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CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

A study of environmental radioactivity measurement of selected Kaolin mining fields in Kwara, Nigeria

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Abstract: This article reports an in-situ measurements of the background gamma radiation dose rates and the activity concentrations of ^{238}U, ^{232}Th and ^{40}K, at kaolin mining-fields in Ilorin-south and Ilorin-west, Kwara, Nigeria. Readings were recorded in 90 randomly selected sample points. For Ilorin-south mining site 50 sample points were recorded, while 40 randomly selected sample points were considered for Ilorin-west mining site. A handheld RS-125 Super-Spec gamma spectrometer was utilized to perform the radioactivity measurements on both mine fields. The results of the activity concentrations showed that the locations are enhanced with ^{40}K activity concentration compared with ^{238}U and ^{232}Th. The mean values of ^{40}K, ^{238}U, ^{232}Th and DR for Ilorin-west were found to be 492.19, 35.63, 44.07 Bqkg^{-1} and 63.28 nGyh^{-1}, respectively. While the mean values for the measured activity concentrations of ^{40}K, ^{238}U, ^{232}Th and DR for Ilorin-south are 263.55, 52.24, 31.29 Bqkg^{-1} and 54.71 nGyh^{-1}, respectively. Consequently, the mean values of the estimated radiological hazard parameters of Ilorin-west were higher than the estimated mean values for Ilorin-south. This shows that the Ilorin-west Kaolin mine field poses more significant source of radiation hazard. The results in this current work can be used as a significant baseline radioactivity data of the mining areas in Nigeria for future epidemiology and monitoring purposes.

Subjects: Earth Sciences; Environment & Health; Physics

Keywords: Kaolin; mining; Nigeria; radioactivity; radiological risk

Mojisola Rachael Usikalu

ABOUT THE AUTHOR

Usikalu Mojisola Rachael is a Lecturer and Head Radiation and Health Physics Research Cluster in Department of Physics, Covenant University. She has worked extensively on the measurement of radioactivity in the soil, rock and water for the estimation of the associated radiological risks in various part of the country. Through these researches, she has been able to identify soils and rocks that are not fit for construction purposes due to high radiation burden (cancer incidence, untimely death) associated with them. The research outcome provides useful information for policy makers on setting guidelines for the populace on type of soil that could be used for building and construction purposes and the safety distance to build houses from mining sites.

PUBLIC INTEREST STATEMENT

Radiation is inevitable as long as we walk on soil, drink water and carry out our day-to-day activities under the sun. This is because soil, water, rock, etc., contain different natural radioactivity concentration in varying proportion. The radiation level in a location depends mainly on the geological makeup of the rock, soil and different activities taking place in the area. In this work, we assessed the natural radioactivity concentration in locations where illegal mining are taking place. The radioactivity measurement was carried out with sodium iodide detector. This was done to verify whether mining activities has impact on the radiation dose from a location. The results from the research established that mining activities increase the radiation dose and the excess lifetime cancer risk of the study area.

1. Introduction

People's exposure to ionizing radiation has become a growing source of public concern because of its associated health effects such as cancer (Ajibola et al., 2021; Joel et al., 2019; Orosun et al., 2020a). The background radiation is made up of radioactive nuclei that are found in air, soil and water either naturally or as a result of human activities. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimates that the global average human exposure from natural radiation sources is 2.4 $mSvy^{-1}$, with natural sources of terrestrial and cosmic origin accounting for 82% of this amount (Oyeyemi et al., 2017; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000). The terrestrial component is made up of long-lived radionuclides in the earth's crust, whereas the cosmic component is made up of cosmic rays from space. Furthermore, man-made sources such as nuclear disasters, reactor accidents, nuclear testing and the use of technical items have an impact on background radiation levels in a region. Although natural radiation is the primary source of the world's population's external dosage, the potential dangers of increased or heightened levels of radioactive chemicals in air, water and soil are usually considered a public health concern. As a result, environmental radioactivity measurements are routinely carried out by researchers all over the world in order to ascertain the nationwide background radiation levels.

The Nigerian Nuclear Regulatory Authority, which is mandated by law to guarantee that radiation protection and safety rules are followed, is in charge of nuclear and radiation generating sources in Nigeria. Several studies have been carried out around the world to analyze natural radioactivity levels in soil/sediment in specific places, as well as raw materials utilized in construction and building. Natural radionuclides and radiological risk assessment of a granite mining field in Asa, North-central Nigeria (Orosun et al., 2019), dataset on ground radiometric survey in part of the Eastern Dahomey Basin, SW Nigeria (Orosun et al., 2019), dataset on ground radiometric survey in part of the Eastern Dahomey Basin, SW Nigeria (Orosun et al., 2019), dataset on ground radiometric survey in part of the Eastern Dahomey (Oyeyemi et al., 2017), dataset on radioactivity measurement of Beryllium mining field in Ifelodun and Gold mining field in Moro, Kwara State (Orosun et al., 2020a), natural radioactivity concentration and its health implication on dwellers in selected locations of Ota, (Usikalu et al., 2019), investigation of natural environmental radioactivity concentration in soil of coastline area of Ado-Odo/Ota Nigeria and its radiological implications (Joel et al., 2019), and natural radioactivity and geological influence on subsurface layers at Kubwa and Gosa area of Abuja, Northcentral Nigeria. In recent years, there has been widespread dumping of mining tailings in the vicinity of mining sites throughout the zone. One of the main activities of the residents in the chosen location is mining. Due to the existence of naturally occurring radioactive materials (NORM) in the earth, mining by-products, and wastes resulting from mining operations, individuals are likely to be exposed to radiation. The objective of this study is to assess natural environmental radioactivity levels in the soil/sediment of Kaolin mining field in Ilorin-South and Ilorin-West, Kwara State, Nigeria. The air absorbed external gamma-radiation exposure, annual effective radiation dose, and external radiation hazard index were all determined during this investigation. The information gathered in this study will serve as a baseline for radiation exposure in an environment where mining is taking place, and it may be useful to authorities in developing radiation protection standards for the general public in the country, as well as conducting further research on the subject.

2. Materials and methods

Figure 1 below provides the flow chart of the research method process. Pearson's correlation technique was employed to further investigate the degree of strength and nature of relationship between the measured activities of ^{238}U, ^{232}Th, ^{40}K and the radiation dose rate at both mining sites.

