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Assessment of Natural Radioactivity and Radiological Hazard indices in Soil of Some Geological Formations in Sokoto Group of Sokoto Basin, Northwestern Nigeria

Dahiru Dahuwa[1] and Lawal Abba[2]*

[1]Depertment of Physics, Federal University of Health Sciences Azare, Bauchi State Nigeria
[2]Depertment of Physics, Al-Qalam University Katsina, Katsina State, Nigeria

*Corresponding Author's e-mail: mlabbadtm@gmail.com Phone: +2348031802231

ABSTRACT
This study measured and assessed natural radioactivity and radiological hazard indices associated with the soil of some geological formations of Sokoto group of Sokoto basin. Total of twelve soil samples from Dange and Kalambaina geological formations were collected and analysed using gamma ray spectroscopy of Center for Energy Resarch and Development (CERD), Ile-Ife. Generally, samples from Dange formation recorded higher values than those from Kalambaina. The overall mean values for the soil samples from the study area were 55.5545±4.22 Bqkg^{-1}, 120.2435±24.77 Bqkg^{-1}and 1972.793±10.98 Bqkg^{-1} for the radionuclides ^{238}U, ^{232}Th and ^{40}K respectively. These values are greater than worldwide average of 35 Bqkg^{-1}, 30 Bqkg^{-1} and 400 Bqkg^{-1}. Out of the seven radiological parameters evaluated only absorbed dose rate, radium equivalent and external hazard index with recorded values of 180.56 nGyhr^{-1}, 1.02 and 377.43 Bqkg^{-1} are the only parameters with values slightly higher than their respective recommended safety limits. In the meantime, use of soil from the studied area may not pose any immediate health hazard to the populace, hence, can safely be used for building and farming activities while continuous radioactivity monitoring should be conducted for the entire Sokoto basin.

Keywords: Natural radioactivity, Geological formation, Sokoto Basin, Gamma spectroscopy, Health hazard

1.0. INTRODUCTION

The world is naturally radioactive and about 90% of human radiation exposures arise from natural sources such as cosmic radiations, exposure to radon gas, and terrestrial radiations (UNSCEAR, 2008). Though, radiation plays an important and sometimes vital role in our everyday lives, concern on the environmental pollution caused by radiations has increased in the recent years (Muhammad and Abbasi, 2025). Studies on radiation levels and radionuclide distribution in the environment provide vital radiological baseline information (Durusoy and Yildirim, 2017).). Such information is essential in understanding human exposure from natural and manmade sources of radiation and necessary in establishing rules and regulations relating to radiation protection (Abba *et al.*, 2016). Naturally occurring radioactivity materials (NORMS) acknowledged as the largest source of exposure to human health (UNSCEAR, 2000). Gamma radiations from radionuclides with half-lives comparable to the age of the earth such as K-40 and radionuclides from Th-232 and U-238 series and their decay products are the main contributors of external source of irradiation to human body. Average crustal abundances of these elements quoted in the literature are in the range 2-2.5% K, 8-12 ppm Th and 2-3 ppm U. (IAEA., 2003). The nuclides existing in bedrock are

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weathered off; chemically or physically and through transportation are finally deposited in lakes or seas. Other human activities such as, mining and cement processing increases the concentration both in end products or wastes to produce technologically enhanced naturally occurring radioactive materials (TENORM). These radionuclides contribute to enhanced radiations exposure to humans and biota (William, 2012).

Natural environmental radioactivity and the associated external exposure due to the gamma radiation depend primarily on the geological and geographical conditions and appear at different levels in the soils of each region in the world. The study of the distribution of the primordial radionuclides (^{40}K, ^{232}Th and ^{238}U) and their daughters allows the understanding of the radiological implications of these elements due to the ɣ-ray exposure in the body (William, 2012). According to geological formation, the distribution of radioactivity in soil varies with the type of rock from which the soil is derived and with its geological composition (UNSCEAR, 2000). Radiation exposure in soil sediments can be divided into external and internal exposures. The external exposure is caused by direct gamma radiation, from the nuclei in the soil sediments whereas the internal exposure is caused by the inhalation of radioactive inert gas such as radon ^{222}Rn, a daughter product of ^{238}U and its short lived secondary decay products (Abba *et al.*, 2020). Determination of specific activity levels primordial radionuclides (^{40}K, ^{232}Th and ^{238}U) in soil sediments is crucial in estimating various radiological parameters. Some recent research has been reported on potential health risk associated with naturally occurring radioactive materials which are present in a variety of environmental media (Muhammad and Abbasi, 2025: AlZahrani, 2022: Avwiri, 2005: Wiiliams, 2012: Sa'idu: Andzej, 2011).

