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Radiological hazards assessment of laterite mining field in Ilorin, North-central Nigeria

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► ***Original article***

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ABSTRACT

Background: Assessment of activity concentrations of ^{238}U, ^{232}Th, ^{40}K and gamma dose rate (DR) was carried out over a laterite mining field in Ilorin-south, Nigeria. ***Materials and Methods:*** A well calibrated Super-Spec (RS-125) gamma spectrometer was used to measure the activity concentrations of ^{40}K, ^{238}U, ^{232}Th and gamma doses rate at 1 m above the ground level over the laterite mining field. Fifty (50) measurements of the activity concentration of the radionuclides were obtained at about 1 meter above the topsoil. For each point, measurements were taken four (4) times for better accuracy. ***Results:*** The overall mean of the activity concentrations of ^{40}K, ^{238}U and ^{232}Th are 81.38, 43.89 and 38.79 $Bqkg^{-1}$ respectively. The mean value for DR was found to be 46.44 $nGyhr^{-1}$. The mean activity concentrations of ^{238}U and ^{232}Th are higher than the recommended limits provided by UNSCEAR. This is a cause for worry as significant enhancement in the concentration of ^{238}U and ^{232}Th will increase the level of the background radiation and possibly render the soil unfit for use in building and construction. The results of most of the radiological impact parameters (RIP) are above the limits provided by UNSCEAR. ***Conclusion:*** From the results, it implies that the risk of indoor gamma radiation exposure is high for this lateritic soil. So the lateritic soil from this mine field may not be too suitable for building and construction purposes.

Keywords: *Radioactivity, background radiation, gamma spectrometry, radiological impact parameters, Ilorin.*

INTRODUCTION

To achieve rapid economic development, third-world countries like Nigeria often resort to mining to exploit natural resources. Consequently, mining is an important economic activity which has the potential of contributing to the development of areas endowed with the resources. It contributes to the revenue of countries; increase the Gross Domestic Product (GDP) and foreign exchange earnings [(1)]. But as desirable and necessary as this is, it became an albatross because of the lack of appropriate policies to guide it in Nigeria. The impact of these mining activities on our environment and health can never be over-emphasized. Recent investigations revealed that mining and smelting activities are the main causes for the increasing pollution of radionuclides and other toxic contaminants [(2–4)]. The enhancement of these radionuclides from the mining, milling and smelting activities can cause potential radiation exposure to members of the public leading to harmful and even lethal effects. The human health effects of the ionizing radiation from these mineral resources hinge on the use of mineral soils from the contaminated sites. These mineral soils, particularly laterites (a reddish clayey soil, rich in aluminum and iron oxides, formed as a result of weathering of igneous rocks in moist temperate climates) are used in building and construction of houses in Nigeria

[5, 6]. Although Lateritic soils are sometimes used as an iron ore and a source of nickel, they are widely used as construction materials for houses, roads, dam embankment, landfills and flexible pavement foundations, etc. Because blocks made from these soils (laterites) are naturally obtainable (available), cheap, energy efficient to produce and have good geotechnical properties, it becomes a handy material for construction that even the underprivileged and low class or low income earners can afford [7]. Considering the radiological health implications linked with the exposure to indoor ionizing radiation, regulatory bodies such as United State Environmental Protection Agency (USEPA), the World Health Organization (WHO), and International Commission on Radiological Protection (ICRP) etc. have implemented stringent measures intended to reduce such exposures. Consequently, the call for the measurement and assessment of natural radionuclides in soils used for building and construction purposes (particularly soils around mining, milling and smelting industries) worldwide becomes obligatory [5, 8, 9].