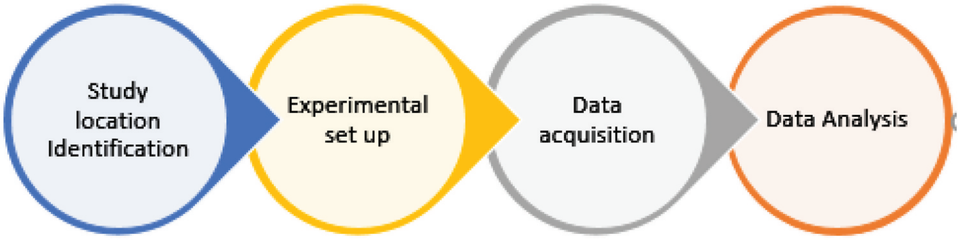


Figure 1. Flow chart of research method process.

2.1 Study area

The areas under study are Fufu village in Ilorin-south and Akerebiata area of Ilorin-west LGA in Kwara, Nigeria. It is located within latitudes 8°20ʹ N and 8°50ʹ N and Longitudes 4°25’ E and 4°65′E (Figures 2 a, b). Kwara is situated in the North-central part of the country with tropical wet and harmattan times of year with normal annual precipitation of about 1,200 mm. A temperature of 26.2°C is its mean annual temperature; which tops in the month of March with about 30°C (Orosun et al., 2020a). Wet period usually take place between the months of April and October, while dry periods are experienced between the months of March and November.

The geology of the study area is of crystalline pre-Cambrian basement complex rocks. The soils are formed from the basement complex rocks (metamorphic and igneous rocks), which is about 95%. The metamorphic rocks consist of biotite gnesiss, banded gnesiss, quartzite augitegnesiss and granitic gnesiss. The intrusive rock comprises of pegmatite and vein quartz (Orosun et al., 2019, 2020a, 2021b). Detail geology of the study area can be found in Orosun et al. (2019, 2020b, 2021a).

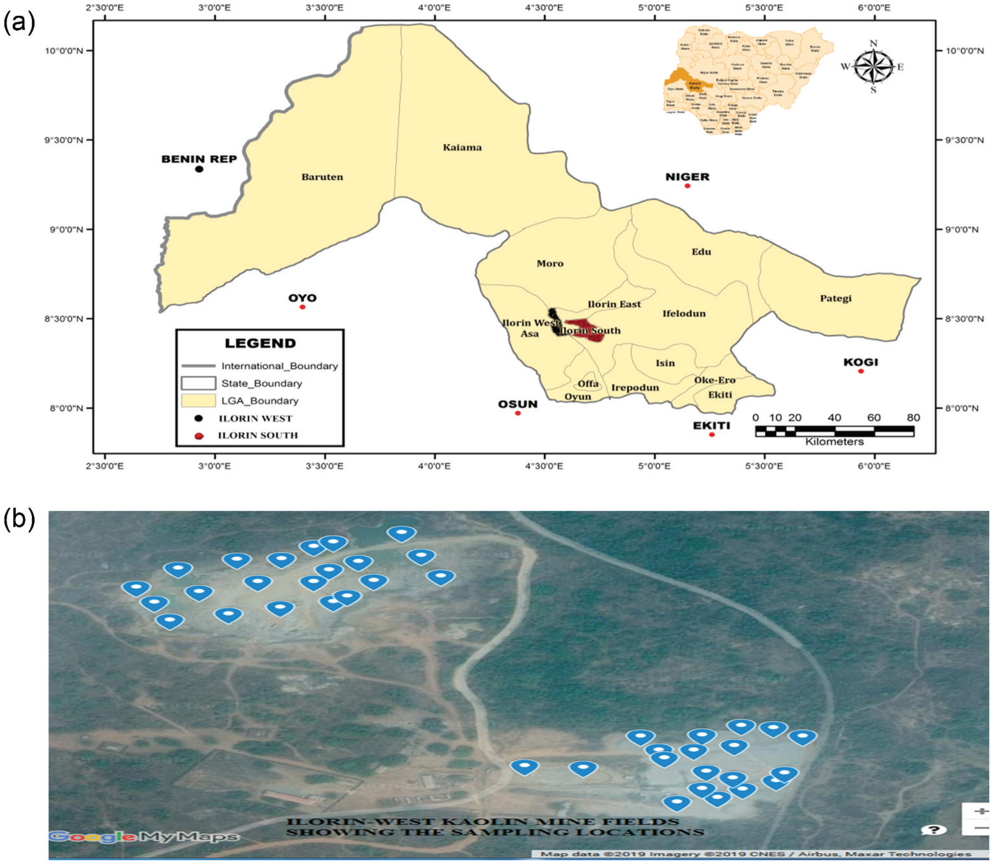


Figure 2. (a) Map of Nigeria showing the selected locations. (b) Kaolin mining field showing the sampling locations.

2.2 Field survey

Estimations of the activities of ^{40}K, ^{232}Th, ^{238}U and the radiation dose exposures were done in-situ with help of Super SPEC RS-125 spectrometer (see, Figure 3) with enormous 2.0 × 2.0 NaI crystal (106 cm^3). The estimation of the activities of the primordial radionuclides and radiation doses was done at around 1 meter over the ground level (Orosun et al., 2021b, 2019, 2021a). The RS-125 spectrometer is a small handheld detector with high precision and a 5-percentage-point error. It has a well-integrated design with a pleasant user interface. The detector was made in Canada by the Canadian Geophysical Institute. It has the ability to store large amounts of data, allowing it to track a variety of activities. The detector was calibrated in compliance with Canadian Geophysical Institute guidelines. On a 1 × 1 m testpad, 5 minutes of spectra accumulation on potassium, uranium, and thorium pads were used, followed by 10 minutes of aggregation on the ambient pad. It uses a thallium [Tl] doped Sodium Iodide [NaI] crystal as activator. The energy range of the instrument varies from 30 to 3000 keV, which is adequate to measure the greater part of the radiation emitted from the earth sources (for example, ^{214}Bi (609.31 and 1764.49 keV) gamma beams was used to measure ^{238}U, ^{212}Pb (238.63 keV), ^{208}Tl (583.19 keV) and ^{228}Ac (911.21 keV) gamma beams were employed to measure ^{232}Th and the energy peaks of ^{40}K which occurs in the background spectrum at 1460.83 keV. Runtime of 120 s for each test was utilized for greater accuracy and precision as expressed in the Radiation

Figure 3. Super SPEC RS-125 gamma spectrometer.