This study aims at determination of natural radioactivity concentrations and risk assessment in soil from Sokoto group of Sokoto basin. The results of this study provides a baseline data for natural radioactivity in the study area.

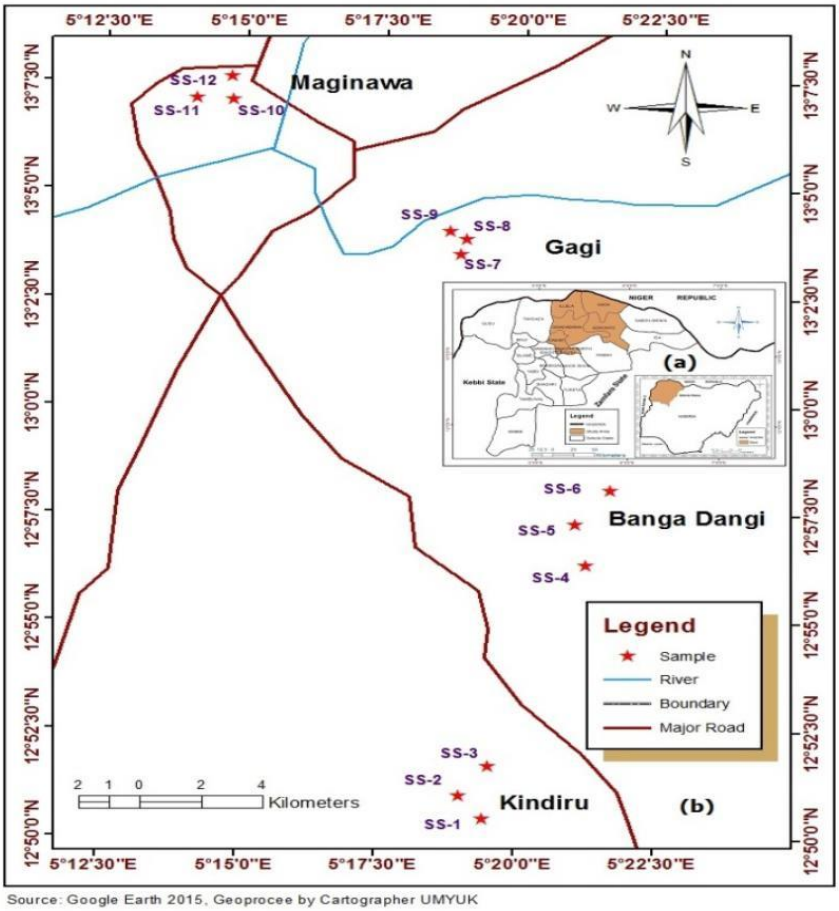
2.0. MATERIALS AND METHOD

2.1. Study area

The Sokoto Group is a major sedimentary sequence within the Sokoto Basin, an extension of Iullemmeden in northwestern Nigeria. It consists mainly of Late Cretaceous to Paleogene sedimentary rocks deposited in shallow marine and continental environments (Adegoke, *et al.*, 1978). The group records a major marine transgression and regression, making it important for reconstructing the geological history of the region (Kogbe, 1979). Geological formations of Sokoto group contain economically important mineral resources such as limestone, phosphate, gypsum, and clay, and they also serve as important groundwater reservoirs (Obaje 2009). The group is commonly subdivided into several formations, including Dange formation (shales and mudstones), Kalambaina formation (limestone-rich deposits), Taloka formation (sandstone and siltstone), Dukamaje (fossiliferous shale and limestone) and Gamba formation (clays and shales) (Kogbe, 1979). These formations contain economically crucial mineral resources such as limestone, phosphate, gypsum and clay. They also serve as important aquifers (Albert *et al.*, 2016)

2.2. Sample collection, preparation and analysis

Samples of soil were collected from four selected localities, two each from geological Dange and Kalambaina geological formations of Sokoto group. Three soil sediments samples were collected by stratified random sampling from each sampling location (Figure 1).