In Nigeria, the levels of ^{238}U, ^{234}Th and their respective progenies together with the non-series ^{40}K have been studied in different mineral soils from many parts of the country [10 – 19]. But there is no data on the activity concentration of natural radionuclides (^{238}U, ^{234}Th and ^{40}K) in Laterites in this part of the country, despites the level of the mining activities. Also, data from University of Ilorin Teaching Hospital (UITH) shows that 74 different cancers of 2,246 (891 male and 1355 female) cancer patients within the age of 1-105 were recorded at the University of Ilorin Teaching Hospital (UITH) cancer registry between the period of 2007 and 2016 [20]. Hence the aim of this research work is to assess the *activity concentrations of ^{238}U, ^{232}Th, ^{40}K and gamma dose rate (DR)* over the Laterite mine field in Ilorin, North central Nigeria using a well calibrated Super-Spec (RS-125) gamma and use the results to estimate the radiation absorbed dose rates, annual effective dose, external and internal radiation hazard indices and other radiological hazard parameters. The results of this research will serve as a firsthand information that can be used to assess the radiological health implications on the general populace due to the use of laterites from the mining sites in Ilorin-south, Kwara, North central Nigeria. This will help the Government to make policies that will help to regulate the mining activities and keep the standard of living of the people as high as possible.

Study area

The study area is along Ajasse-Ipo road in Ilorin-south LGA in Kwara state, Nigeria. It is situated between latitudes 8º20' N and 8º50' N and Longitudes 4º25' E and 4º65'E (figure 1a and b). For the geology of the study area, a large part of Ilorin town is underlain by basement complex rock. The soils are formed from 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 [21, 22, 23]. The assortment of basement complex rocks brings about large number of ferruginous groups of soils. Therefore, lateritic soil type (generally deep red in colour with high clay content) is the major type of soil in Ilorin. Detail geology of Ilorin can be found in [22, 23, 24].

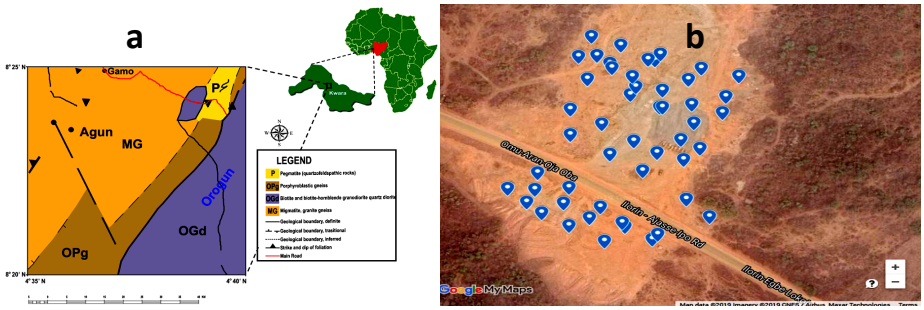

Figure1. (a) Map of Nigeria showing the survey area **(b)** Laterite mining field in Ilorin-south LGA showing the sample collection points.

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MATERIALS AND METHODS

Field Survey

For the *in situ* measurements of activity concentrations of ^{40}K, ^{232}Th, ^{238}U and the radiation dose exposures, Super SPEC RS-125 spectrometer with large 2.0 × 2.0 NaI crystal was used. The measurement of the activity concentration of the radionuclides was carried out at about 1 metre above the topsoil [19, 25]. The RS-125 is a transportable handheld radiation detector with high accuracy and likely error of about 5%. It presents superior integrated design with big detector, good sensitivity and easy to use. The model RS-125 super-spec is manufactured by Canadian Geophysical Institute, Canada. It comes with a large data storage which allows one to take multiple readings with ease. The RS-125 spectrometer was calibrated in accordance with Canadian Geophysical Institute i.e., the instrument was calibrated on 1 × 1 m test pads, which employs 5min spectra accumulation on potassium, uranium and thorium pads and 10 min accumulation on the Background pad. It makes use of sodiumiodide (NaI) crystal doped with thallium [Tl] as activator. The energy range of the instrument, is from 30 to 3000 keV, which is enough to detect most of the radiation giving off from the terrestrial sources (i.e. ^{214}Bi (609.31 and 1764.49 keV) gamma rays to determine ^{238}U, ^{212}Pb (238.63 keV), ^{208}Tl (583.19 keV) and ^{228}Ac (911.21keV) gamma rays to determine ^{232}Th and the photopeaks of ^{40}K which occours in the background spectrum at 1460.83 keV). The total count of 120 s per assay was employed for best accuracy as stated in Radiation Solutions Inc (Radiation solution Inc, 2015; Adgunodo *et al*., 645[2]). The assay mode of the instrument gives the activity concentration of ^{40}K in percentage (%), ^{238}U and ^{232}Th in part per million (ppm). The data was converted to the conventional unit $Bqkg^{-1}$ using conversion factors given by [26, 27].

