

**Assessment of Human Exposures to Natural Sources of Radiation in Soils of the Cretaceous-Paleocene Formation of Sokoto Basin, Sokoto, Northwestern, Nigeria**Lawal Abba¹, A. Galadima², A. N. Baba – Kutigi³ and Musa Momoh⁴¹Katsina State, College of Nursing and Midwifery, Katsina, Nigeria²Center for Research, Federal University, Gusau, Zamfara State, Nigeria³Department of Physics Federal University, Dutsin – Ma, Katsina State, Nigeria⁴Department of Physics Usmanu Danfodiyo University, Sokoto, Nigeria.Corresponding author: mlabbadtm@gmail.com +2348031802231

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Abstract

Natural radioactivity is a source of continuous exposure to human beings. It originates from both extraterrestrial sources and radioactive elements in the earth's crust. The amount of radioactivity in soil varies geographically and geologically across the world. In Sokoto city and its environs, data on the levels of natural radioactivity in soils is absent. It was therefore considered imperative to measure the activity concentration of ^{226}Ra , ^{232}Th , and ^{40}K in soil samples collected from various areas of Sokoto. Activity concentrations were measured by means of Sodium Iodide gamma-ray spectrometry. A total of 12 surface soil samples were collected from around Sokoto city. The measured activity concentrations of these radionuclides were compared with the data reported worldwide. Mean measured activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K were $53.6 \pm 8.28 \text{ Bq kg}^{-1}$, $115.29 \pm 28.4 \text{ Bq kg}^{-1}$, and $2003.1 \pm 278.1 \text{ Bq kg}^{-1}$, respectively. Mean values of radium equivalent activity, air absorbed gamma radiation dose rate, and external radiation hazard index were $378.71 \pm 40.19 \text{ Bq kg}^{-1}$, $1.09 \pm 0.06 \text{ nGy h}^{-1}$, and 1.006 Bq kg^{-1} , respectively. The annual effective radiation dose was calculated to be 1.09 mSv y^{-1} . The result of this work has established the fact that soils from Sokoto contain enhanced level of gamma radiation that may be hazardous to the inhabitants of the area.

Keywords: Gamma - Ray Spectrometry; Soil; Radionuclides; Cretaceous–Maastrichtian; Sokoto Basin.

1.0 INTRODUCTION

The great interest expressed worldwide for the study of naturally occurring radiation and environmental radioactivity has led to the interest of extensive surveys in many countries (Alaamer, 2008). Natural sources still contribute almost 80% of the collective radiation exposure of the world's population (UNSCEAR, 1993). The concern on the environmental pollution caused by radiations has increased in the recent years. According to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2001) more data on exposures from natural, man-made and occupational sources at low levels are needed. Hereditary effects of radiation on human population are still not properly quantified (UNSCEAR, 2002). Studies on radiation levels and radionuclide distribution in the environment provide vital radiological baseline information (Dawood, 2011). 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 (Ibrahim *et al.*, 2006). There are many sources of radiation and radioactivity in the environment. Gamma radiation emitted from naturally occurring radionuclides, also called terrestrial background radiation, represent the main external source of irradiation of the human body. Human beings are exposed to radiation from sources outside their bodies; mainly cosmic rays and gamma ray emitters in soils, building materials, water, food, and air (Alaamer, 2008).

Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world (Dawood, 2011). Natural environmental radioactivity arises mainly from primordial radionuclides, such as ^{40}K , and the radionuclides from ^{232}Th - and ^{238}U -series, which occur at trace

levels in all ground formations (Tzortziset *et al.*, 2004). It is important to monitor the terrestrial background radiation mainly due to these natural radionuclides in soil. Several studies performed worldwide have measured the activity concentration of natural radionuclides in soil (Karahana *et al.*, 2000; Kebwaro, 2009; Ibrahim *et al.*, 2006; Jibiri and Agomuo, 2007; Fatima *et al.*, 2008;).

