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RADIOLOGICAL IMPACT ASSESSMENT DUE TO NATURAL RADIONUCLIDES IN THE SOILS FROM ALABATA, SOUTHWESTERN NIGERIA

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ABSTRACT

The radioactivity levels of ^{40}K, ^{226}Ra and ^{232}Th and their corresponding gamma absorbed dose rate, effective doserate, and hazard indices were determined in soil samples from a soft-sand collection field at Alabata Abeokuta for building construction purposes. Soil samples were collected randomly from twenty locations in the area and prepared for spectrometric analysis. The activity concentrations of the natural radionuclides in the samples was measured using a single crystal 51mm x 51mm NaI (Tl) detector coupled to a multichannel analyser for spectrometric analysis. The activity concentrations of the radionuclides obtained were used to determine the radiological hazard indices. The mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the soil samples were 829.1±260.6 $Bqkg^{-1}$, 61.7±21.7 $Bqkg^{-1}$ and 50.1±16.6 $Bqkg^{-1}$ respectively. The mean gamma absorbed dose rate was 71.45±15.58 $nGyh^{-1}$ while the mean effective dose rate was 0.09±0.02 $mSvy^{-1}$. The mean radium equivalent, external hazard index, internal hazard index and gamma index were 197.2±36.8; 0.53±0.10, 0.70±0.14 and 0.73±0.14 respectively. The absorbed gamma and effective dose rates were 21.1% and 28.6% higher than the world average values of 59 $nGyh^{-1}$ and 0.07 $mSvy^{-1}$ respectively. The radiological hazard indices were lower than 1.0 world's recommended limit.

Keywords: Impact assessment, activity concentration, hazard indices, natural radionuclides, Alabata- Abeokuta

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INTRODUCTION

Natural or artificial ionizing radiation is useful for medical, scientific and technological purposes but some health risk is associated with radiation exposure. The human environment is often subjected to radiation exposures originating from natural background sources comprising terrestrial and extra-terrestrial; and artificial or man-made sources (Shiva *et al.,* 2008).

The natural background radioactivity accounts for 96.1% of the total radiation dose to the world population while the man-made sources account for the remaining 3.9% (Jibiri *et al.,* 2009).

The terrestrial background radiations are mainly from the primordial radionuclides that include the decay series radionuclides (^{226}Ra and ^{232}Th) with their progenies and non-decay series radionuclide, ^{40}K,. Out of the total natural background radiation dose that the world population receives about 85% is from terrestrial sources (IAEA, 1996) and about 23% of the average annual dose to human from all radiation sources (NCRP, 1987).

The great global interest in the study and survey of naturally occurring radiation and environmental radioactivity had been essentially based on the importance of using the results from such studies for the assessment of public radiation exposure rates and the performance of epidemiological studies (UNSCEAR, 2000).

The understanding of the radionuclide inventory and factors that determine radionuclide availability and the health effects to members of the public will help both government and individual to device methods to protect themselves against radiation exposure (Vines and Beard, 2012).The presence of radionuclides in the soil resulting from rocks' weathering is one of the main sources of the natural radioactivity (Taskin *et. al.,* 2009). The level of natural radioactivity in the soil and surrounding environment in a region depends mainly on the

geographical and geological settings of the area(Ivanovich and Harmon 1982).The primordial radionuclides (^{40}K, ^{226}Ra and ^{232}Th) are present in the earth crust since the creation of the earth (Shiva *et al.,* 2008).Soils are used by man for various purposes including construction of houses, schools, mosques, churches, and recreation centers among many others. This implies that human is continuously exposed to natural radionuclides in addition to the artificial radioactivity from modern scientific and technological activities (Chougankar *et al.* 2003).

The study area is a field located in Alabata Abeokuta Ogun State. Cattle were seen grazing freely on the field and the residents reported that various tippers come to collect soft-sand from the field for infrastructural construction purposes including houses.