Source: Google Earth 2015, Geoprocee by Cartographer UMYUK

Figure 1: Map of Nigeria, Showing Sokoto Basin in Relation to the Scope of the Study. Inset: Location of (b) Simplified Geographical Map of Sokoto Group Showing the Sampling Locations and Points

The samples were labeled at the point of collection and geographical coordinates recorded, Table 1. At each sampling point soil of about 1 kg was collected and put in a well labeled polythene bags. The samples were transported to the laboratory for analysis at the Center for Research and Development (CERD), Obafemi Awolowo University (OAU) Ile Ife, Osun State.

Table 1: Locations and geological information of the soil samples

Location for soil samples	Elevation(m)	Latitude (N)	Longitude (E)	Geology information
1.Kindiru				Dange formation
A. SS1	333	12°56'19.7"	005°21'14.8"	Shale with mud
B. SS2	334	12°56'19.0"	005°21'16.4"	Phosphatenodular
C. SS3	335	12°56'19.2"	005°21'17.1"	Shale
2.Banganangi				Dange formation
A. SS4	341	12°50'54.8"	005°19'29.3"	Phosphate nodule
B. SS5	349	12°50'55.0"	005°19'30.0"	Phosphate nodule
C. SS6	346	12°50'55.8"	005°19'30.1"	Shale
4.Gagi				Kalambaina formation
A. SS7	281	13°03'24.5"	005°18'37.0"	Phosphate
B. SS8	283	13°03'24.0"	005°18'40.3"	Shale
C. SS9	286	13°03'22.0"	005°18'42.8"	Shale with Phosphate

3.Maginawa				Kalambaina formation
A. SS10	250	13°07'24.5"	005°14'45.5"	Phosphate
B. SS11	254	13°07'24.0"	005°14'45.5"	Shale
C. SS12	256	13°07'22.0"	005°14'43.5"	Silt stone

The samples were dried in a tray at room temperature in the laboratory. Each sample was then pulverized using crushing machine into powder at (CERD), Obafemi Awolowo University (OAU) Ile Ife sieved with a 1 mm mesh to obtain homogenized samples and packed in cylindrical plastic container. The samples were carefully weighed to about 300-350 g each and then sealed with a masking tape (Kolo 2014). The containers were hermetically sealed to ensure $^{222}_{86}Rn$ and $^{220}_{86}Rn$ does not escape consistent with procedure adopted in Williams (2012). The samples were stored for a month to achieve secular equilibrium between ^{232}Th and ^{238}U and their progeny for the Gamma Spectrometry.

The activity concentrations of the natural radionuclides in the soil samples were determined using a well calibrated 76 mm x 76 mm NaI(Tl) scintillate detector (Bicron Corp model 3M/3) shielded from background radiation by a 5 cm thick Lead shield located at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife. The detector was coupled with a preamplifier (Bicon Corp Model PA-14), an amplifier (Canberra Model 2022), and an analogue-to-digital converter (ADC) (Canberra Model 8075) and multichannel analyzer (MCA) card slotted in a desktop computer. The output is displayed on the desktop through a Canberra S100 multichannel analyzer (MCA) software. Standard sample with reference number IAEA-375 for radionuclides and trace elements from International Atomic Energy Agency (IAEA), Vienna, Austria was used for the detector calibrations. The gamma-ray energy lines of 1460 keV for ^{40}K; 1120.30 keV for ^{214}Bi; and 911keV for 228Ac were used to measure activity concentration of ^{40}K; ^{238}U and ^{232}Th, respectively. The system was preset to 25,200 seconds counting time. The activity concentrations for a particular radionuclide in the measured samples were evaluated using the following equation 1 (Gambo, 2014).

$$C = \frac{A}{t\epsilon m p_\gamma} \quad (1)$$

Where A is the net area of the peak, t is the counting time in seconds, m is the mass of the sample, ϵ is the detection efficiency at the energy line and pγ is the gamma yield. This method requires the variation of detection efficiency.

Specific activity of a radioisotope is obtained by direct comparison with the same radionuclide in a given standard. The specific radioactivity C_x in the sample and the corresponding specific radioactivity C_s in the standard are related via equation 2, (Gambo, 2014).

$$C_x = \frac{m_s A_x}{m_x A_s} \quad (2)$$

Where x denote the sample, s the standard, while m and A, are the mass and the net area under the peaks respectively.