Uranium is a naturally occurring element that has been in rocks since the earth was formed. Not all rocks contain uranium, but there are some places in Montana where uranium is in the bedrock and in valley fill sediments that have eroded from the bedrock of the adjacent upland or mountainous areas. Uranium breaks down (decays) very slowly into other elements including radium and radon gas. These other elements are part of a sequence formed through a transformation (decay) process that begins with the most prevalent form of "natural" (unprocessed) uranium (U-238) (Umar, *et al.*, 2013). Abnormal occurrences of uranium and its decay products in rocks and soils and thorium in monazite sands are the main sources of high natural background areas that have been identified in several areas of the world. In addition to high level of external ionizing radiation, individuals living in high background radiation areas can be exposed internally especially through the intake of foodstuffs. Both routine and accidental releases of nuclear wastes result in radionuclides sipping into the environment and ground (Jibiri and Agomuo, 2007). Figure 1, demonstrates the key identified pathways for human and environmental exposure due to radionuclides. According to IAEA (1989), pathways to human populace include ingestion through food, agricultural activities, external exposures and through drinking water "Figure 1".

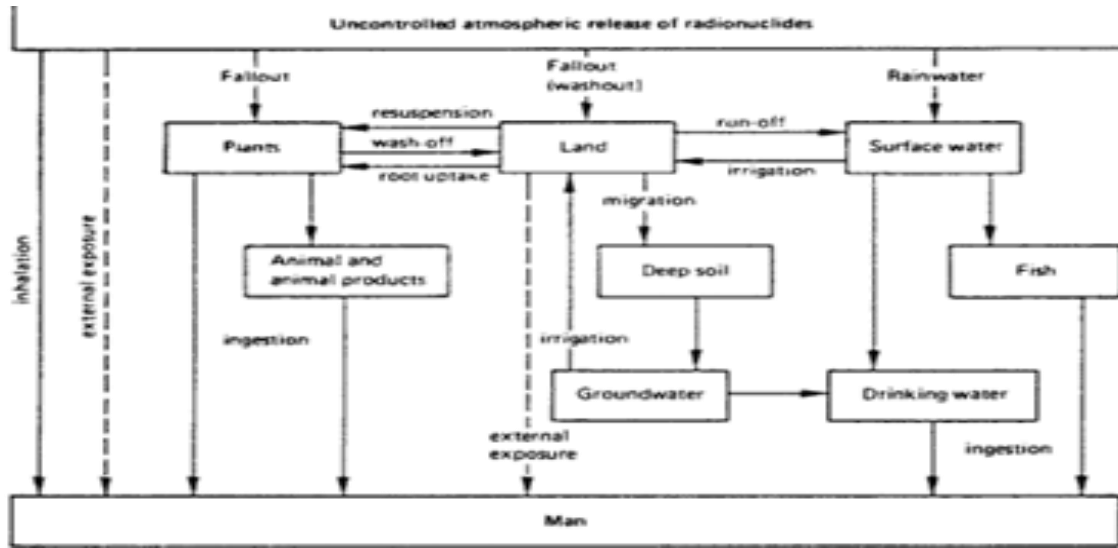


Figure 1: Major Pathways of Radionuclides to Man in the Event of an Uncontrolled Release of Radioactivity. Adapted from IAEA (1989).

Data regarding levels of natural radioactivity in soils and the corresponding radiation doses to the population are lacking for most parts of Nigeria. The objectives of the present study are to measure the natural radioactivity levels in the surface soils of Sokoto and to assess the air absorbed external gamma-radiation exposure, annual effective radiation dose, and external radiation hazard index. The data generated in this study will provide base line values of natural radioactivity in soils and may be useful for authorities in the implementation of radiation protection standards for the general population in the country, as well as to conduct further studies on this issue.

1.10 Location, Geomorphologic and Climatic Setting

Sokoto Basin which lies between latitudes 10°55' and 13°52' N and longitudes 5.00° and 6.00° E in north-western part of Nigeria (Figure 2). It falls within a region where rainfall distribution is irregular in time and space and characterized by a prolonged dry season and a short rainy season. The Sokoto sedimentary basin in northwestern Nigeria consists

predominantly of a gentle undulating plain with an average elevation varying from 250 to 400 m above sea level. This monotonous plain (according to Kogbe, 1979) is occasionally interrupted by steep-sided, flat-topped hills with a low escarpment, called the “Dange Scarp” as the most prominent feature in the basin. The escarpment itself is closely related to the geology of the area and has undergone intensive erosion to the extent that the Dange Scarp is no longer recognizable today (Udoh, 1970).

The climate is semiarid with a zone of savannah-type vegetation as part of the sub-Saharan Sudan belt of West Africa. Rainfall in the Sokoto Basin shows a marked variation, with annual mean precipitation varying from 350 mm (at Kalmalo in the extreme north) to 670 mm (at Sokoto Airport). Rainfall is concentrated in a short wet season, which extends from mid-May to mid-September whilst the dry season (with no single rain) lasts more than 7 months. Mean annual temperatures are from 21.5 to 34.9°C. The highest temperature occurs between April and July, the lowest in August (during the rainy season).

