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Assessment of Natural Radionuclides Concentrations and Radiological Hazards from Soil Samples in Alabata and Its Environs, Ogun State, Southwestern Nigeria

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ABSTRACT

The natural occurring level of radioactivity in any soil is one of the main causes of external gamma exposure. The activity concentrations of natural radionuclides from soils in granitic area of Alabata, southwest Nigeria were determined with the aim of knowing the levels and evaluating the radiological hazards. Soil samples were collected and analysed by gamma-ray spectrometry method utilizing NaI scintillation detector. Results show that the ranges (and the conforming average values) of the estimated activity concentrations for ^{238}U, ^{232}Th and ^{40}K are 6.46 ± 0.00 to 66.57 ±15.05; 211.56 ± 96.10 to 6.46 ± 0.00, and 211.56 ± 96.10 to 470.02 ± 91.28 Bq/Kg, respectively. 238U was mostly below detection limits (BDL) All the estimated radiological hazards were observed to be within the threshold limit of 370 Bq/kg, 60 nGy/h per UNSCEAR standards, 1 mSv/yr, 1.45 × 10^{-3}, and 1 for radium equivalent activity, absorbed dose rate, effective dose, excess life cancer risk, and external and internal hazard index respectively as recommended by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Specifying that ^{238}U was mostly below detection limits (BDL). Further investigation into the levels and radiation exposures of quarry soils within the vicinity of the study area is highly suggested.

Keywords:
Soil samples,
Radiation exposure,
Radiological hazards,
Natural radionuclides,
Gamma ray spectrometry,
Activity concentrations.

INTRODUCTION

Naturally occurring radionuclides such as potassium, uranium, thorium, and their progenies are sources of radiation exposure to humans (Masok et al 2018, Aladeniyi et al 2019, Beogo et al 2022). These terrestrial radionuclides exist in various geological formations and environmental media such as soil, rock, plant, and water (Nguelem et al 2016, Beogo et al 2022). Naturally, the levels of these primordial radionuclides in soil vary from one region to another due to the geological and mineralogical characterization of an area (Navas et al 2002, Mehra et al 2010 Ferdous et al., 2015). Natural radioactivity level in the environment is also enhanced by anthropogenic sources such as mining and industrial activities (Galhardi et al., 2017; Orosun et al., 2019). Hu et al. (2010) and Joel et al. (2021) chronicled several anthropogenic sources of natural radionuclides in the environment. In environmental monitoring and protection, radionuclides measurements in the environment are essential in ensuring human exposure is as low as reasonably achievable (ALARA) . According to ICPR, 1991

Several studies have reported radionuclide variation with various geological formations globally, which has led to regional environmental studies around the world (Odoh et al., 2018; Missimer et al., 2019; Adewoyin et al., 2022). Gbadebo (2011) measured radionuclide levels in rocks and soils of the non-quarry site of Alabata but, the findings from. The abundance of ^{40}K and low radiological level observed is said to be due to the abundance of granite rocks. Similarly, Olabamiji et al. (2020) reported mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in the Basement complex part of Abeokuta, Nigeria to be 829.1260.6 Bq/kg, 1.721.7 Bq/kg, and 50.116.6 Bq/kg, respectively, which are higher than the 400 Bg/kg, 35 Bq/kg, and 30 Bq/kg threshold levels recommended by (UNSCEAR, 2000). The absorbed gamma and effective dose rates were also observed to be 21.1% and 28.6% higher than the world average values of 59 nGy/h and 0.07 mSv/y using gamma

spectrometry. Albata granitic geology is significant for radionuclide studies because granites have naturally high concentrations of radionuclides, particularly ^{40}K, ^{232}Th and ^{238}U). These elements are often concentrated in minerals like K-feldspar, zircon, and apatite, which are common in granite, making it a key geological type for studying natural radioactivity and its radiological hazards Therefore, this study seeks to investigate the levels of naturally occurring radionuclides in Alabata soils together with its corresponding radiological effect in humans within the study area.

