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Assessment of Natural Radioactivity Concentration in Soils from Irrigation Farming Areas within Kudan Local Government Area, Kaduna State, Nigeria

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Abstract

The activity concentrations of natural radionuclides ^{238}U, ^{232}Th and ^{40}K in soil samples from Kudan Local Government Area irrigation farming areas have been evaluated using gamma-ray spectrometry. The results of the activity concentrations of ^{238}U, ^{232}Th and ^{40}K range between 18.15 to 34.66 Bq/kg, 16.01 to 18.83 Bq/kg and 205.51 to 461.25 Bq/kg respectively. The activity concentration of ^{40}K was seen to be higher than the world average value of 370 Bq/kg at Kauran Wali South (GO3K) 375.25 Bq/kg, Doka (GB1K) 389.60 Bq/kg, Kauran Wali North (GB2K) 420.15 Bq/kg, Likoro (GB4K) 383.65 Bq/kg, Garu (GB5K) 461.25 Bq/kg, Zabi (GB6K) 372.76 Bq/kg and Kudan (GB7K) 382.50 Bq/kg. The activity concentrations of ^{238}U and ^{232}Th were observed to be high at Garu (GB5K), with values of 34.66 and 18.83 Bq/kg respectively, however, these values were still below the world average value of 40 Bq/kg as reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSEAR) in 2000. The average values for the indoor absorbed dose rate (Din), Internal Hazard Index (Hin), External Hazard Index (Hex) and Indoor Annual Effective Dose (ADE) were evaluated to be 83.07 nGy/hr, 0.35, 0.28 and 0.41 mSv respectively. The estimated radiological indices were seen to fall within the internationally acceptable limits except for the indoor absorbed dose rate (Din) whose values were all higher than the acceptable limit of 60 nGy/hr as recommended by UNSCEAR in 2000. The high values obtained from this study could be attributed to the excessive use of fertilizers by the farmers within the study area.

Keywords: Activity concentration; gamma-ray spectrometry; Radiation, Soil; Irrigation.

I. INTRODUCTION

Ionization radiation is an evitable feature of life on Earth. This radiation is found naturally in the environment and originates from both terrestrial and cosmic sources [1]. Natural radiation has always been part of our environment. Its primary constituents are radiation from radioelements in the air and water, gamma radiation from radionuclides in rocks and soil, and cosmic and cosmogenic radiation [2]. Radionuclides are present in trace amounts in naturally

occurring radioactive materials (NORMs), but when these materials are disturbed or changed from their native environments, their concentrations are often elevated above background radiation levels. The population and the environment may be in greater danger of radiation exposure because of this [3]. Long-lived radionuclides, such as ^{238}U, ^{232}Th, and ^{40}K, are mostly responsible for radioactivity in the environment, and their distribution in the Earth's crust is influenced by the kind of rock formation beneath the crust [4]. These radioactive elements are only found in nature, and their redistribution is caused by human activities like mining and farming. In addition to being exposed to background gamma radiation dose level (GRDL) from both terrestrial and cosmic sources, humans are continuously in contact with these radioactive elements through food and water consumption [5].

Radionuclides are usually transported to the soil by rain and water flow when rocks naturally disintegrate [6]. One of the primary factors influencing background radiation is the concentration of radioactive elements in the soil. The protection, measurement, geoscientific research, and guidelines for the use and management of these materials are significantly influenced by our understanding of the distribution of these radionuclides in soil, water, sediment, rock, and building materials [7].

The primary cause of the radioactivity found in continental surface waters is the earth's crust, which contains radioactive elements. Activities carried out by humans, such as farming, burning fossil fuels, producing fertilizers, mining, milling, processing ores and mineral sands, etc. also tend to increase the levels of naturally occurring radioactivity. There are various ways by which these radioactive materials from each process or activity can end up in surface environmental waters. Rainwater carrying radioactive elements that have leached from cities, mine waste, weathering soil, and agricultural areas can contaminate rivers and dam water [8]. Furthermore, due to secondary contamination processes, radioactivity in a water body may continue to remain at significant levels over time and this contamination can lead to significant levels of radioactivity in urban water bodies, resulting in heavy pollution. The sediment compartment of the aquatic ecosystem is primarily home to the largest concentration of radioactive materials due to gravitational settling and other depositional phenomena also serve as a means of transporting radionuclides within the ecosystem [9, 10]. In addition, radioactive deposition from wastes directly dumped into land or waterways or from initial radioactive discharges into the atmosphere can also contaminate the soil [11].