The aim of the present study therefore is to measure the radioactivity levels in the soils from the field with a view to achieve the following objectives:

(I) measure the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th, in soil from the study area

(ii) determine the external absorbed and outdoor effective dose rates

(iii) estimate the radiological hazard indices including radium equivalent, gamma index, external and internal hazard indices.

Materials and Methods

Soil sample collection and preparation

Alabata Abeokuta, the study area is underlain by basement complex consisting predominantly migmatite as shown in Figure 1 and the coordinates of the sampling locations is presented in Table 1.Soil samples were collected to a depth of 150mm and a surface area of about 250 sq. mm from four different points at each sampling site. Thereafter, the soil samples were thoroughly mixed together to provide a representative sample for that site. A total of 20 representative samples were collected. The soil samples were air dried, thoroughly crushed and sieved with a 2mm mesh-wire. The samples were then oven dried until the mass of the samples was constant and 200g each of the soil samples was packed into a clean and radon-impermeable plastic container of uniform size and sealed for a period of about 30 days. This was done to allow for secular equilibrium to be established between ^{226}Ra and ^{228}Ra and their respective gaseous progenies prior to spectroscopic measurements.

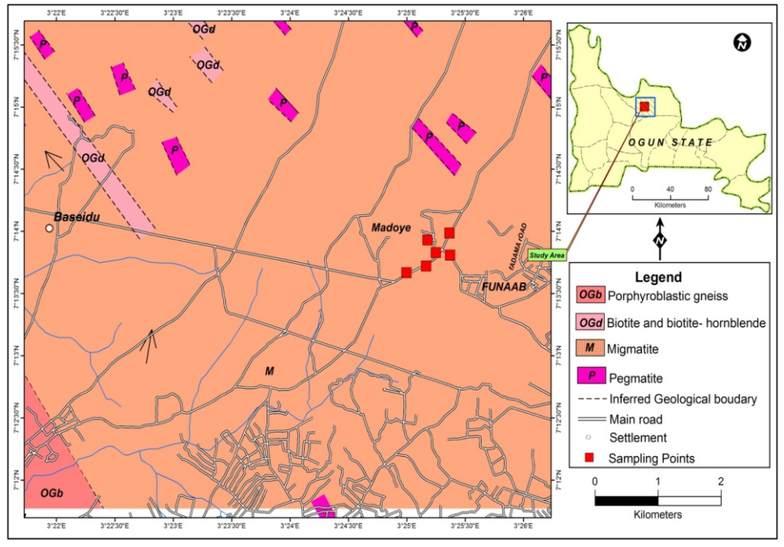

Figure 1: Geological map of Ogun State showing some of the sampling locations (After Elueze and Bolarinwa, 2001)

Measurements of activity concentrations of the radionuclides The samples were analyzed using a single crystal 51mm x 51mmNaI(Tl) detector, manufactured by Scintitech Instrument, USA, and coupled through Hamamatsa (R1306NSV3068) photomultiplier tube to Multichannel Analyzer, MCA (2100R:01) manufactured by Price Gamma Technology, USA. The MCA 2100R which performs an automatic adjustment to the detector bias and amplifier gain includes Quantum MCA software for qualitative analysis. All calibration functions were made through the software. The standard reference soil sample from Rocketdyne Laboratories, California, USA with activity concentrations traceable to a mixed standard gamma source (Ref. No. 48722-356) by Analytic Inc., Atlanta Georgia were used for efficiency calibration of the detector.

The detector has an energy resolution of Full Width at Half Maximum (FWHM) of about 6.2%.The 0.662MeV gamma transition was used for determination of ^{137}Cs concentration. The activity concentration of ^{214}Bi determined from its 1.760MeV γ-ray peak was chosen to provide an estimate of ^{226}Ra (^{238}U) in the sample, while that of the daughter radionuclide ^{208}Tl, determined from its 2.615MeV γ-ray was chosen to estimate ^{232}Th. The ^{40}K radionuclide was determined by measuring the 1.460MeV γ-ray emitted during its decay. All these transition energies lines for the determination of their radionuclides were considered good enough to distinguish the gamma ray energies of interest.Each of the samples was placed on top of the detector and analysed for a period of 36000 seconds (10 hrs).