MATERIALS AND METHODS

Description of the Study Area

The study area is located within the latitude 7° 19' 0" and 7° 30' 0" North and longitude 3° 30' 0" and 3° 55' 0" East (Figure 1). The research area is located within the humid tropical region associated with high precipitation and rainforest vegetation (Olurin et al., 2021). Alabata, which lies within the Basement complex rock of Abeokuta, comprises varieties of gneisses and older granites, along with granites and sedimentary rocks. The dominant rock type underlies the study area as well as the soil sampling points are shown in Figure 1

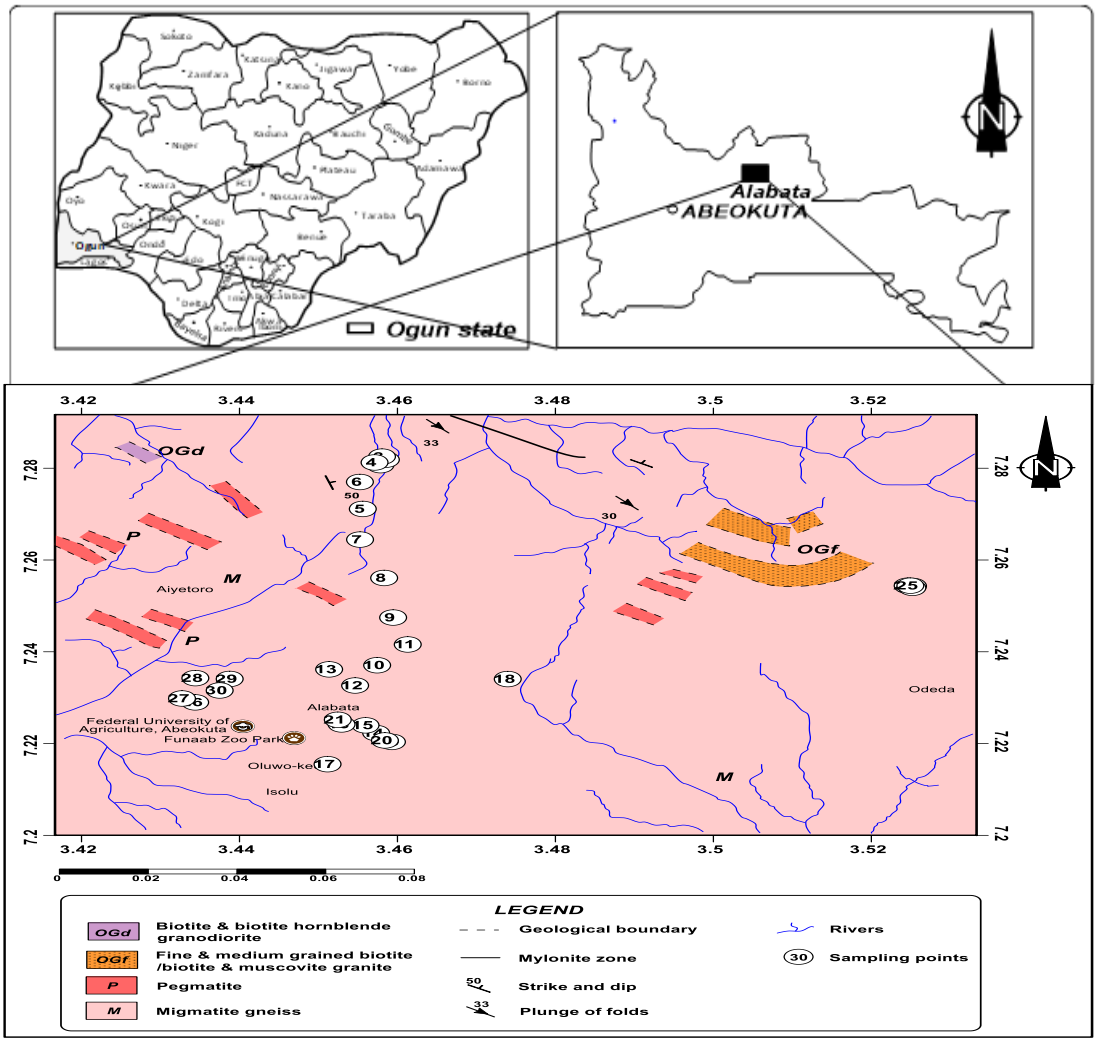

Figure 1: Geological Map of the Study Area Showing the Soil Sampling Points

Sample Collection and Preparation

Soil samples were collected randomly from different location within Alabata area of Abeokuta, Ogun State, due to the lithological homogeneity of the area (Navas *et al.*, 2011). A global positioning system was used to measure the location's coordinates before collecting surface soil samples (0 -30 cm). The collected soil samples were packed into a well-labeled polythene bag for proper identification and further preparation before analysis. Soil samples were weighed, dried, crushed into a fine powder, sieved with a 2mm mesh screen to obtain a fine-grained homogenous soil sample. A mass of about 200g from each of the dried/sieved sample was put inside a plastic container, sealed with paper cellotape (airtight containers to prevent the escape of ^{220}Rn and ^{222}Rn) and then kept for 30 days in order to bring the daughter

radionuclides into secular equilibrium with their respective long-lived parents (Jibiri and Okeyode, 2011; Beogo et al., 2022).

Experimental Method