1.20 Geological Setting

Sokoto Basin is the Nigeria's sector of the Iullemeden Basin "Figure 2". Its sediments were deposited during three main phases of deposition which include the continental Mesozoic and Cenozoic phases, with an intervening marine Maastrichtian to Palaeocene phase. The sedimentary rocks of the Sokoto

Basin have been classified into four main groups. The pre-Maastrichtian (Lower Cretaceous) sediments are of fluvial and lacustrine origin. They belong to the Gundumi and Illo Formations which extend northwards into the Republic of Niger.

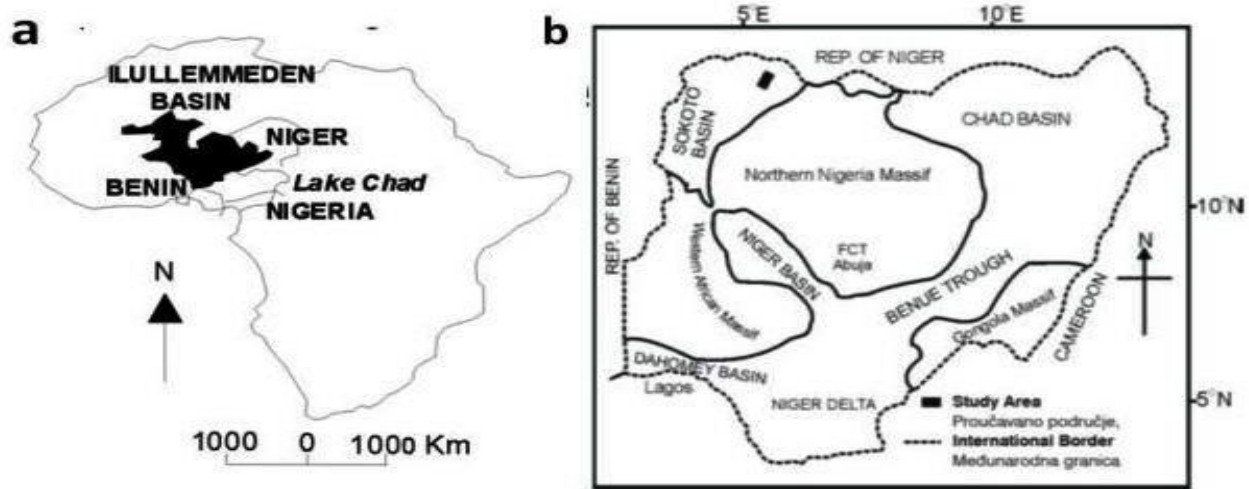


Figure 2: Maps of Africa (a) and Nigeria (b) showing the location of Iullemeden Basin and Sokoto Basin respectively (Yelwa *et. al.*, 2005).

The second phase in the depositional history of the northwestern Nigerian basin began during the Maastrichtian when the Rima Group was deposited unconformably on the Lower Cretaceous sediments as the Taloka, Dukamaje and Wurno Formations. The Taloka Formation also referred to as the lower sandstone and mudstone and lignite, consists of interbedded grey to dark brown mudstone and light coloured, medium to fine-grained sand with some thick

bands of carbonaceous shale or lignite (Kogbe, 1972). The Dukumaje Formation consists predominantly of shales with some limestone and mudstones. The shales contain numerous fragments of vertebrate and limb-bones. A richly fossiliferous bone bed lies near the base. The Wurno Formation consists of thin, friable, fine-grained sandstone intercalated with soft mudstone and siltstones. It is very similar to the Taloka Formation. (Eminue and Bassey, 2014).

2.0 MATERIALS AND METHODS

Soil samples were collected from twelve (12) points around the Rima Group of Sokoto basin. Three (3) of these soils samples were collected from a locality making them to be four locations (Figure 3). Two locations were considered each under Dukamaje and Wurno Formations of Sokoto Group. All sampling sites were preferred to be undisturbed and non-eroded without any influence of man-made structures to ensure that samples were representatives of the sites from where they were taken. The samples were labeled at the point of collection and the

coordinates recorded. The location of the sampling points {Elevation, North (Latitude) and East (Longitude)} have been determined using Global positioning system (GPS) (Model: GPSMAP 78s) with the geological information giving a total of twelve (12) samples (Table 1). In each sampling point soil of mass about 1kg was collected and put in a well labeled polythene bag (Kolo, 2014). The content of each polythene bag was then measured to about 500g using electronic balance and put in a well labeled polythene bag properly sealed and put

them in a plastic bucket to avoid cross contamination of the samples. 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.