The activity concentrations of the radionuclides in the samples were determined using Equation 2.1 (Jibiri and Bankole, 2006).

$$C(Bq/kg) = \frac{C_n}{\varepsilon_p I_\gamma m_s} \qquad (2.1$$

where C is the activity concentration of the radionuclide in the sample (Bqkg^{-1}); C_n is the count rate under the photo peak, ε_p is the detector efficiency at the specific γ-ray energy, Iγ is the absolute transition probability of specific γ-ray and m_s is the mass (kg) of the sample.

Results

Activity concentrations

Using Equation 2.1, the activity concentrations of the radionuclides in the soil samples from the study area were determined. The mean with standard deviation of the measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the soil samples and the coordinates of the sampling locations are presented in Table 1

Table 1: Activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil samples from the study area

Sampling locations	Latitude	Longitude	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
1	07^0 13' 48.2"	003^0 25' 22.4"	1302.0±10.2	56.7±5.6	49.3±5.6
2	07 13' 51.9"	003^0 25' 18.1"	713.4±11.4	32.7±8.4	56.3±4.81
3	07^{0}13' 53.7"	003^0 25' 19.4"	1329.0±51.4	43.1±15.5	60.7±11.5
4	07^{0}13' 55.3"	003^0 25' 20.3"	764.3±44.2	71.9±1.4	29.9±2.9
5	07^{0}13' 57.2"	003^0 25' 21.4"	979.5±19.2	85.2±7.1	51.4±3.7
6	07^{0}13' 58.9"	003^0 25' 21.8"	789.0±74.3	20.9±5.4	32.2±9.7
7	07^{0}13' 50.9"	003^0 25' 14.1"	889.6±18.2	48.3±20.4	46.4±11.4
8	07^0 13' 51.2"	003^0 25' 12.4"	628.5±22.4	71.8±9.3	64.1±9.4

Sampling locations	Latitude	Longitude	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
9	07^0 13' 52.4"	003^0 25' 12.6"	749.7±11.4	60.0±6.5	68.9±7.0
10	07^0 13' 53.7"	003^0 25' 13.4"	987.3±16.2	19.9±11.4	46.4±5.4
11	07^0 13' 55.7"	003^0 25' 11.3"	624.7±41.3	81.1±10.0	37.9±4.1
12	07^{0}13' 54.6"	003^0 25' 08.7"	876.8±61.2	54.1±11.3	77.7±3.4
13	07^{0}13' 52.5"	003^0 25' 09.5"	548.5±22.2	94.7 ±17.6	87.8±7.5
14	07^{0}13' 49.5"	003^0 25' 14.6"	596.8±11.4	78.3±11.0	25.3±11.6
15	07^{0}13' 46.7"	003^0 25' 13.4"	654.3±11.4	52.2±14.1	38.9±6.4
16	07^{0}13' 45.3"	003^0 25' 11.9"	1243.6±31.9	87.4±6.4	41.3±15.3
17	07^{0}13' 43.2"	003^0 25' 09.3"	687.5±11.1	68.6±4.4	63.8±9.2
18	07^{0}13' 42.8"	003^0 25' 06.7"	364.7 ± 17.6	50.9±11.4	46.8±7.3
19	07^0 13' 41.0"	003^0 25' 00.9"	744.5±16.3	88.4±19.4	29.7±3.4
20	07^{0}13' 40.5"	003^0 25' 00.5"	1108.1±31.1	69.1±9.8	47.1±11.3
	Mean±δ		829.09±260.6	61.7±21.8	50.1±16.6