Gamma ray spectrometric analysis of soil samples was done using a well shielded Na (TI) detector. The detector is coupled to a computer based multichannel analyser (MCA) system, with maestro 2000 software used for data acquisition and spectra analysis. The Na (TI) detector used for gamma spectrometry is available at the Physics Department, Federal University of Agriculture, Abeokuta, Nigeria, with the necessary energy and efficiency calibration done using IAEA standard source. Each sample was counted for 10,800 seconds and activity concentration of ^{232}Th and ^{238}U was determined using the gamma lines of their decay products: ^{214}Bi (1764.5 keV) and ^{208}Ti (2614.5 keV), respectively while the activity concentration of ^{40}K was determined using its 1460 keV gamma lines. Activity concentrations A (Bq/kg) of the three naturally occurring radionuclide was calculated using (1)

$$A(BqKg^{-1}) = KA_n \quad (1)$$

Where A_n the count rate under the corresponding peak is, $K = \frac{i}{\varepsilon \rho_\gamma M_s}$ is the efficiency of the detector at specific gamma-ray energy, ρ_γ is the absolute transition probability of the specific gamma-ray, M_s is mass of the sample

Radium Equivalent

Radium equivalent provides the weighted sum of the activities of the three naturally occurring radionuclides (Beogo et al., 2022). It is based on the estimation of 1Bq/kg of ^{226}Ra, 0.7 Bq/kg of ^{232}Th, and 13 Bq/Kg of ^{40}K produce the same radiation dose rates as presented in (2).

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

A_{Ra}, A_{Th}, and A_K are the activity concentrations of ^{226}Ra(^{238}U), ^{232}Th and ^{40}K, respectively. The use of material whose concentration exceeds 370Bq/kg is discouraged to avoid radiation hazards

Human Health Risk Assessment

Human health risk to radionuclides is assessed using some of the quantities and units used for assessing dose exposure to ionizing radiation and its biological effectiveness such as absorbed dose rate in air, annual effective dose equivalent, excess lifetime cancer risk, and radiation hazard indices. They provide a useful guideline for local and international regulatory authorities for proper environmental monitoring and protection.