Several radiological studies conducted in the vicinity of various industrial areas have reported no discernible environmental radiological health burden because of these activities [12, 13]. They promptly pointed out, though, that longer operating durations for these activities might raise the levels of radioactivity because of long-term cumulative effects, and that the radiological indices from industrial areas were higher than those from nearby communities.

Given that Kudan Local Government Area is an irrigated farming area where vegetables and sugarcanes are the most grown plants, it is important to determine the level of radioactivity in the area to ascertain if the natural radioactivity levels are within the standard limit set by the regulatory body for the protection of public health.

This study is carried out to assess the natural radioactivity levels in soil from the irrigation farming area of Kudan Local Government Area of Kaduna State, Nigeria.

A. Study Area

The farms considered for this study are located within Kudan Local Government. These farms alongside their codes, latitude and longitude are Sabon Garin Hunkuyi (GO1K) (11.29° N, 7.65° E), Hunkuyi (GO2K) 11.26° N, 7.64° E, Kauran Wali South (GO3K) 11.30° N, 7.84° E, Doka (GB1K) 11.27° N, 7.73° E, Kauran Wali North (GB2K) 11.32° N, 7.82° E, Taban Sani (GB3K) 11.27° N, 7.78° E, Likoro (GB4K) 11.20° N, 7.72° E, Garu (GB5K) 11.25° N, 7.70° E, Zabi (GB6K) 11.28° N, 7.72° E and Kudan (GB7K) 11.28° N, 7.66° E. All investigated farms grow vegetables and sugarcanes through irrigation using surface water or shallow hand-dug wells.

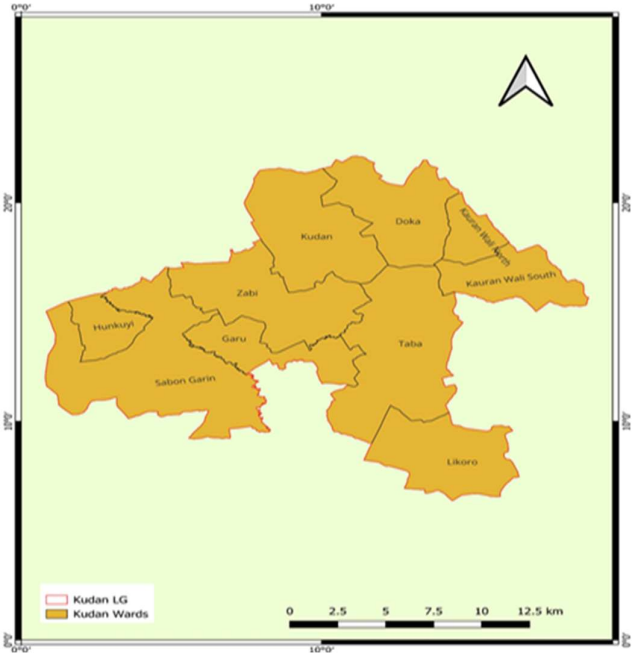

Fig. 1 Map of the study area [14].

II. MATERIALS AND METHODS

A. Materials

Materials used in this study include Portable Geiger Muller (GM) universal survey meter: RDS-120 by RADOS Finland, an erect stand/ support for placing the universal survey meter, portable handheld Global Position System (GPS) meter, Gamma-ray spectrometer: Lead shielded 76 x 76 mm NaI (TI) detector crystal (Model No.727 series), Canberra Inc. coupled

with a Canberra series 10 plus Multichannel Analyzer (MCA) (Model No. 1104), weighing scale.

B. Methods

1) Sample collection

Soil samples were collected in a radon-impermeable cylindrical plastic container. The topmost soil was cleared and the soil beneath was taken. The soil samples were collected and labelled for easy identification and taken to the laboratory for preparation and analysis.