In this work, four (4) readings were recorded at each data point at the interval of 120 seconds. 50 sample points were recorded to cover the area of the mining field. The field was divided into grids of approximately equal size (i.e. 50 semi-rectangular boxes) with each box representing a data collection point. At each of these samples location (point), the coordinate and elevation were determined using a global positioning system (GPSMAP78). More details about the instrument can be found in earlier works where this same Super SPEC RS-125 spectrometer was used [19, 25, 28, 29].

Estimation of the radiological impact parameters (RIP)

Absorbed dose rate

Estimating the absorbed dose rate is usually the initial step for evaluating the health risk. The biological effects of ionizing radiation are unswervingly associated with the absorbed dose rate [30]. The outdoor absorbed dose rate at 1 meter height above the ground level (it is assumed that the naturally occurring radionuclides will have a uniform distribution at this height) is calculated using equation (1) [16, 25, 31, 32, 33].

$$D_{outdoor}(nGy\ h^{-1})=0.462_u+0.604C_{Th}+0.041C_K \quad (1)$$

But fortunately, this outdoor dose rate was measured *in situ* using the RS-125 Gamma Spec.

The laterite from study area as emphasized earlier, is used predominantly for building purposes. Consequently, the indoor radiation dose rate in a characteristic building of typical room 4 × 5 × 2.8 m size having wall thickness of about 20 cm and density of the structure 2350 kgm^{-3} was calculated using the equation provided by [31] and [34] for building materials as used by numerous researchers [16, 31, 34, 35, 36, 37]:

$$D_{intdoor}(nGy\ h^{-1}) = 0.92C_u + 1.1C_{Th} + 0.08C_K \quad (2)$$

C_u, C_{Th} and C_K are the radioactivity concentration in $Bqkg^{-1}$ for ^{238}U, ^{232}Th and ^{40}K respectively.

Annual effective dose (AED)

The effective dose which is the tissue-weighted aggregate of the equivalent doses in all specified tissues and organs of the body. It corresponds to the stochastic health risks to the whole body. The annual effective dose received indoor and outdoor by a member

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of the public was calculated from dose rates given in equations (1) and (2) by using dose conversion factor of 0.7 $SvGy^{-1}$ and occupancy factor for outdoor and indoor as 0.2 and 0.8 respectively [16, 31].

$$AED_{outdoor}\ (mSvy^{-1}) = D_{outdoor}\ (nGyh^{-1}) \times 8760\ h \times 0.7\ (SvGy^{-1}) \times 0.2 \times 10^{-6} \quad (3)$$

$$AED_{intdoor}\ (mSvy^{-1}) = D_{indoor}\ (nGyh^{-1}) \times 8760\ h \times 0.7\ (SvGy^{-1}) \times 0.8 \times 10^{-6} \quad (4)$$

Radium equivalent activity index (Ra_{eq})

The radium equivalent (Ra_{eq}) activity which is a weighted sum of activities of ^{238}U, ^{232}Th and ^{40}K based on the assumption that 5 $Bqkg^{-1}$ of ^{238}U, 0.7 $Bqkg^{-1}$ of ^{232}Th and 57 $Bqkg^{-1}$ of ^{40}K produce the same radiation dose rates. This permit a solitary index or figure to portray the gamma output due to different combination of ^{238}U, ^{232}Th and ^{40}K in a material. This radiation hazard index estimates the appropriateness of the laterite soil to be used as a building material. It was calculated using equation (5) [38]:

$$Ra_{eq} = C_u + 1.43C_{Th} + 0.077C_K \quad (5)$$

C_U, C_{Th} and C_K are as defined in equation (1) and (2) above. The recommended average value for Ra_{eq} is 370 $Bqkg^{-1}$.