Absorbed Dose Rate

The absorbed dose rate in air due to terrestrial gamma rays at 1 m above the ground level, which is used to measures the amount of radiation deposited per unit time is estimated from the activity concentration of ^{226}Ra(^{238}U), ^{232}Th and ^{40}K using (3 (UNSCEAR, 2000; Odoh et al., 2018; Beogo et al., 2022).

$$D\left(\frac{nGy}{hr}\right) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (3)$$

Where D (nGy/h) is the absorbed dose rate, A_{Ra}, A_{Th}, and A_K are the activities concentrations of ^{238}U, ^{232}Th and ^{40}K, respectively.

Annual Effective dose Equivalent (AEDE)

The absorbed dose rate in air does not provide the radiological risk to which an individual is exposed. Therefore, annual effective dose due to terrestrial radionuclide is also estimated using the dose conversion factor (0.7 Sv/Gy) and an outdoor occupancy factor of 0.2 to convert absorbed dose rate in air to effective dose using (4) (UNSCEAR, 2000) .

$$AEDE\left(\frac{mSv}{yr}\right) = D\left(\frac{nGy}{hr}\right) \times 8760 \times 0.2 \times 0.7\left(\frac{Sv}{Gy}\right) \times 10^{-6} \quad (4)$$

International Commission on Radiation Protection recommends 1mSy/yr for members of the public to avoid radiological health effects (Ajayi *et al.*, 2017).

Excess Life Cancer Risk (ELCR)

Excess life cancer risk is used to express the probability of developing cancer over a lifetime at a given exposure level (Jibiri and Okeyode, 2011). It is estimated from the annual effective dose equivalent using risk factor for stochastic effects (0.05 Sv-1) and average duration of life estimated to be 70 years using (5) (Qureshi *et al.*, 2014).

$$ELCR = AEDE \times 70 \times 0.05 \quad (5)$$

External and Internal Hazard Index

External and internal hazard index are used to quantify the effect of radon, a progeny of radium and its short-lived products to the respiratory organs. They are estimated using (6) and (7) respectively

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

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

The values of both hazard indices must be less than unity for the radiation hazard to be negligible (Taskin *et al.*, 2009; Beogo et al., 2022).

RESULTS AND DISCUSSION

The results of activity concentrations of naturally occurring radionuclides in the soil samples from the study area are presented in Table 1 along with its corresponding radium equivalent. The average activity concentration of ^{238}U, ^{232}Th, and ^{40}K in all the sampled locations range from below the detectable limit (BDL) to 6.46 ± 0.00, 66.57 ± 15.05 to 92.45 ± 53.67 and 211.56 ± 96.10 to 470.02 ± 91.28 respectively. The low concentrations of ^{238}U of the soil samples within the study area could be as a results of geochemical processes

like weathering and metamorphism which cause the mobilization and leaching of uranium from the source rock. Table 2 presented the estimated average absorbed dose, annual effective dose, excess lifetime cancer risk, external hazard index, and internal hazard index. The average absorbed dose, annual effective dose, excess life cancer risk, external hazard index, and internal hazard index were observed to vary from 52.66 ± 9.76 to 75.44 ± 30.88, 64.59 ± 11.97 to 92.52 ± 37.87, 226.06 ± 41.89 to 323.81 ± 132.54, 0.32 ± 0.06 to 0.46 ± 0.20, and 0.32 ± 0.06 to 0.46 ± 0.20 in all the sampled locations, with mean values of 65.05 ± 10.24, 79.78 ± 12.56, 279.22 ± 43.96, 0.40 ± 0.06, and 0.40 ± 0.06 respectively. The activity concentrations of ^{40}K and ^{232}Th in the study area is presented in figures 2 and 3, respectively as spatial maps and it ranges from 29.36 Bq/kg to 1038.66 Bq/kg and 13.42 Bq/kg to 272.76 Bq/kg with mean values of 352.00 ± 40.96 and 83.23 ± 0.22 for ^{40}K and ^{232}Th respectively.