2.3. Radiological hazard parameters

2.3.1. Dose Rate

The absorbed dose at 1 metre above the ground was calculated from the measured activities of ^{40}K, ^{232}Th and ^{238}U in sediments samples, Equation 3 (Ramasamy, 2009; UNSCEAR, 2000).

$$D\ (nGyh^{-1}) = 0.462C_U + 0.604C_{Th} + 0.0417C_K \quad (3)$$

Where D is the absorbed dose rate and C_K, C_{Th} and C_U are the activity concentrations (in $Bqkg^{-1}$) of and ^{40}K, ^{232}Th and ^{238}U in the samples, respectively.

2.3.2. Annual Effective Dose Rate (AEDR)

The annual effective dose rates, $AED_\gamma(mSvy^{-1})$ were estimated, using equation 4 (Hafezi *et al.*, 2005).

$$AED_\gamma(mSvy^{-1}) = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (4)$$

where D is dose rate in $nGyh^{-1}$, the value 8760 are the hours in a year, the conversion coefficient from the absorbed dose in the air to the effective dose is 0.7 $SvGy^{-1}$ and outdoor occupancy factor is 0.2 as proposed by UNSCEAR, (2000).

2.3.3. Hazard Indexes

Radium equivalent activity, Ra_{eq} ($Bqkg^{-1}$), is the weighted sum of the activities of ^{40}K, ^{232}Th and ^{238}U based on the assumption that 10 $Bqkg^{-1}$ of ^{238}U, 7 $Bqkg^{-1}$ of ^{232}Th and 130 $Bqkg^{-1}$ ^{40}K deliver equal gamma dose rates and it was evaluated using equation 5 (Tufail *et al.,* 2007). Internal and external hazard indexes (H_{in} and H_{ex}) and Radium equivalent activity, were calculated respectively, through equations 6 and 7 (UNSCEAR 2000: Osoro, *et. al.,* 2011).

$$Ra_{eq} = \left(\frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810}\right) \leq 370 \quad (5)$$

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \leq 1 \quad (6)$$

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \leq 1 \quad (7)$$

Where $C_{K,}$ C_{Th} and C_U are the activity concentrations ($Bqkg^{-1}$), 370, 259 and 4810 are the permissible limit activity concentrations ($Bqkg^{-1}$) of ^{238}U, ^{232}Th and ^{40}K, respectively (ICRP, 1991). The stricker denominator for C_U (185 instead of 370 in internal index) reflects additional danger of radon inhalation (UNSCEAR, 2000).

Also, both gamma representative index (Iγ) and alpha representative index (Iα) were calculated through equations 8 and 9 respectively (Xinwei *et al.*, 2006).

$$I_\gamma = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_k}{1500} \leq 1 \quad (8)$$

$$I_\alpha = \frac{C_U}{200} \leq 1 \quad (9)$$

3.0. RESULTS AND DISCUSSION

The specific activities of the radionuclides detected in the twelve (12) soil samples collected from the four sampling locations, Table 2. The overall mean values for the soil samples from the study area were 55.5545±4.22 $Bqkg^{-1}$, 120.2435±24.77 $Bqkg^{-1}$and 1972.793±10.98 $Bqkg^{-1}$ for the radionuclides ^{238}U, ^{232}Th and ^{40}K respectively. The recorded specific activity for the radionuclides ^{238}U, ^{232}Th and ^{40}K recorded values ranged 72.95±5.45 - 32.36±3.11 $Bqkg^{-1}$, 211.97±44.50 - 78.71±18.86 $Bqkg^{-1}$, and 3319.31±17.81 - 800.54±5.64 $Bqkg^{-1}$ for soil samples from Dange formation and 85.83±6.40 - 27.05±2.74 $Bqkg^{-1}$, 178.58±37.45 - 38.79±10.88 $Bqkg^{-1}$ and 2301.74±12.96 - 1450.87±9.01 $Bqkg^{-1}$ for soil samples from Kalambaina formation respectively. Generally, soil samples from Dange formation have higher specific activity for ^{238}U, ^{232}Th and ^{40}K compared to those from Kalambaina formation formation. This could be attributed to relatively higher phosphate content in soil of Dange than that of Kalambaina formations and phosphate is known to have relatively higher activity concentration (Andzej, 2022: AlZahrani *et al.*, 2011: Obaje 2014). Though, this result is higher than UNSCEAR, 2000 reported worldwide mean values of ^{238}U, ^{232}Th and ^{40}K activity concentrations were 35 $Bqkg^{-1}$, 30 $Bqkg^{-1}$ and 400 $Bqkg^{-1}$ respectively it is similar to the result for the study on natural radioactivity and risk assessment of Sokoto phosphate rock Northwestern Nigeria (Kolo 2014). All the seven radiological parameters evaluated only absorbed dose rate, radium equivalent and external hazard index with recorded values of 180.56 $nGyhr^{-1}$, 1.02 and 377.43 $Bqkg^{-1}$ are the only parameters with values slightly higher than their respective safety limit, Results of this study were compared with other relevant studies, Table 3.