Solutions Inc (Orosun et al., 2019, 2020c, 2021a; Radiation Solution Inc, 2015). The assay mode of the RS-125 gamma detector gives the activities of ^{238}U and ^{232}Th in part per million (ppm) and ^{40}K in percentage (%). The measured dataset was converted to Bqkg^{-1} that was the conventional unit using conversion rates provided by the International Atomic Energy Agency (1989, 2000).

In this current study, measurements were repeated four (4) times at every geolocation at the interim of 120 seconds. Ninety (90) sampling locations were recorded altogether for the two (2) mining fields (For Ilorin-south mining site, 50 sample points were recorded together with their standard error while 40 randomly selected sample points were considered for Ilorin-west mining site. The number of sampling points was based on the area of each location). At each of these sampling points, the coordinates and elevation were determined using global positioning system (GPSMAP78). Detail information about this detector can be found in works where this device was utilized (Orosun et al., 2019, 2021b, 2021c; Usikalu et al., 2018; Omeje et al., 2014; Oyeyemi et al., 2017).

2.3 Evaluation of the radiological impact parameter

The data acquired were used to calculate both the radiological impact a ssessment and risk evaluation of human and then comparing them with the universal recommended limits, by calculating the dose rates, effective doses, hazard indices and cancer risk because of the concentration of characteristic natural radionuclides in the samples evaluated.

2.4 Radium equivalent activity index (Ra_{eq})

The distribution of ^{238}U, ^{232}Th and ^{40}K in environment is not uniform, so that with respect to exposure to radiation, the radioactivity has been defined in terms of radium equivalent activity (Raeq) in Bqkg^{-1} (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000; Usikalu et al., 2020; Orosun et al., 2021c).

$$Ra_{eq} = A_U + 143A_{Th} + 0.0077A_K \tag{1}$$

where A_U,A_{Th} and A_K are radioactivity activity concentration in $Bqkg^{-1}$ for ^{238}U, ^{232}Th and ^{40}K respectively.

2.5 Hazard indices (H_{int} and H_{ext})

Equations (2) and (3) were used to calculate the hazard indices, which are the external radiation hazard (H_{ext}) and the internal radiation hazard (H_{int}). A small radiation hazard for both the Hint and Hext should not be greater than or equal to unity for the soil to be declared less toxic (Orosun et al., 2019).

$$H_{ext} = \left(\frac{A_U}{370}\right) + \left(\frac{A_{Th}}{259}\right) + \left(\frac{A_K}{4810}\right) \tag{2}$$

$$H_{\text{int}} = \left(\frac{A_U}{185}\right) + \left(\frac{A_{Th}}{259}\right) + \left(\frac{A_K}{4810}\right) \tag{3}$$

where A_U,A_{Th} and A_K are radioactivity activity concentration in $Bqkg^{-1}$ for ^{238}U, ^{232}Th and ^{40}K respectively.

2.6 Estimated absorbed dose rate ($D_{outdoor}$ and D_{indoor})

The outdoor absorbed dose rate was measured in situ using the RS-125 Gamma Spec; however, equation (4) was used to calculate the outdoor absorbed dose so as to be able to compare the calculated result with the result from the detector (Orosun et al., 2020b).

$$D_{outdoor}(nGyh^{-1}) = 0.462A_U + 0.604A_{Th} + 0.041A_K \quad (4)$$

$$D_{\mathrm{indoor}}(\mathrm{nGyh}^{-1}) = 0.922\mathrm{A_U} + 1.1\mathrm{A_{Th}} + 0.08\mathrm{A_K} \quad (5)$$

2.7 Annual Effective Dose (AED)

The annual effective dose received indoor and outdoor by a workers in the mining field and member of the public was calculated using Equations (6) and (7). Dose conversion factor of 0.7 Sv Gy^{-1} and occupancy factor for outdoor and indoor as 0.2 and 0.8 were adopted (Orosun et al., 2019)

$$Eout\left(\frac{\mu Sv}{y}\right) = Doutdoor\left(\frac{nGy}{h}\right) \times 24\,h * 365days \times 0.2 \times 0.7 * \ 0.001 \quad (6)$$

$$Ein\left(\frac{\mu Sv}{y}\right) = Dindoor\left(\frac{nGy}{h}\right) \times 24\,h \times 365days \times 0.8 \times 0.7 \times 0.001 \quad (7)$$

2.8 Excess Lifetime Cancer Risk (ELCR)

The Excess Lifetime Cancer Risk (ELCR) was evaluated using Equation (8):

$$\mathrm{ELCR} = \mathrm{AED} \times \mathrm{DL} \times \mathrm{RF}(70, 0.05) \quad (8)$$

3.0 Results and discussion

The results of this work is dataset that covers the estimated levels of activities of ^{40}K, ^{238}U, ^{232}Th and the dose rate for Kaolin mining areas in Ilorin-south and Ilorin-west LGAs, Kwara, Nigeria. Tables 1 and 2 presented the estimated activities from the points measurements and their geolocations and the summary of the descriptive statistical analyses of the obtained data. Furthermore, detailed statistical analyses were done on the original dataset to grasp the statistical distribution of the measured levels of activities. The depth descriptive statistical analyses of the in-situ measurement of activity concentrations of ^{238}U, ^{232}Th, ^{40}K and the gamma dose rate (DR) using the Super-Spec RS125 Gamma-Spectrometer is also given in Table 1. It presents the lowest, highest, mean, standard deviation, range, coefficient of variation (CV) and Skewness. The estimated values for ^{238}U, ^{232}Th, ^{40}K and DR were slightly skewed as a large portion of the proportion of the asymmetry of their probability distribution about their means ranges between −1 and +1 ("Normality Testing, Skewness and Kurtosis," 2020). The computation of the coefficient of variation shows the variability in the distribution of the measured activities of the primordial radionuclides and the gamma dose rate at the mining sites. Coefficient of variation ≤ 20% shows slight variability, 20 < coefficient of variation ≤ 50% suggests moderate variability, whereas 50% < coefficient of variation ≤ 100% demonstrates high variability and coefficient of variation value greater than 100% is viewed as been exceptionally high (Isinkaye, 2018).