Table 1: Activity Concentration of ^{238}U, ^{232}Th and ^{40}K in Soils of Alabata and Environs

Locations	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Raeq (Bq/kg)
A	6.46 ± 0.00	83.47 ± 21.94	378.07 ± 60.14	148.84 ± 34.53
D	BDL	66.57 ± 15.05	298.77 ± 34.04	118.19 ± 22.72
F	BDL	88.40 ± 42.06	211.56 ± 96.10	142.70 ± 66.21
Q	BDL	92.45 ± 53.67	470.02 ± 91.28	168.39 ± 73.82
Average	6.46 ± 0.00	83.23 ± 15.36	352.00 ± 40.96	146.34 ± 23.70
UNSCEAR (2000)	30	35	400	370

BDL implies below detection level (1.0 Bq/kg)

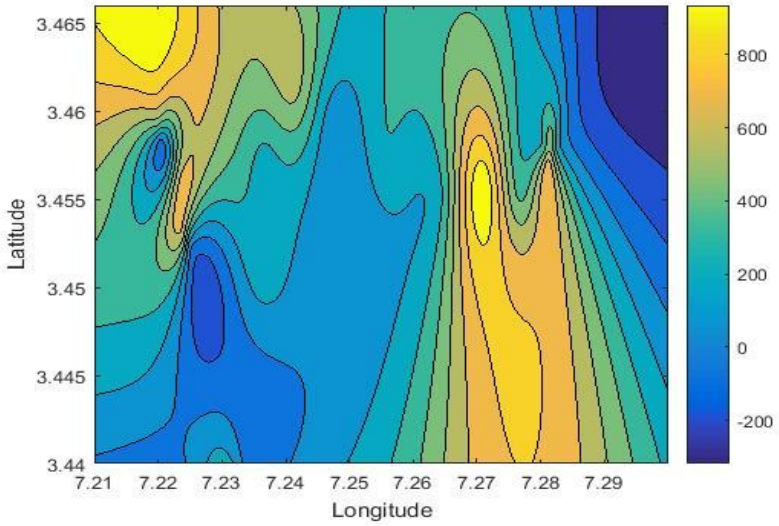

Figure 2: Activity Concentration of Potassium in Alabata and its Environs

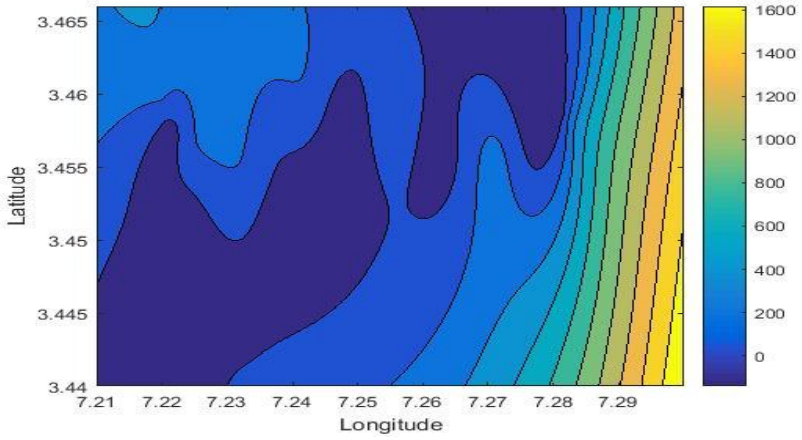

Figure 3: Activity Concentration of Thorium in Alabata and its Environs

Table 2: Estimated Absorbed dose, Effective dose, Excess Life Cancer Risk, INTERNAL and External Hazard Index in Soils of Alabata and its Environs