Radiation hazard indices

The external radiation hazard (H_{ext}) and the internal radiation hazard (H_{int}) were calculated using equation 6 and 7.

$$H_{ext} = \left(\frac{C_U}{370}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_K}{4810}\right) \quad (6)$$

$$H_{int} = \left(\frac{C_U}{185}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_K}{4810}\right) \quad (7)$$

H_{int} and H_{ext} ought to be less than 1 for the radiation hazard to be insignificant. Natural radionuclides in soil produce an external field to which all humans are exposed. H_{ext} equal to unity translates to the upper limit of radium equivalent dose (370 $Bqkg^{-1}$) [31, 38].

Excess lifetime cancer risk (ELCR)

The Excess Lifetime Cancer Risk ($ELCR$) was calculated using the following equation:

$$ELCR = AED_{indoor} \times DL \times RF \quad (8)$$

AED_{indoor} is the indoor annual equivalent dose should the laterite be used for building construction, DL is the average duration of life (estimated to 70 years) and RF is the risk factor (Sv^{-1}), i.e. fatal cancer risk per Sievert [31, 39].

Annual gonadal equivalent dose (AGED)

There are some organs that are considered of interest by UNSCEAR because of their sensitivity to radiation. These organs include; the gonads, the bone marrow and the bone surface cells [31]. An increase in $AGED$ has been known to result in leukemia which is very fatal. This hazard parameter for the residents using the laterite for building was evaluated using equation (9) [31, 38]:

$$AGED\ (\mu Svy^{-1})\ C = 3.09C_U + 4.18C_{Th} + 0.314C_K \quad (9)$$

C_U, C_{Th}, and C_K maintain their usual meanings.

Representative Level Index (RLI)

This hazard parameter estimates the gamma radiation hazard associated with the natural radionuclide in the samples under examination. The RLI was estimated using equation 10 [31, 38]:

$$RLI = \frac{C_u}{150} + \frac{C_{Th}}{100} + \frac{C_k}{1500} \leq 1 \quad (10)$$

C_U, C_{Th}, and C_K maintain their usual meanings.

RLI values of 5 corresponds to an AED of less than or equal to 1 mSv, while RLI = 0.5 corresponds to AED less or equal to 0.3 $mSvy^{-1}$. Thus, RLI serves as a screening tool for identifying building materials that may possibly be of concern to be used as construction materials [31, 38].

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RESULTS

The result and statistical analysis (Min, Max, Median, Mean, STDEV, SKE and KURT) of the measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th, the elevations and the dose rate for the 94 sample locations is presented in table 1. The measured values for all the parameters (i.e. ^{238}U, ^{232}Th, ^{40}K and DR) were moderately skewed (the distribution is approximately or moderately symmetric) since most of the measure of the asymmetry of their probability distribution about their means is in the range of -2 and +2 [40]. As expected, the mean activity concentration of ^{40}K is higher than the ^{238}U and ^{232}Th mean activities. ^{40}K has highest activity concentration of 187.80 ± 2.44 $Bqkg^{-1}$ and lowest value of 31.30 ± 1.00 $Bqkg^{-1}$. The highest and lowest activity concentrations of ^{238}U and ^{232}Th were found to be $^{1}9.78/\ 6.66$, $^{0}9.^{11}/\ 6.4^{3}$ $Bqkg^{-1}$ and 21.00 ± 0.82, 16.65 ± 2.66 $Bqkg^{-1}$ respectively. The overall mean of the activity concentrations of the measured radionuclides was calculated and found to be 81.38, 43.89 and 38.79 $Bqkg^{-1}$for ^{40}K, ^{238}U and ^{232}Th respectively. The measured values and estimated mean value for ^{40}K were lower than the global average of 420.00 $Bqkg^{-1}$ for normal background radiation levels given by UNSCEAR (figure 2). Surprisingly, the mean activity concentrations of ^{238}U and ^{232}Th are higher than their corresponding global average of 32.00 $Bqkg^{-1}$ and 30.00 $Bqkg^{-1}$ respectively provided by UNSCEAR. This is a cause for worry as significant enhancement in the concentration of ^{238}U and ^{232}Th will increase the level of the background radiation and possibly render the soil unfit for use in building and construction purposes. The values for the measured outdoor dose rate (DR) ranges between 70.80 ± 6.23 and 30.10 ± 2.03 $nGy\ hr^{-1}$ with an average value of 46.44 $nGy\ hr^{-1}$. This mean value for the outdoor dose is lower than 59 $nGyh^{-1}$ provided by UNSCEAR.

