosage for the naturally occurring radionuclides ^{40}K, ^{226}Ra, and ^{232}Th in the city of Abeokuta in southwestern Nigeria. In Lafaru and Kuto, the concentrations of ^{232}Th are 2578.07±28.87 and 2362.40±2.65 Bq/kg, respectively. These values are more than triple the average of the area studied. In Leme and Adedotun, the concentrations of ^{40}K are 1312.42±14.69 and 1147.0±12.84 Bq/kg, respectively. These values are more than twice the average of the study area. The city has unusually high activity concentration level which is explained by these abnormally high concentrations. This could be as a result of the numerous outcrops that dot a large portion of the city. Abeokuta town has a high radiation dosage. According to the results, ^{232}Th is the most common naturally occurring radioactive element in the region under consideration.

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