2) Sample preparation

The samples were properly dried at room (ambient) temperature ($37°C$) and crushed to fine powder to obtain a uniformly homogeneous sample matrix. After which samples were filled into plastic containers of known weight. The weight of the samples and the container is then measured using the weighing balance. The inner portion of the lid of the plastic container was coated with Vaseline and the container was sealed with candle wax with masking tape. This traps the gaseous radionuclide within the container and allows for circular equilibrium for a period of 24 days before the counting takes place (the period for which all the radionuclide is expected to have formed a saturated mixture). The weight of the sample is obtained by subtracting the weight of the empty container [15, 16, 17].

The samples are labelled, and the sealed date recorded to avoid sample loss, after which the sample can be counted using the gamma-ray spectrometer with doped sodium iodide and thallium as a detector to determine the low background level of NORMS (which are daughters of ^{238}U, ^{232}Th and ^{40}K).

3) Soil samples analysis

Radiometric analysis of the samples was carried out using a NaI Thallium detector the crystal is housed in an aluminium canister with a 0.5mm thick beryllium entrance window. A lead shield, built with a 5 cm thick lead brick surrounds the detector to prevent it from external background radiation reaching the detector. The detector is coupled to a Canberra signal processing unit which contains the power supply, amplifier, and analogue to digital converter. Digitized counts are collected in a Canberra 5100 multi-channel analyser. The detector is connected to an uninterrupted power supply (UPS). The detector is cooled with liquid nitrogen at $-196°C$ $(77\ K)$ provided in a 35 litre Dewar. The ambient temperature around the detector varied between 16^0C and $37°C$ during the period of measurement.

Prior to the analysis of the samples, energy and efficiency calibrations were performed to enable the identification and quantification of the radionuclides of interest. The detector system was calibrated using the multi-nuclide reference standard solution (NW 146) provided by the International Atomic Energy Agency (IAEA).

4) Radiological detriments

To quantify the radiation detriment to the members of the public because of the activity concentration in the soil. The external hazard index (Hex) and Internal Hazard Index (Hin), indoor absorbed dose rate and the corresponding indoor annual effective dose (AED) were used as Radiological indicators to estimate the radiological implications.

5) Indoor absorbed dose rate (DIN)

The indoor absorbed dose rate (Din) due to the external gamma radiation from the ^{238}U, ^{232}Th and ^{40}K radionuclides in the soil used was evaluated using a guide set by the IAEA.

6) Estimation of annual effective dose (AED)

The dose rate was used to estimate the annual effective dose (AED) due to exposure to gamma radiation dose level (GRDL). The indoor AED were calculated using (1),

$$AED(mSv/yr) = GRDL(nGy/hr) \times 0.7Sv/Gy \times 0.8 \times 8760hr \times 10^{-6} \quad (1)$$

Where GRDL is the measured dose rate for each sampling point, 0.7 is the conversion factor to convert the absorbed dose rate to the effective dose equivalent in air received by an adult [18], OF is the occupation factor equal to 0.2 for outdoor activities, 0.8 is the occupation factor (OF) for indoor activities, 8700 hr is the number of hours in a year and 10^{-6} is the conversion factor between nano and milli [19, 20].

7) External and Internal Hazard Indices

The External Hazard Index (Hex) and the Internal Hazard Index (Hin) values were calculated using the following equations.

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (2)$$

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (3)$$

Where, C_U, C_{Th} and C_K are activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg respectively [3].

III. RESULTS AND DISCUSSION

The results of the Radioactivity level from ten (10) soil samples from the irrigated farming area of Kudan Local Government Area of Kaduna state, Nigeria were determined.

Table I depicts the activity concentration in (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K in the sampled. The activity concentration of ^{238}U, ^{232}Th and ^{40}K in the samples ranged between 18.15 to 34.66 Bq/kg, 16.01 to 18.83 Bq/kg, and 205.51 to 461.25 Bq/kg with an average of 25.74 Bq/kg, 17.51 Bq/kg and 367.46 Bq/kg respectively. The activity concentration of potassium was higher than that of uranium and thorium. This high value could be attributed to the excessive use of fertilizers within the study area. High activity concentrations of ^{238}U and ^{232}Th were equally observed in Garu (GB5K) and Kudan (GB7K) with activity concentrations of 34.66 and 29.54 Bq/kg respectively, with both values less than the world's average value of 40 Bq/kg [21].