From Table 1, eleven sample sites were found to have a dose rate value fall below the global average of 59 ± 00 $nGyh^{-1}$. However, twenty-nine sample sites have the absorbed dose rate value higher than the global average, with the highest found at site IWS27 with a factor of 1.64 ± 7.16. This implies that the miners and habitat at this mining field are at risk of over exposure to radiation with time. Twenty-one sample locations have their ^{40}K value below the global average as shown in Table 1. IWS5 recorded highest value of ^{40}K with a factor of 1.86 ± 27.04. Twenty-five sample codes have a ^{238}U values higher than the global average of 32.00 the highest value was found at IWS5 with a factor of 2.16. IWS29 recorded the highest value of ^{232}Th, which is higher than the world average with a factor of 1.49. The mean activity concentrations of ^{238}U, ^{40}K and the gamma radiation dose rates measured at Kaolin fields in Akerebiata area of Ilorin-west LGA were found to be higher than the global average value.

From Table 2, thirty-five sample sites were found to have a dose rate value below the global average of 59 ± 00. However, fifteen sample sites have the absorbed dose rate value higher than the global average, with the highest found at site ISK40 with a factor of 1.50 ± 6.45. This implies that the miners and habitat at this mining field are at risk of over exposure to radiation with time. Forty one sample locations have their ^{40}K value below the global average value for ^{40}K as shown in Table 2. ISK325 recorded highest value of potassium with a factor of 1.27. Forty-one sample codes have a ^{238}U values higher than the global average of 32.00 the highest value was found at ISK36 with a factor of 4.13. ISK35 recorded the highest value of ^{232}Th, which is higher than the world average with a factor of 1.53. Only the mean activity concentrations of ^{238}U at Kaolin mining field in Fufu area of Ilorin-south LGA was found to be higher than the global average value.

The continuous dumping of waste and tailings from mine sites into the immediate environment during mining exercises has been known to cause the enhancement and bioaccumulation of radionuclides and other toxic elements in water, air (dust), soil, and the food crops. As provided by International Commission on Radiological Protection (1991, 1991), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) reports, the threshold values recommended for public due to exposure to ^{238}U, ^{232}Th, ^{40}K and DR are given as 32.00, 45.00, 420.00 $Bqkg^{-1}$ and 59.00 $nGyh^{-1}$, respectively.

Comparing the mean values of ^{40}K, ^{238}U, ^{232}Th and *DR* for the two studied fields with selected studies from literatures (local and international), as shown in Table 3, it was revealed that these average values obtained in this study compare well with the values reported for Ifonyintedo (Kaolin, Nigeria; Adagunodo et al., 2018), as well as Asa (Granite, Nigeria; Orosun et al., 2019 and 2020), and Ilorin (Laterite, Nigeria; Orosun et al., 2020b).

3.1. Correlation analyses

To further investigate the degree of strength and nature of relationship between the measured activities of ^{238}U, ^{232}Th, ^{40}K and the radiation dose rate at both mining sites, Pearson's correlation technique was employed. The outcomes of the Pearson's correlation analysis are presented in Tables 4 and 5. The values were categorized by the correlation coefficient R (Orosun et al., 2020a,) 12, 22, as follows:

$0.8 \le |R| \le 1$ suggests a strong correlation;

$0.5 \le |R| \le 0.8$ suggests a significant correlation;

$0.3 \le |R| \le 0.5$ suggests a weak correlation; and

$|R| < 0.3$ suggests an insignificant correlation.

For Ilorin-west, a significant correlation was found to exist between ^{238}Th and dose rate (R = 0.5515) and weak correlation (R = 0.4234, and 0.3940) exist between ^{40}K and dose rate, and ^{238}U and dose rate respectively. For Ilorin-south, a significant correlation was observed between ^{238}Th and dose rate (R = 0.7289) and between ^{238}U and dose rate (R = 0.6474), respectively. However, an insignificant correlation was observed to exist between the primordial radionuclides

Table 1. In-situ mean activity concentrations of ^{40}K, ^{238}U, ^{232}Th and the absorbed dose rates from Kaolin mining field in Ilorin-west

SAMPLE Code	Latitude ^0N	Longitude ^0E	Elevation (*m*)	*DR* (*nGyh*$^{-1}$)	^{40}K (*Bqkg*$^{-1}$)	^{238}U (*Bqkg*$^{-1}$)	^{232}Th (*Bqkg*$^{-1}$)
IWS1	8.570288	4.577442	343	50.01 ± 7.14	344.30 ± 11.30	38.29 ± 2.03	29.23 ± 4.16
IWS2	8.569996	4.577592	342	63.14 ± 2.05	375.60 ± 9.62	59.28 ± 3.16	33.70 ± 2.50
IWS3	8.569656	4.577710	342	63.90 ± 3.14	469.50 ± 27.44	62.99 ± 7.39	25.98 ± 2.13
IWS4	8.569778	4.578155	342	74.42 ± 4.47	500.80 ± 23.57	62.99 ± 2.40	41.82 ± 4.27
IWS5	8.570198	4.577925	341	77.86 ± 7.31	782.50 ± 27.04	69.16 ± 3.62	24.36 ± 1.45
IWS6	8.570648	4.577764	339	52.86 ± 4.03	438.20 ± 24.15	33.35 ± 1.24	30.86 ± 1.61
IWS7	8.570813	4.578220	339	56.52 ± 5.29	688.60 ± 7.68	24.70 ± 1.47	29.64 ± 2.41
IWS8	8.570394	4.578381	341	70.06 ± 7.21	657.30 ± 13.51	30.88 ± 2.30	48.31 ± 5.30
IWS9	8.569906	4.578547	342	73.02 ± 7.83	344.30 ± 11.80	44.46 ± 2.97	64.15 ± 7.16
IWS10	8.570007	4.578960	340	78.01 ± 9.32	344.30 ± 7.32	64.22 ± 4.11	57.65 ± 6.16
IWS11	8.570388	4.578815	341	58.28 ± 3.15	406.90 ± 9.64	23.47 ± 1.65	49.94 ± 2.79
IWS12	8.570829	4.578563	342	50.02 ± 2.36	344.30 ± 8.23	27.17 ± 1.22	37.76 ± 2.34
IWS13	8.571062	4.578815	344	61.54 ± 4.86	438.20 ± 21.15	30.88 ± 1.83	49.13 ± 3.10
IWS14	8.570611	4.578933	341	75.58 ± 7.49	688.60 ± 27.25	35.82 ± 1.32	49.53 ± 3.83
IWS15	8.570113	4.579067	343	48.98 ± 2.25	344.30 ± 8.44	38.29 ± 2.57	29.23 ± 2.71
IWS16	8.570410	4.579266	342	45.92 ± 2.14	375.60 ± 9.25	21.00 ± 1.25	33.70 ± 2.39
IWS17	8.570776	4.579158	341	78.88 ± 7.64	406.90 ± 11.28	49.40 ± 2.67	65.77 ± 7.67
IWS18	8.571142	4.578960	339	81.13 ± 7.42	657.30 ± 21.40	59.28 ± 4.20	44.66 ± 4.24
IWS19	8.571327	4.579491	`341	62.82 ± 4.01	406.90 ± 13.11	35.82 ± 2.11	49.94 ± 4.84
IWS20	8.570887	4.579641	342	49.72 ± 2.07	344.30 ± 11.42	27.17 ± 1.14	37.76 ± 2.80
IWS21	8.570500	4.579786	344	71.29 ± 4.63	438.20 ± 14.21	30.88 ± 1.46	64.96 ± 7.22
IWS22	8.566198	4.581599	341	61.58 ± 5.30	375.60 ± 12.44	35.82 ± 2.13	49.53 ± 6.43
IWS23	8.566283	4.581910	343	62.98 ± 7.03	657.30 ± 23.05	38.29 ± 3.49	29.23 ± 2.86
IWS24	8.566442	4.582103	342	56.85 ± 4.22	375.60 ± 12.23	46.93 ± 3.56	33.70 ± 2.31
IWS25	8.566606	4.582366	342	46.76 ± 2.46	156.50 ± 2.10	51.87 ± 4.76	25.98 ± 2.68
IWS26	8.566750	4.582420	342	60.20 ± 1.98	187.80 ± 4.15	58.05 ± 4.12	41.82 ± 4.40