Radiological impact parameters (*RIP*) were estimated to evaluate the radiological risks that are associated with the lateritic soil from Ilorin-south LGA. The estimated hazards parameters are presented in table 2. The outdoor absorbed dose rate (D_{out}) at 1 meter height above the level ground was estimated using equation 1. The resulting values of the outdoor absorbed dose rate were used to estimate outdoor annual effective dose ($AED_{outdoor}$) using equation 3. The estimated mean values for the D_{out} and $AED_{outdoor}$ are 47.04 $nGyh^{-1}$ and 0.06 $mSvy^{-1}$ respectively. These values are lower than 59.00 $nGyh^{-1}$and 0.07 $mSvy^{-1}$ provided by UNSCEAR. The indoor gamma dose (D_{in}) incurred by the general public as a result of the radionuclides concentration in the lateritic soil from the mine field ranges between 135.68 and 58.58 $nGyh^{-1}$ with an average value of 89.56 $nGyh^{-1}$. The D_{in} was used to estimate indoor annual effective dose (AED_{indoor}) using equation 4. The resulting highest, lowest and mean values of AED_{indoor} are 0.67, 0.29 and 0.44 $mSvy^{-1}$ respectively. The estimated mean values of D_{in} and AED_{indoor} are above the recommended limits of 84.00 $nGyh^{-1}$ and 0.41 $mSvy^{-1}$ respectively provided by UNSCEAR [9, 16, 17, 19, 31]. This follows that the risk of indoor gamma radiation exposure is high for this lateritic soil and the general public are not safe from overexposure to indoor ionizing radiation.

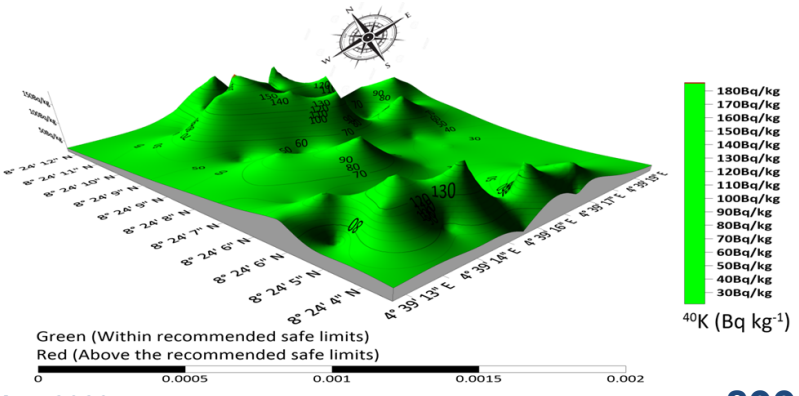

Figure 2. Isopotassium map of the laterite mining field.

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Table 1. Measured activity concentrations of ^{40}K, ^{238}U, ^{232}Th and the absorbed dose rates from Ilorin-south LGA.