Table I: Activity concentrations of natural radionuclides of soil from irrigation farming area of Kudan.

Location	Sample ID	Activity Concentration (Bq/kg) ^{238}U	^{232}Th	^{40}K
Sabon Garin Hunkuyi	GO1K	26.07	17.75	205.51
Hunkuyi	GO2K	26.29	17.96	315.38
Kauran Wali South	GO3K	27.97	16.01	375.25
Doka	GB1K	28.34	16.16	389.60
Kauran Wali North	GB2K	19.83	18.52	420.15
Taban Sani	GB3K	27.21	17.39	368.55
Likoro	GB4K	19.34	18.10	383.65
Garu	GB5K	34.66	18.83	461.25
Zabi	GB6K	18.15	16.76	372.76
Kudan	GB7K	29.54	17.63	382.50
Min		18.15	16.01	205.51
Max		34.66	18.83	461.25
Mean		25.74	17.51	367.46

Table II depicts the estimated Din and AED values for the samples ranging from 63.56 nGy/hr to 83.36 nGy/hr and 0.31 mSv/yr to 0.53 mSv/yr respectively. The estimated mean value of Din, 71.5 nGy/hr is lower than the world average indoor absorbed gamma-ray dose rate of 84nGy/hr. The mean estimated annual effective dose rate of 0.39 mSv is less than the permissible limit.

For Radiological detriment, the value of Hin and Hex should be greater than or equal to 1, however, from Table II, the estimated Hin and Hex can be seen to be less than 1 with values ranging from 0.24 to 0.35 and 0.19 to 0.28 respectively. This infers that the farmlands can be used for irrigation from the internal dose point of view.

Table II. Indoor Annual Effective dose, Indoor Absorb Dose radioactivity indices associated with soil samples. In Kudan LGA.

Sample ID	Indoor Absorbed Dose rate Din (nGy/hr)	Hazard Indices Hin	Hex	Annual Effective Dose AED (mSv)
GO1K	74.70	0.25	0.28	0.36
GO2K	64.10	0.28	0.21	0.36
GO3K	83.07	0.29	0.21	0.41
GB1K	71.96	0.29	0.22	0.35
GB2K	69.10	0.27	0.21	0.33
GB3K	76.16	0.29	0.22	0.37
GB4K	79.00	0.25	0.20	0.38
GB5K	83.36	0.35	0.26	0.41
GB6K	65.23	0.24	0.19	0.32
GB7K	63.56	0.31	0.23	0.32
Min	63.56	0.24	0.19	0.32
Max	83.07	0.35	0.28	0.41
Mean	73.22	0.28	0.22	0.36
World average	60.00	1.00	1.00	1.00

Table III presents a comparison of natural radionuclide activity concentration values of soil samples from three studies from India, Ghana and Turkey compared with this study and the world average.

Table III Comparison of natural radionuclide activity concentration values (Bq/kg) of soil samples from other studies compared with this study and the world average.

Country	^{238}U	^{232}Th	^{40}K	Descriptions	Reference
World average	40	40	370		[19]
India	7.31	46.85	384.03	Sediment Ponnaiyar Rivers	[22]
Ghana	7.31	6.91	379.94	Sed Tono Irrigation Dam	[3]
Turkey	39	38	573	Sediment samples in Firtina Valley	[23]
Nigeria	25.74	17.51	367.46	Kudan local government	This study

IV. Conclusion

A total of ten (10) soil samples across Kudan Local Government Area of Kaduna State, Nigeria were collected and measured to determine their radioactivity concentrations in Bq/Kg. Results obtained indicate the activity concentration of ^{238}U, ^{232}Th and ^{40}K in the samples ranged between 18.15 to 34.66 Bq/kg, 16.01 to 18.83 Bq/kg and 205.51 to 461.25 Bq/kg with an average value of 25.74 Bq/kg, 17.51 Bq/kg and 367.46 Bq/kg respectively. The activity concentration of ^{40}K was seen to be higher than that of ^{238}U and ^{232}Th, and greater than the world average of 370 Bq/kg, while that of ^{238}U and ^{232}Th were all well below the world average of 40 Bq/kg each. This high value could be ascribed to the excessive use of fertilizers by the farmers within the study area.

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