(Continued)

Table1. (*Continued*)

SAMPLE Code	**Latitude ^0N**	**Longitude ^0E**	**Elevation (*m*)**	***DR* (*nGyh*$^{-1}$)**	**^{40}K (*Bqkg*$^{-1}$)**	**^{238}U (*Bqkg*$^{-1}$)**	**^{232}Th (*Bqkg*$^{-1}$)**
IWS27	8.567450	4.582570	355	81.92 ± 7.16	751.20 ± 22.09	34.58 ± 2.54	58.06 ± 7.32
IWS28	8.567614	4.582340	356	79.68 ± 6.44	657.30 ± 14.16	54.34 ± 4.13	45.47 ± 5.10
IWS29	8.567651	4.582093	356	55.83 ± 4.23	344.30 ± 9.40	1.24 ± 0.13	66.99 ± 5.72
IWS30	8.567471	4.581792	357	53.48 ± 4.37	657.30 ± 13.24	19.76 ± 2.10	29.23 ± 4.12
IWS31	8.567455	4.581315	358	47.28 ± 6.23	594.70 ± 15.63	22.23 ± 2.53	22.33 ± 1.60
IWS32	8.567190	4.581465	358	54.46 ± 6.49	563.40 ± 12.12	35.82 ± 2.80	23.95 ± 2.11
IWS33	8.567185	4.581723	359	64.59 ± 4.62	657.30 ± 12.87	1.24 ± 0.13	62.93 ± 7.51
IWS34	8.567275	4.582044	357	67.20 ± 7.23	500.80 ± 11.42	12.35 ± 1.17	66.18 ± 5.70
IWS35	8.567036	4.581508	357	61.66 ± 3.27	657.30 ± 12.50	7.41 ± 0.11	52.37 ± 3.23
IWS36	8.566787	4.581825	358	64.01 ± 1.23	688.60 ± 1.34	1.24 ± 0.12	56.84 ± 5.28
IWS37	8.566887	4.580435	341	64.20 ± 7.52	406.90 ± 9.49	35.82 ± 2.20	49.94 ± 5.74
IWS38	8.566856	4.580880	342	61.94 ± 1.49	657.30 ± 19.45	28.41 ± 3.21	36.95 ± 2.15
IWS39	8.566458	4.581787	344	73.20 ± 9.43	438.20 ± 4.52	34.58 ± 3.65	64.15 ± 3.50
IWS40	8.566659	4.582028	341	69.34 ± 7.32	563.40 ± 14.90	35.82 ± 4.30	49.13 ± 2.73
Minimum				45.92 ± 2.14	156.50 ± 2.10	1.24 ± 0.12	22.33 ± 1.60
Maximum				81.92 ± 7.16	782.50 ± 27.04	69.16 ± 3.62	66.99 ± 5.72
Mean				63.28	492.19	35.63	44.07
Standard Deviation				10.48	156.90	17.66	13.94
Skewness				0.12	0.03	−0.08	0.14
Coefficient of Variation				16.56	31.88	49.56	31.63
Global Average			-	59.00	420.00	32.00	45.00

Table 2. In-situ mean activity concentrations of ^{40}K, ^{238}U, ^{232}Th and the absorbed dose rates from Kaolin mining field in Ilorin-south