2.10 Sample Preparation

The soils samples were dried in a tray at room temperature in the laboratory. Each sample were then pulverized by using crushing machine into powder at the Centre for Energy Research and Development, sieved with a 1 mm mesh to obtain homogenized samples and pack in cylindrical plastic container. The samples were carefully weighed 300-350g each and then sealed with a masking tape. The containers were hermetically sealed to ensure $^{222}_{86}\text{Rn}$ and $^{220}_{86}\text{Rn}$ does not escape (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.

At secular equilibrium, the activity of each radionuclide in a given series is equal to the activity of the nuclide that heads the series, thus the parent nuclide. Therefore,

$$\lambda_1 N_1 = \lambda_2 N_2 = \lambda_3 N_3 = \dots = \lambda N \quad (1)$$

Where:

λ_i is the decay constant of nuclide i

N_i is the number of radioactive atoms of nuclides i

$\lambda_1 N_1$ is the activity of parent nuclide

$\lambda_i N_i$ is the activity of daughter and granddaughter nuclides respectively

2.20 Gamma (γ) ray Analysis

The method of γ –ray spectrometry as has been severally reported (Jibiri and Aguomo., 2007; Avwiri, 2005) was adopted in the analyzing radionuclide in variety of matrices. The spectrometer consists of a Canberra 7.6cm by 7.6cm NaI (Tl) (Model No 802 – series) detector coupled to a Canberra series 10 plus Multichannel Analyzer (MCA) through a preamplifier base. The transition lines of 1.460 MeV of ^{40}K , 1764.5 KeV of ^{214}Bi and 2614.7Kev of ^{208}Tl were used to determine the concentrations of ^{40}K , ^{238}U and ^{232}Th respectively. The soil samples were sieved through a 2mm mesh screen and then placed in a container for 28 days to enable them reach secular equilibrium before the analysis. The spectral for the soils were measured by counting for 2 hours and the area under the photo peaks were computed using the algorithm of the MCA.

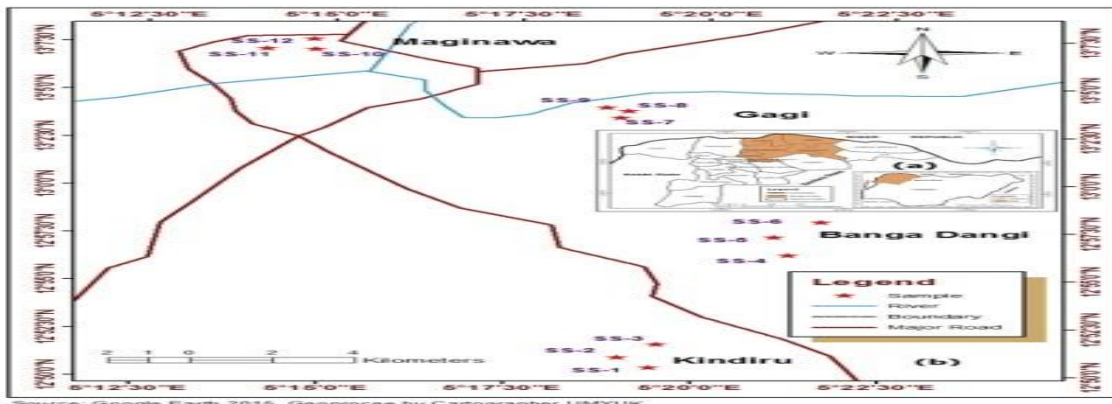


Figure 3: (a) Map of Nigeria, Showing Sokoto Basin in Relation to the Scope of the Study. Inset: Location of (b) Simplified Geographical Map of Sokoto Group Showing the Sampling Locations and Points.