Absorbed and outdoor effective dose rates

The external absorbed dose rate, D (nGy h^{-1}) in air at 1.0 m above the ground level due to the radionuclides in the samples was calculated using the equation (Jibiri *et al.,* 2009):

$$D_{ext} = \uparrow_{R} A_R DC_{ext.R} \qquad (2)$$

where $DC_{ext,R}$is the coefficient of dose rate per unit activity concentration of radionuclide, R(nGy h^1/Bq kg^{-1}) and A_R is the concentration of the radionuclide R in the sample (Bq kg^{-1}). According to UNSCEAR (2000), the coefficients of dose rate per unit activity concentration of radionuclide, $(DC_{ext,R})$ are 0.043for ^{40}K, 0.427 for ^{238}U and 0.662 for ^{232}Th. Using Equation 2, the absorbed dose rates were calculated and the results with the measures of location (mean and median) are presented in Table 2.

In order to determine the outdoor effective dose rates, two factors including conversion factor and outdoor occupancy factors are employed. The conversion factor (0.7 SvGy^{-1}) converts the absorbed dose rates in air to radiological human outdoor effective dose rates and the occupancy factor (0.20) which on average translates to 20% of the total time every individual is exposed to outdoor radiation (UNSCEAR, 2000). The effective dose rate resulting from the absorbed dose rate values was calculated using (Jibiri *et al.,* 2009)

$$E_{ext} = TfQD_{ext}\varepsilon \qquad (3)$$

where: E_{ext} is the effective dose rate (μSvy^{-1}), T *is the* time (8766 hy^{-1}), f *is* the outdoor occupancy factor, Q *is* the factor that converts absorbed dose rate in air to the effective dose rate, ε is the factor converting nano (10^{-9}) into micro (10^{-6}) and $D_{ext}$is the absorbed dose rate in air (nGyh^{-1}).Using equation 3 the effective dose ratewas calculated and the results (range, mean, median)are presented in Table 2.

Radiological Hazard Indices

Radium equivalent

The radium equivalent (Ra_{eq}) is commonly used as an index to compare the specific activity concentrations of radionuclides in sample matrices. It is an equivalent gamma dose rate based on the sum of the weighted activity of 130 Bqkg^{-1} for ^{40}K, 10 Bqkg^{-1} for ^{238}U (^{226}Ra) and 7 Bqkg^{-1} for ^{232}Th that will deliver by the sample matrices (Shiva *et al.*, 2008). The radium equivalent was calculated using the relation (Nwankwo et al., 2015):

$$Ra_{eq} = 0.077A_K + A_{Ra} + 1.43A_{Th} \qquad (4)$$

where A_K, A_{Ra} and A_{Th} are the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in Bqkg^{-1} respectively. Using Equation 4,the radium equivalent was determined and the results (minimum, maximum, mean and median) are presented in Table 2.

Gamma index

The gamma index (I_γ) referred to as representative index is a hazard parameter used to correlate the annual dose rate due to the excess external gamma radiation caused by any superficial materials. The index is used to estimate the radiation hazard levels related to the natural radionuclides present in the samples. It is also used as screening tool for identifying materials that might be threat to human health when used for building construction (Tufail *et al.,* 2007). The European Commission (EC) (1999) proposal was used to calculate gamma index as:

$$I_\gamma = \frac{A_K}{3000} + \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} \qquad (5)$$

where A_K, A_{Ra} and A_{Th} are the activity concentrations (Bqkg^{-1}) of ^{40}K, ^{226}Ra and ^{232}Th respectively. The gamma index was determined using Equation 5 and the results are presented in Table 2.

External hazard index

The external hazard index (H_{ex}) is used to measure the external hazard due to the emitted natural gamma radiation. It is an important criterion used to assess the radiological suitability of a material for building purposes and it was calculated using the relation (Yang et al., 2005):

$$H_{ex} = \frac{A_K}{4810} + \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} \qquad (6)$$

whereAK, ARa, AThare the activity concentrations (Bqkg^{-1}) of ^{40}K, ^{226}Ra and ^{232}Th respectively. Using Equation 6,the external index was calculated and the results are presented in Table 2.