SAMPLE Code	Latitude ^{0}N	Longitude ^{0}E	Elevation (*m*)	*DR* (*nGyh*$^{-1}$)	^{40}K (*Bqkg*$^{-1}$)	^{238}U (*Bqkg*$^{-1}$)	^{232}Th (*Bqkg*$^{-1}$)
ISK1	8.391960	4.707837	408	29.10 ± 2.01	156.50 ± 21.20	37.05 ± 2.33	9.74 ± 0.12
ISK2	8.390710	4.708084	408	26.90 ± 2.33	125.20 ± 17.31	40.76 ± 2.38	5.28 ± 0.80
ISK3	8.390336	4.708406	408	28.60 ± 3.21	62.60 ± 7.07	38.29 ± 1.03	13.40 ± 1.33
ISK4	8.390661	4.708366	410	13.90 ± 1.41	31.30 ± 2.15	9.88 ± 0.30	14.21 ± 0.62
ISK5	8.391430	4.708655	410	58.00 ± 6.53	375.60 ± 30.37	38.29 ± 3.05	37.76 ± 4.58
ISK6	8.391376	4.708052	411	23.80 ± 2.26	156.50 ± 13.11	19.76 ± 1.17	13.80 ± 1.05
ISK7	8.391196	4.707751	410	24.30 ± 2.38	31.30 ± 1.39	25.94 ± 1.59	17.86 ± 1.01
ISK8	8.391270	4.708116	408	54.80 ± 6.84	156.50 ± 11.20	59.28 ± 5.93	32.89 ± 2.04
ISK9	8.391016	4.708535	409	80.70 ± 7.08	219.10 ± 17.10	88.92 ± 7.70	48.72 ± 1.77
ISK10	8.391196	4.708792	411	59.60 ± 6.04	187.80 ± 13.67	62.99 ± 4.80	36.95 ± 1.29
ISK11	8.391100	4.707258	411	44.40 ± 4.52	406.90 ± 28.10	12.35 ± 0.96	34.10 ± 2.20
ISK12	8.390549	4.708932	411	59.00 ± 3.66	375.60 ± 22.33	39.52 ± 2.20	38.98 ± 2.84
ISK13	8.390145	4.707269	409	54.80 ± 2.43	532.10 ± 31.21	22.23 ± 0.86	34.10 ± 1.12
ISK14	8.389922	4.707966	410	77.50 ± 7.62	500.80 ± 29.95	38.29 ± 1.98	59.68 ± 3.16
ISK15	8.389816	4.708449	406	63.80 ± 5.67	250.40 ± 13.25	69.16 ± 3.94	34.51 ± 1.08
ISK16	8.389806	4.708814	408	58.90 ± 6.60	469.50 ± 22.01	46.93 ± 2.48	28.83 ± 1.84
ISK17	8.390103	4.708449	408	49.10 ± 2.05	125.20 ± 11.72	53.11 ± 7.11	32.07 ± 3.23
ISK18	8.390262	4.707558	409	54.00 ± 3.15	156.50 ± 10.33	96.33 ± 9.76	7.71 ± 0.08
ISK19	8.390188	4.708760	410	56.50 ± 4.19	125.20 ± 13.32	60.52 ± 5.20	36.95 ± 1.90
ISK20	8.390623	4.707719	408	38.60 ± 2.42	250.40 ± 12.65	1.24 ± 0.01	42.63 ± 1.89
ISK21	8.390718	4.707376	409	76.10 ± 6.35	219.10 ± 11.10	55.58 ± 3.51	64.96 ± 3.11
ISK22	8.390607	4.708380	411	72.40 ± 5.62	250.40 ± 9.43	49.40 ± 5.03	60.09 ± 7.42
ISK23	8.389944	4.707430	411	83.70 ± 7.26	62.60 ± 4.36	112.39 ± 7.97	47.50 ± 4.72
ISK24	8.390060	4.706861	411	50.20 ± 4.04	125.20 ± 9.03	81.51 ± 4.58	12.59 ± 1.09
ISK25	8.391440	4.709350	408	48.90 ± 2.33	187.80 ± 12.54	48.17 ± 2.12	29.23 ± 2.62
ISK26	8.391022	4.709322	407	57.80 ± 1.41	187.80 ± 11.39	92.63 ± 7.42	14.62 ± 1.71
ISK27	8.391440	4.709350	411	56.20 ± 3.03	406.90 ± 17.35	55.58 ± 5.62	21.11 ± 1.50
ISK28	8.391716	4.708095	411	65.90 ± 3.88	500.80 ± 23.94	59.28 ± 2.71	29.23 ± 4.79
ISK29	8.391440	4.708350	412	52.50 ± 2.61	375.60 ± 26.46	49.40 ± 2.99	23.55 ± 2.34
ISK30	8.391281	4.708459	411	47.50 ± 1.22	375.60 ± 23.32	33.35 ± 3.39	25.58 ± 2.36
ISK31	8.391440	4.709350	410	57.50 ± 5.07	156.50 ± 13.31	66.69 ± 7.15	31.67 ± 2.68
ISK32	8.391292	4.708953	412	51.50 ± 4.89	532.10 ± 32.06	25.94 ± 3.13	26.39 ± 1.95
ISK33	8.391695	4.709157	412	45.80 ± 3.07	313.00 ± 22.08	61.75 ± 2.37	8.93 ± 0.09

(Continued)

Table2. (*Continued*)

SAMPLE Code	Latitude ^0N	Longitude ^0E	Elevation (*m*)	*DR* (*nGyh*$^{-1}$)	^{40}K (*Bqkg*$^{-1}$)	^{238}U (*Bqkg*$^{-1}$)	^{232}Th (*Bqkg*$^{-1}$)
ISK34	8.391228	4.709820	409	73.20 ± 7.18	344.30 ± 18.01	97.57 ± 7.24	23.55 ± 2.68
ISK35	8.390665	4.709307	414	84.30 ± 6.28	313.00 ± 21.31	56.81 ± 3.59	69.02 ± 5.02
ISK36	8.390665	4.708610	410	79.80 ± 5.97	31.30 ± 1.28	132.15 ± 13.01	30.04 ± 2.38
ISK37	8.390729	4.708288	412	43.30 ± 2.38	93.90 ± 7.80	28.41 ± 7.49	41.41 ± 2.67
ISK38	8.390729	4.707987	412	32.00 ± 1.01	250.40 ± 9.25	40.76 ± 2.29	5.68 ± 0.80
ISK39	8.390814	4.707719	411	46.40 ± 5.09	313.00 ± 13.10	38.29 ± 1.96	25.58 ± 1.58
ISK40	8.390952	4.707440	409	88.30 ± 6.45	156.50 ± 11.32	82.75 ± 7.27	69.02 ± 3.15
ISK41	8.390941	4.707730	413	42.00 ± 3.43	187.80 ± 12.35	34.58 ± 2.10	29.64 ± 2.59
ISK42	8.390856	4.708041	413	57.90 ± 2.73	344.30 ± 15.82	54.34 ± 4.97	29.23 ± 2.13
ISK43	8.390729	4.708234	412	73.70 ± 6.25	125.20 ± 9.31	95.10 ± 3.12	40.19 ± 6.81
ISK44	8.390602	4.708588	412	53.60 ± 4.91	313.00 ± 27.84	60.52 ± 6.99	21.11 ± 2.27
ISK45	8.390485	4.708932	412	54.60 ± 4.98	406.90 ± 21.34	39.52 ± 2.54	29.23 ± 1.64
ISK46	8.390331	4.709206	412	54.80 ± 3.03	344.30 ± 23.60	32.11 ± 3.30	40.19 ± 1.80
ISK47	8.391408	4.708769	413	60.40 ± 8.28	406.90 ± 24.98	54.34 ± 5.76	29.23 ± 2.09
ISK48	8.389339	4.708824	412	57.30 ± 2.11	438.20 ± 21.08	45.70 ± 2.35	27.61 ± 2.65
ISK49	8.391387	4.709146	412	54.00 ± 2.62	532.10 ± 30.07	13.59 ± 0.97	38.16 ± 2.28
ISK50	8.390973	4.709350	412	57.40 ± 2.59	187.80 ± 13.55	53.11 ± 3.13	40.19 ± 6.98
Minimum				13.90 ± 1.41	31.30 ± 1.28	1.24 ± 0.01	5.28 ± 0.80
Maximum				88.30 ± 6.45	532.10 ± 30.07	132.15 ± 13.01	69.02 ± 3.15
Mean				54.71	263.55	52.24	31.25
Standard Deviation				16.68	145.18	27.01	15.60
Skewness				−0.18	0.26	0.73	0.60
Coefficient of Variation				30.49	55.09	51.70	49.90
Global Average			-	**59.00**	**420.00**	**32.00**	**45.00**