Locations	Absorbed dose nGy/yr	Effective dose mSv/yr	ELCR	Hin	Hex
A	66.35 ± 14.98	0.08 ± 0.02	0.28 ± 0.06	0.40 ± 0.09	0.40 ± 0.09
D	52.66 ± 9.76	0.06 ± 0.01	0.23 ± 0.04	0.32 ± 0.06	0.32 ± 0.06
F	62.22 ± 28.71	0.08 ± 0.04	0.27 ± 0.12	0.39 ± 0.19	0.39 ± 0.19
Q	75.44 ± 30.88	0.09 ± 0.04	0.32 ± 0.13	0.46 ± 0.20	0.46 ± 0.20
Average	65.05 ± 10.24	0.08 ± 0.01	0.28 ± 0.04	0.40 ± 0.06	0.40 ± 0.06
UNSCEAR (2000)	60.00	1.00	1.45×10^{-3}	1.00	1.00

Discussion

The activity concentrations of naturally occurring radionuclides in all the sampled locations vary slightly due to the lithological homogeneity and potential anthropogenic influences of nearby quarry within the study area. The average activity concentration of ^{40}K is highest in location Q (470.02 ± 91.28 Bq/kg), which is above the UNSCEAR (2000) threshold level of 400 Bq/kg, while the lowest concentration was recorded in location D with average value of 298.77 ± 34.04 Bq/Kg. Similarly, ^{232}Th is found to have its highest activity concentration in location Q (92.45 ± 53.67), which is above the UNSCEAR (2000) threshold level of 35 Bq/kg and lowest activity concentration in location D (66.57 ± 15.05). It must be noted that the observed value of ^{232}Th activity concentration in location D was also above the UNSCEAR (2000) threshold level. ^{238}U was below the detection level in all the sampled locations except for location A with a value of 6.46 ± 0.00 Bq/kg.

The average values obtained for the activity concentrations of ^{40}K and ^{232}Th in all the sampled locations, were 352.00 ± 40.96 Bq/kg, and 83.23 ± 15.36 Bq/kg, respectively. The obtained averages are higher than the world's average value of 400, and 35 Bq/Kg for ^{40}K and ^{232}Th, respectively. The results showed that the average activity concentration of ^{238}U was 6.46 ± 0.00 Bq/kg in the study area, thus lower than the world's average value of 30 Bq/kg as reported by UNSCEAR (2000) unlike that of ^{40}K and ^{232}Th. This is in agreement with similar result obtained by Olabamiji *et al.* (2020). The abundance of ^{40}K in analysed samples might be due to the abundance of granite parent material in Alabata and its environs (Gbadebo, 2011; Olabamiji *et al.*, 2020; Jibiri and Okeyode, 2011).

Radium equivalent activity, absorbed dose rate, effective dose, excess life cancer risk, external and internal hazard index, used to assess exposure risk in all the sampled locations have their mean values as 146.34 ± 23.70 Bq/kg, 65.05 ± 10.24, 0.09 ± 0.01, 0.28 ± 0.04, 0.40 ± 0.06 and 0.40 ± 0.06, in respectively. All the estimated radiological hazard indices were observed to be within the threshold limit of 370 Bq/kg, 60 nGy/yr, I mSv/yr, 1.45×10^{-3} and 1 for radium equivalent activity, absorbed dose rate, effective dose, excess life cancer risk, internal and external radiation index, respectively as recommended by UNSCEAR (2000). The low radiological hazard indices imply there is no radiation exposure threat in the study area, making the surface soil safe for agricultural purposes, which is the principal occupation of its residents.

CONCLUSION

The study revealed that the activity concentrations of ^{0}K and ^{232}Th obtained in the soils of Alabata and its environs are obviously higher than the world average values recommended by UNSCEAR. Granite usually contains higher-than-average radioactive elements, but this study, the specific activity level of ^{238}U levels was five times lower than the world average which may be as a result near-surface weathering can leach uranium, reducing its concentration in the rock. The average values of assessed radiological indices are lower than the endorsed maximum limit values. The surface soils in the study area did not pose any serious radiological hazards to the inhabitants of the area. Further investigation can be conducted to examine the long-term health risks to nearby communities**.**

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