2.30 Assessment of radiation hazards

2.3.1 Radium equivalent activity

The radiation hazards associated with the radionuclides are estimated by calculating the radium equivalent activity (Raeq). Radium equivalent activity is the weighted sum of the activities of ^{40}K , ^{232}Th and ^{226}Ra based on the assumption that 10 Bqkg⁻¹ of ^{226}Ra , 7 Bqkg⁻¹ of ^{232}Th and 130 Bqkg⁻¹ ^{40}K deliver equal gamma dose rates (Tufail *et al.*, 2007).

$$Ra_{eq} (\text{Bqkg}^{-1}) = C_{Ra} + \frac{10}{7} C_{Th} + \frac{10}{130} C_K \quad (2)$$

Where C_K , C_{Th} and C_{Ra} are the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K respectively.

2.3.2 Air absorbed gamma radiation dose rate (D)

Effects of gamma radiation are normally expressed in terms of the absorbed dose rate in air, which originate from radioactive sources in the soil. The activity concentrations in soil correspond to the total absorbed dose rate in air at 1 m above the ground level. The absorbed dose rate in air (D) for the population living in the studied area is calculated using the following equation (Ramasamy, 2009; UNSCEAR, 2000).

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

3.0 RESULTS AND DISCUSSION

The mean values of measured activity concentrations of selected radionuclides of ^{226}Ra , ^{232}Th and ^{40}K in soil samples from all the selected 12 sites around Sokoto are shown in Table 2. The activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K are in the range of 38.35-69.09 Bq kg⁻¹, 89.33-149.96 Bq kg⁻¹, and 1309.59-2972.52 Bq kg⁻¹ with a mean value of 53.6±8.28 Bq kg⁻¹, 115.29±28.4 Bq kg⁻¹, and 2003.103± 278.1 Bq kg⁻¹, respectively. The measured activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K were compared with the values reported worldwide (Baeza *et al.*, 1992; Mustapha *et al.*, 1999; UNSCEAR, 2000; Narayana *et al.*, 2001;

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

2.3.3 Annual effective dose (AEDR)

The annual effective dose received is calculated using (UNSCEAR, 2000; Hafezi *et al.*, 2005):

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

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).

2.3.4 External radiation hazard index

(H_{ex})

External radiation hazards due to natural radionuclides of ^{40}K , ^{232}Th , and ^{226}Ra are defined in terms of external or outdoor radiation hazard index (equation 5) as denoted by (Osoro, *et al.*, 2011) and it is based on the assumption that 370 Bq.kg⁻¹ of ^{226}Ra , 259 Bq.kg⁻¹ of ^{232}Th , and 4810 Bq.kg⁻¹ of ^{40}K produce the same gamma radiation dose rate.

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (5)$$

Arogunjo *et al.*, 2004; Tahir *et al.*, 2005) as shown in "Table 3". It is found that the measured activity concentrations of 3 naturally occurring radionuclides in this study are higher than most of the reported values from other countries as well as the world's average values. The mean values of air absorbed gamma radiation dose rate (D) is 222.52±20.42 nGy h⁻¹ as shown in Table 4.

Radium equivalent activity (Raeq) owing to activity concentration of 3 natural radionuclides from all sites varies from 278.12±39.03 to 521.31±25.73 Bq kg⁻¹. The mean value of Raeq is 378.71±40.19 Bq kg⁻¹, which is slightly

higher than the threshold value of 370 Bq kg⁻¹. Both, Radium equivalent activity (*Raeq*), Mean annual effective dose (*ADER*), and external radiation hazard index (*Hex*) calculated in this

work are shown in “Table 5”. All these are values computed in this work are much higher than the values reported worldwide.

Table 1: Locations and Geological Information for the Positions of Soil Samples.

Location for soil samples	Elevation (m)	Latitude (N)	Longitude(E)	Geology information
1.Banganangi A. SS1 B. SS2 C. SS3	333 334 335	1256'19.7" 1256'19.0" 1256'19.2"	00521'14.8" 00521'16.4" 00521'17.1"	Dange formation Shale with mud Phosphate nodular Shale
2.Kindiru A. SS4 B. SS5 C. SS6	341 349 346	1250'54.8" 1250'55.0" 1250'55.8"	00519'29.3" 00519'30.0" 00519'30.1"	Dange formation Phosphate nodule Phosphate nodule Shale
3.Maginawa A. SS7 B. SS8 C. SS9	250 254 256	1307'24.5" 1307'24.0" 1307'22.0"	00514'45.5" 00514'45.5" 00514'43.5"	Kalambaina formation Phosphate Shale Silt stone
4.Gagi A. SS10 B. SS11 C. SS12	281 283 286	1303'24.5" 1303'24.0" 1303'22.0"	00518'37.0" 00518'40.3" 00518'42.8"	Kalambaina formation Phosphate Shale Shale with Phosphate

Table 2: Mean Activity Concentration of Radionuclides ^{40}K , ^{238}U and ^{232}Th in Each Location.