Table 3. Comparison of the mean activity concentration and dose rate with other studies

Material	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Dose rate (nGy h^{-1})	Location	References
Soil	19.16	48.56	1146.88	89.6	India	Chandrasekaran et al. (2019)
Kaolin	38.2	65.1	93.9	59.6	Nigeria (Ifonyintedo)	(Adagunodo et al., 2018).
Granite	11.51	15.42	441.06	32.72	Nigeria	(Orosun et al., 2020).
Granite	18.15	42.86	570.91	60.11	Nigeria	(Orosun et al., 2019).
Laterite	43.89	38.79	81.38	46.44	Nigeria	(Orosun et al., 2020b).
Kaolin	82	94.8	463.6	117.7	Turkey	(Turhan, 2009).
Clay	39.3	49.6	569.5	74.1	Turkey	(Turhan, 2009).
Floor ceramic	101.22	87.53	304.57	213.98	Iraq	(Amana, 2017).
Wall ceramic	102.12	70.9	328.6	178.4	Iraq	(Amana, 2017).
Kaolin	964.7	251.6	58.9	58.1	Eqypt	(El-Dine et al., 2004).
Phosphogypsum	206.8	99.1	15.1	154.6	Brazil	(Mazzilli & Saueia, 1999).
Kaolin	52.24	31.25	263.55	54.71	Nigeria (Ilorin-south)	Present study
Kaolin	35.63	44.07	492.19	63.28	Nigeria (Ilorin-west)	Present study
Soil and Rock	32	45	420	59	Global Average	(United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000).

for all the mining locations. The correlation results confirm that the enhanced outdoor dose rates was caused principally by ^{232}Th followed by ^{238}U and then ^{40}K.

3.3 Evaluation of the radiological hazard indices for the locations

The radiological risk parameters were computed to appraise the radiological hazards associated with the primordial radionuclides in the locations under study. The summary of the estimated hazards indices are provided in Tables 6 and 7 for Ilorin-west and Ilorin-south, respectively. The mean values of the outdoor absorbed dose rates for these locations are 63.28 ± 10.48 and 54.71 ± 16.68 nGyh^{-1}, respectively for Ilorin-west and Ilorin-south. While the mean value for Ilorin-south are within the recommended limit of 59.00 nGyh^{-1} provided by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000), the values recorded at Ilorin-west exceeds the global average value. Similarly, the estimated mean values of the annual effective doses are 0.08 and 0.07 mSvy^{-1}, respectively, for Ilorin-west and Ilorin-south. While the mean values for Ilorin-south approximately equal to the global average values of 0.07 mSvy^{-1} provided by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000), the mean values for Ilorin-west exceeds this recommended value. This shows that the Ilorin-west Kaolin mine field poses more significant source of radiation hazard. The estimated mean radium equivalent (Raeq), Hext, Hin and the representative level index (RLI) follow similar trends with both locations having values within the respective global averages. The estimated values for the ELCR corroborated our earlier findings with the estimated values for both locations falling within the global average value of 3.75×10^{-3} (see, Figures 4 and 5). If the

Table 4. Pearson's correlation matrix showing the relationship between the measured radionuclides and the gamma dose rate at Kaolin mining field in Ilorin-west

	Dose Rate	^{40}**K**	^{238}**U**	^{232}**Th**
Dose Rate	1.0000			
^{40}K	0.4234	1.0000		
^{238}U	0.3940	−0.2009	1.0000	
^{232}Th	0.5515	−0.0249	−0.3112	1.0000

Table 5. Pearson's correlation matrix showing the relationship between the measured radionuclides and the gamma dose rate at Kaolin mining field in Ilorin-south

	Dose Rate	^{40}**K**	^{238}**U**	^{232}**Th**
Dose Rate	1.0000			
^{40}K	0.2133	1.0000		
^{238}U	0.6474	−0.3386	1.0000	
^{232}Th	0.7289	0.1365	0.0814	1.0000

Table 6. Summary of the estimated *DR, AED,* H_{ext}, H_{int}*and* Ra_{eq} for the measured activity concentrations at Ilorin-west

STAT	***DR* (*nGyh*$^{-1}$)**	***AED***$_{out}$**(*mSvy*$^{-1}$)**	H_{ext}	H_{int}	Ra_{eq} **(*Bqkg*$^{-1}$)**	***ELCR* (*X 10*$^{-3}$)**
MIN	45.92	0.06	0.27	0.32	98.10	0.20
MAX	81.92	0.10	0.48	0.64	175.45	0.35
MEAN ± STDEV	63.28 ± 10.48	0.08 ± 0.01	0.37 ± 0.06	0.47 ± 0.09	136.55 ± 23.20	0.27 ± 0.05
LIMIT	59.00	0.07	≤1	≤1	370.00	3.75

Table 7. Summary of the estimated *DR, AED,* H_{ext}, H_{int} *and* Ra_{eq} for the measured activity concentrations at Ilorin-south

STAT	***DR* (*nGyh*$^{-1}$)**	***AED* (*mSvy*$^{-1}$)**	H_{ext}	H_{int}	Ra_{eq} **(*Bqkg*$^{-1}$)**	***ELCR* (*X 10*$^{-3}$)**
MIN	13.90	0.02	0.09	0.12	32.61	0.06
MAX	88.30	0.11	0.53	0.84	193.49	0.37
MEAN ± STDEV	54.71 ± 16.68	0.07 ± 0.02	0.32 ± 0.10	0.46 ± 0.16	117.28 ± 36.25	0.23 ± 0.07
LIMIT	59.00	0.07	≤1	≤1	370.00	3.75

values of radiological hazard parameters exceeds the recommended values, adjudged to cause serious radiation induced health effects like cancer, which can damage important human organs that could lead to death sometimes (Orosun et al., 2020b, 2019; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000).