Table 2: Activity Concentrations of the Natural Radionuclides ^{238}U, ^{232}Th and ^{40}K for the various samples studied

Geological formation	Sample Code	^{238}U (BqKg^{-1})	^{232}Th (BqKg^{-1})	^{40}K (BqKg^{-1})
Dange Formation	SS1	72.95±5.45	211.97±44.50	2625.72±14.26
	SS2	69.085±3.44	149.955±20.51	2972.515±10.22
	SS3	65.22±5.16	87.94±20.53	3319.31±17.81
	SS4	37.67±3.45	122.21±27.37	2065.03±11.95
	SS5	32.36±3.11	78.71±18.86	1063.19±7.02
	SS6	45.03±3.90	82.29±19.37	800.54±5.64
	Mean	**53.72±4.09**	**122.18±25.19**	**2141.05±11.15**
Kalmbaina Formation	SS7	27.05±2.74	63.49±15.83	1450.87±9.01
	SS8	50.74±4.16	140.28±30.44	1556.25±9.29
	SS9	85.83±6.40	178.58±37.45	2216.02±12.60
	SS10	69.61±5.26	87.01±20.56	1658.48±9.86
	SS11	33.36±3.20	38.79±10.88	2007.63±11.19
	SS12	54.29±4.36	142.20±30.98	2301.74±12.96
	Mean	**53.48±4.35**	**108.39±24.35**	**1865.17±10.82**
Overall Mean		**55.5545±4.22**	**120.2435±24.77**	**1972.793±10.98**

Table 3: Mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soils and radiological parameters compared with other studies and world mean

Radiological parameters	Qureshi et al., (2014)	Avwiri et al., (2014)	Bello (2018)	Bello, (2020)	Present study	RSL*
^{238}U (Bqkg^{-1})	51±1.3	4.76±0.14	26.84±8.94	62.73±23.14	55.55±4.22	35
^{232}Th (Bqkg^{-1})	70±1.5	3.92±0.02	59.99±19	90.66±16.04	120.24±24.77	30
^{40}K (Bqkg^{-1})	532±5.5	16.25±0.19	362±134.3	411.27±247	1972.79±10.98	400
D (nGyh^{-1})	87.47	5.2	64.77	100.89	180.56	≤59
AED_{γ}(mSvy^{-1})	0.92	6.4 × 10-3	0.67	0.124	0.22	≤1
Ra_{eq}(Bqkg^{-1})	190.89	10.84	141	224	377.43	≤370
H_{ex}	NA	0.03	0.6	0.61	1.02	<1
H_{in}	NA	0.05	0.7	0.78	0.57	<1
I_{γ}	NA	0.10	1.02	0.854	0.96	≤1
I_{α}	NA	NA	NA	0.310	0.23	≤1

Legend NA: Not available, RSL*: Recommended safety limit (ICRP 2007: UNSCEAR, 2000).

4.0. CONCLUSION

The activity concentration of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) in the soil samples from Dange and Kalambaina geological formations were measured by gamma ray spectroscopy. The results show that the activity concentrations of the three radionuclides in soil are above the recommended permissible standard. Samples from Dange formation of high phosphate bearing recorded were comparably higher values of activity concentration for the three radionuclides than Kalambaina limestone-rich soil. Absorbed dose rate, Ra_{eq}, H_{ex} are the hazard indices with values higher than worldwide average. However, use of soil from the studied area may not pose any immediate health hazard to the populace, hence, can safely be used for building and farming activities while continuous radioactivity monitoring should be conducted for the entire Sokoto basin.

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