S/N	Sample Location	K-40 (BqKg ⁻¹)		U-238 (BqKg ⁻¹)		Th-232 (BqKg ⁻¹)	
		Range	Mean	Range	Mean	Range	Mean
1.	Banganangi	2625.72-3319.31	2972.52±200.46	65.22-72.95	69.09±2.23	87.94-211.97	149.96±35.85
2.	Kindiru	800.54-2065.03	1309.59±385.71	32.36-45.03	38.35±3.68	78.71-122.21	94.40±13.96
3.	Maginawa	1450.8-2216.02	1741.02±239.73	27.05-85.83	54.54±17.09	63.49-178.58	127.45±33.88
4.	Gagi	1658.48-2301.74	1989.28±286.14	33.36-69.61	52.42±10.52	38.79-142.2	89.33±29.91
	Average	1309.59-2972.52	2003.1±278.1	38.35-69.09	53.6±8.28	89.33-149.96	115.29±28.4

Table 3: Activity concentrations (Bq kg⁻¹) of ^{238}U , ^{232}Th , and ^{40}K measured worldwide.

COUNTRY	^{238}U	^{232}Th	^{40}K	REFERENCE
Pakistan	35 ± 7	41 ± 8	615 ± 143	Tahir et al., 2005
South India	35	29.8	117.5	Narayana et al., 2001
Spain	46	49	650	Baeza et al., 1992
Kenya	28.7 ± 3.6	73.3 ± 9.1	255.7 ± 38.5	Mustapha et al., 1999
Delta Region, Nigeria	16.2 ± 3.7	24.4 ± 4.7	34.8 ± 20.4	Arogunjo et al., 2004
Sokoto Basin, Nigeria	51.26±5.63	120.69±32.07	1870.34±299	Present Study
World's average	35	30	400	UNSCEAR, 2000

Table 4: Average Dose Rates of the Natural Radionuclides and the Total Dose Rates Measured in this Work for all Sampling Sites.

S/N	Location	Dose (nGyhr ⁻¹)	
		Range	Mean
1.	Banganangi	282.76-311.04	297.56±5.81
2.	Kindiru	135.49-217.69	163.07±21.05
3.	Maginawa	138.72-310.42	222.38±34.46
4.	Gagi	155.41-258.91	207.05±20.34
	Total		890.06±81.66
	Average		222.52±20.42

Table 5: Annual Effective Dose Rate (AEDR), Hazard Index (H_{ex}) and Radium Equivalent R_{aeq} for Sediments.

s/n	Location	Mean Annual Effective Dose ($mSvyr^{-1}$)	Mean Activity Index	Mean Radium Equivalent ($BqKg^{-1}$)
1)	Banganangi	1.46±0.02	1.384±0.07	521.31±25.73
2)	Kindiru	0.80±0.06	0.74±0.33	278.12±39.03
3)	Maginawa	1.09±0.09	1.001±0.15	376.08±55.84
4)	Gagi	1.01±0.06	0.9±0.11	339.31±40.18
	Total	4.36±0.23	4.03±0.56	1514.82±160.78
	Average	1.09±0.06	1.01±0.14	378.71±40.19

4.0 CONCLUSION

The present study has been carried out to establish baseline data regarding concentration levels of naturally occurring radionuclides of ^{226}Ra , ^{232}Th , and ^{40}K in soils and the corresponding radiation doses in Rima Group Formations of Sokoto basin, Nigeria. Measured mean activity concentrations of the 3 radionuclides are found to be higher than the world's average values which clearly demonstrates the radiological burden an average member of Sokoto Group bearing are expose to. Calculated values of external radiation doses are

also slightly higher unity. However, it may be necessary to determine the radioactivity concentrations in soils of other adjoining states bordering Sokoto Group to be able to draw better conclusions on the radioactivity levels in the Sokoto Basin of Nigeria. Also, the results may be useful as reference data for monitoring possible radioactivity pollutions in the future and for the introduction of radiation safety standards by the authorized organizations for the protection of general population from radiation hazards owing to terrestrial sources.

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