4.0 Conclusion

A handheld Super Spec RS-125 gamma spectrometer was used to measure the activity concentrations of ^{40}K, ^{238}U, ^{232}Th and the gamma radiation dose rate of Kaolin mining fields in Ilorin-west and Ilorin-south in Nigeria. The results of the activity concentrations obtained were used to estimate the corresponding radiation impact parameters in order to assess the level of radiological hazards to the populace in the study area. The mean values of ^{40}K, ^{238}U, ^{232}Th and *DR* for Ilorin-

Figure 4. Summary of the estimated radiological parameters at Ilorin-west.

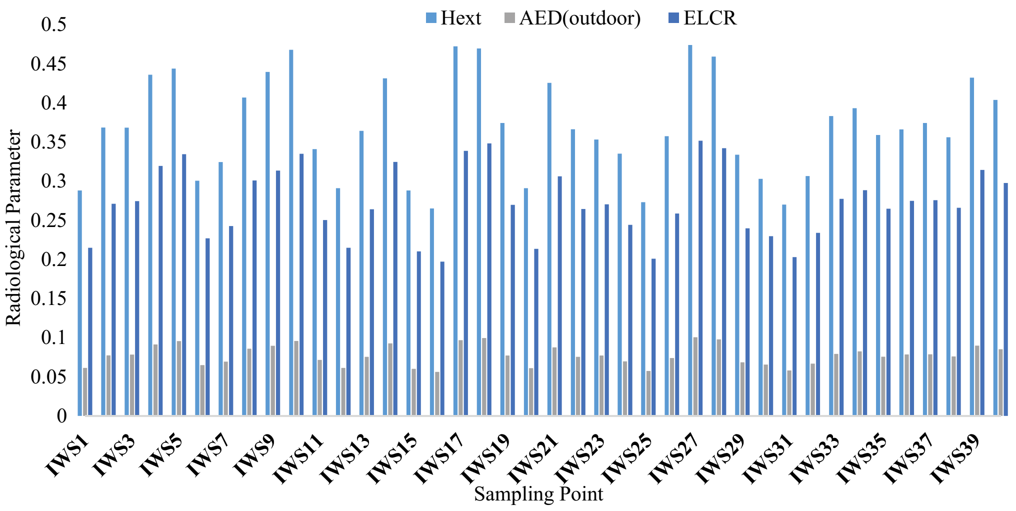
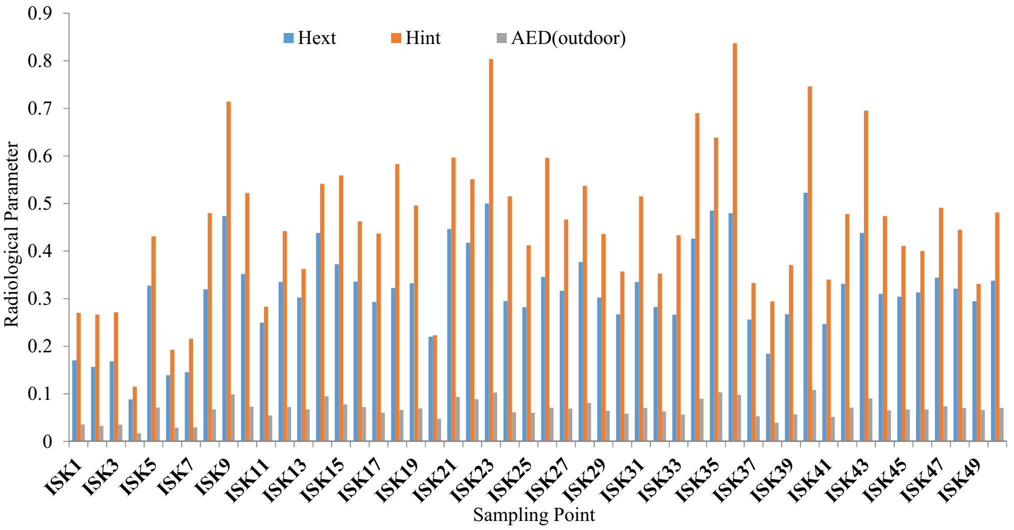


Figure 5. Summary of the estimated radiological parameters (RIP) at Ilorin-south.



west were found to be 492.19, 35.63, 44.07 $Bqkg^{-1}$ and 63.28 $nGyh^{-1}$, respectively. While the mean values for the measured activity concentrations of ^{40}K, ^{238}U, ^{232}Th and DR for Ilorin-south are 263.55, 52.24, 31.29 $Bqkg^{-1}$ and 54.71 $nGyh^{-1}$, respectively. The mean values of ^{40}K, ^{232}Th and DR for Ilorin-west are greater than the corresponding values at Ilorin-south. In contrast, the mean value of ^{238}U for Ilorin-west is less than the estimated mean value for Ilorin-south. Consequently, the mean values of the estimated radiological hazard parameters of Ilorin-west were higher than the estimated mean values for Ilorin-south. This shows that the Ilorin-west Kaolin mine field poses more significant source of radiation hazard. Considering that recommended values for background radiation were exceeded at the Ilorin-west Kaolin mine field, it follows that the Kaolin from Ilorin-west should not be used for building and construction purposes and the local populace should be mindful of health effects like cancer and other radiation induced health effects. Similarly, the dataset generated in this study could be utilized by the Nigerian Nuclear Regulatory Agency (NNRA) and related authorities for enforcement of rules and laws to reduce the mining exercises in the nation.

Article highlights

- The activity concentrations result showed that the locations are enhanced with ^{40}K compared with ^{238}U and ^{232}Th.
- The estimated average values for all radiological hazard parameters for the *in-situ* measurements of Ilorin-west are higher than that of Ilorin-south minefield.

The mean values of the estimated radiological hazard parameters are mostly within the recommended global averages for both locations.

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Consent for publication

All authors have read and agreed to the published version of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability

The data supporting the findings of this study are available on request from the corresponding author.

Author contribution

M.M.O. conceived and designed the research work, performed the risk analysis, and wrote the paper. M.M.O. and A. A. collect the data, performed the risks analysis and compilation of the work. M.R.U. and K.J.O. supervised the work and final editing of the manuscript.

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