Internal hazard index

In addition to the external hazard index, the human respiratory organs are subjected to threat due to inhalation of gaseous radon (^{222}Rn), the decay product of radium (^{226}Ra). The internal hazard index (H_{in}) is a means to reduce the maximum permissible ^{226}Ra activity concentration to one half of the value appropriate for external exposure (Ahmed and El-Arabi, 2005). The internal exposure to radon and its progeny products is quantified by estimating the internal hazard index using equation (Beretka *et al.,* 1985):

$$H_{in} = \frac{A_K}{4810} + \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} \qquad (7)$$

where A_K, A_{Ra} and A_{Th} are the activity concentrations of ^{40}K, ^{226}Raand ^{232}Th in Bqkg^{-1}, respectively. Using Equation 7, the internal hazard index was calculated and the results are presented in Table 2.

Table 2: Absorbed dose, effective dose, radium equivalent, gamma index, external and internal hazard indices due to radioactivity in the soils from the study area

	D_{ext}(nGyh^{-1})	E_{ext}(mSvy^{-1})	Raeq (Bqkg^{-1})	H_{in}	H_{ex}	I_γ
Minimum	45.75	0.06	127.70	0.34	0.40	0.49
Maximum	99.17	0.12	261.89	0.71	0.96	0.94
Mean±δ	71.45±15.58	0.09±0.02	197.2±36.8	0.70±0.14	0.53±0.10	0.73±0.14
Median	73.28	0.09	200.03	0.54	0.74	0.73

Table 3: Comparison of activity concentrations in the soil samples with other regions

^{40}K (Bqkg^{-1})	^{226}Ra (^{238}U) (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	Region (Country)	Reference
14.6-344.9	8.2-68.4	5.9-77.2	West coast of	Karunakara
(152.2)	(30.6)	(38.2)	India	*et al.* (2005)
40-800	10-200	3-60	Republic of	Mc-Aulay and
(350)	(60)	(26)	Ireland	Moran (1988)
48-1570	13-165	7-204	Spain	Baeza *et al.* (1992)
(650)	(46)	(49)		
440-913	40.2-442	32.6-88.1	China	Yang *et al.* (2005)
(672)	(112)	(71.5)		
1015.5-1484.9	82.3-166.9	151.9-275.6	Turkey	Merdanoglu and
(1207)	(115)	(192)		Altinsoy (2006)
303-945	21.5-48.0	22-59	Punjab Pakistan	Tahir *et al.* (2005)
(615)	(35)	(41)		
584.8-696.1	28.8-36.5	49.9-58.4	Bahawalpur	Matinllah *et al.* (2004)
(646.4)	(32.9)	(53.6)	Pakistan	
100-700	8-160	4-130	World average	UNSCEAR (2000)
(420)	(32)	(40)		
364.7-1329.0	19.9-94.1	25.3-87.8	Alabata	Present study
(829.1)	(61.7)	(50.1)	Abeokuta	

* Numbers in parenthesis are the mean values

Discussion and Conclusion

As could be seen from Table 1, the activity concentrations of ^{40}K ranged from (364.7 to 1329.0) Bqkg^{-1} with an average value of 829.1±260.6 Bqkg^{-1}, 19.9 to 94.7 Bqkg^{-1} for ^{238}U with an average value of 61.7±21.8 Bqkg^{-1} and 25.3 to 87.8 Bqkg^{-1} for ^{232}Th with an average value 50.1±16.6 Bqkg^{-1}.

In Nigeria, the radioactivity levels in the soils from few locations have been measured and reported. Jibiri and Bankole (2006) reported 219.8 Bqkg^{-1} for ^{40}K, 20.3 Bqkg^{-1} for ^{226}Ra and 21.1 Bqkg^{-1} for ^{232}Th in soil samples from Ibadan and Egunyinka, *et al.* (2009) reported 261.37 Bqkg^{-1} for ^{40}K, 50.01 Bqkg^{-1} for ^{238}U and 84.6 Bqkg^{-1} for ^{232}Th in soil samples from the University of Ibadan. All these reported values were lower than the values obtained in the study. Gbadebo (2011) reported lower mean activity concentrations of 61.86±6.34 Bqkg^{-1}, 11.07±3.46 Bqkg^{-1} and 13.29±4.81 Bqkg^{-1} for ^{40}K, ^{238}U and ^{232}Th respectively in Alabata Abeokuta. However Farai and Jibiri (2000) reported higher mean activity concentrations of 83±18 Bqkg^{-1} and 218±70 Bqkg^{-1} for ^{238}U and ^{232}Th respectively in Abeokuta. This showed that the radioactivity levels in Abeokuta varied and the variations may be attributed to the different geology of sampling locations.

A comparison of the radioactivity levels in the results with other countries (Table 3) indicates that the ^{226}Ra (^{238}U) and ^{232}Th activity concentrations reported by Yang et al, (2005) and Merdanoglu and Altinsoy (2006) were higher than the values recorded in the study. However the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th radionuclides in soil samples from the remaining countries shown in Table3 were lower than the levels in the study.

The absorbed dose rates as could be seen from the Table 2 ranged from (45.75 to 99.17) nGyh^{-1} with a mean value of 71.45±15.58 nGyh^{-1}. The mean absorbed dose rates in the study was higher than 28.9 nGyh^{-1} reported for Abeokuta (Okedeyi *et al.*, 2012) and higher than world average value of 59 nGyh^{-1} (UNSCEAR, 2000)

The outdoor effective dose rates in the study shown in Table 2 ranged from (0.06 to 0.12) mSvy^{-1} with a mean value of 0.09±0.02 mSvy^{-1}. The effective dose was higher than the world permissible limit of 0.07 mSvy^{-1}(Ajayi and Ibikunle 2013)

The radium equivalent (Raeq) obtained and shown in Table 2, ranged from (127.70 to 261.89) Bqkg^{-1} with an average value of 197.2±36.8 Bqkg^{-1}. The mean radium equivalent activity value in the study was lower than the value of 350±270 Bqkg^{-1} reported for Jos (Jibiri *et al.,* 2009) but within the world permissible limit of 370 Bqkg^{-1} (UNSCEAR, 1988).

As shown in the Table 2, the gamma index ranged from 0.49 to 0.94 with a mean value of 0.73±0.14. The gamma index in the study conformed to the criterion I_γ 1 (Turhan et al., 2008) It could be observed from the Table 2, that the external hazard index ranged from 0.40 to 0.96 with a mean value of 0.53±0.10. However the maximum allowed external hazard index value corresponds to the upper limit of Raeq 370 Bq kg-1 is determined as

$$H_{ex} \otimes \frac{Ra_{eq}}{370}$$

that is Hex 1). This is an indication that the calculated external hazard index in the study conformed to the criterion of Hex 1

The internal hazard index from Table 2 ranged from 0.34 to 0.71 with an average value of 0.70±0.14. For radiological safety precautions in the use of materials for construction of dwellings, the criterion recommended is that Hin 1. The mean value of internal hazard index obtained in the study was less than one and conformed to the criterion of Hin 1. However radiological hazard indices are the sum of the hazard quotients due to all radionuclides to which an individual is exposed. And according to Xinwei *et al,* (2006) any component of radiation hazard indices that is within the world recommended criterion suggests no hazard and detrimental health impacts including cancers are expected to occur.

The activity levels of ^{40}K, ^{238}U and ^{232}Th, gamma absorbed and effective dose rates; and radiological hazard indices have been determined in the soil samples from the study area. The results revealed that theradiological hazard indices in the study were within the world permissible limits for building materials. Therefore the soils from the study area may be considered safe for building constructions.

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