SAMPLE Code	Latitude ^{o}N	Longitude ^{o}E	Elevatn (*m*)	DR ($nGyh^{-1}$)	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)
ISS1	8.401632	4.653531	341	44.00±1.13	93.90±2.00	23.47±3.66	49.94±2.22
ISS2	8.401484	4.653681	342	35.10±2.52	31.30±2.00	27.17±2.20	37.76±4.61
ISS3	8.401367	4.653799	344	48.20±1.91	125.20±3.60	30.88±2.11	49.13±2.02
ISS4	8.401229	4.654014	341	48.00±3.07	62.60±1.03	35.82±1.00	49.53±1.98
ISS5	8.401059	4.654293	343	35.70±3.10	31.30±6.30	38.29±1.63	29.23±4.05
ISS6	8.401080	4.654668	342	31.20±2.22	62.60±2.63	21.00±0.82	33.70±2.22
ISS7	8.401218	4.654454	342	65.90±6.51	156.50±3.03	64.22±2.01	50.34±5.44
ISS8	8.401314	4.654175	342	62.00±2.93	187.80±2.44	62.99±2.00	41.82±2.11
ISS9	8.401473	4.653971	341	48.30±2.05	156.50±2.61	59.28±1.05	24.36±2.02
ISS10	8.401622	4.653746	339	39.00±1.32	125.20±2.60	33.35±2.11	30.86±1.08
ISS11	8.401802	4.653767	339	31.20±1.07	62.60±2.20	24.70±2.04	29.64±2.33
ISS12	8.401643	4.654014	341	44.20±2.44	31.30±2.20	30.88±2.82	48.31±2.04
ISS13	8.401431	4.654260	342	52.10±3.20	31.30±1.60	44.46±1.08	50.34±2.20
ISS14	8.401261	4.654432	340	52.10±4.32	31.30±4.30	33.35±0.98	59.28±2.20
ISS15	8.401133	4.654711	341	30.10±2.03	125.20±2.63	27.17±1.02	21.52±4.12
ISS16	8.401324	4.655119	339	30.20±1.83	31.30±1.85	35.82±1.44	21.52±2.01
ISS17	8.401515	4.654936	340	34.80±2.22	31.30±2.13	45.70±2.04	21.11±1.02
ISS18	8.401823	4.654593	341	32.50±1.45	31.30±5.65	46.93±1.80	16.65±2.66
ISS19	8.402004	4.654336	341	59.20±2.84	125.20±1.06	49.40±2.21	53.19±2.81
ISS20	8.402216	4.654024	341	55.40±5.47	93.90±2.20	49.40±2.28	49.13±2.23
ISS21	8.402492	4.654024	339	55.00±3.74	31.30±4.61	59.28±1.02	44.66±2.67
ISS22	8.402333	4.654271	340	32.10±2.13	31.30±1.40	30.88±1.05	29.23±1.82
ISS23	8.402147	4.654523	341	50.00±4.10	31.30±2.60	71.63±2.20	25.98±2.12
ISS24	8.402020	4.654706	342	33.10±2.11	31.30±1.20	25.94±1.02	33.70±2.01
ISS25	8.401945	4.654915	341	70.80±6.23	31.30±1.60	75.34±2.22	58.06±2.51
ISS26	8.402067	4.655044	342	46.10±2.02	31.30±2.61	59.28±2.08	30.04±2.20
ISS27	8.402163	4.654894	341	37.20±1.21	31.30±2.63	55.58±2.00	20.71±1.20
ISS28	8.402513	4.654725	341	40.10±2.75	156.50±3.11	44.46±1.08	22.33±0.95
ISS29	8.402651	4.654494	342	49.50±3.12	156.50±2.60	32.11±0.75	46.69±2.33
ISS30	8.402821	4.654161	342	40.20±2.19	156.50±1.02	32.11±2.60	31.67±2.21
ISS31	8.403076	4.654231	341	65.90±2.02	93.90±2.60	49.40±2.07	65.77±2.09
ISS32	8.402991	4.654338	339	55.10±2.32	31.30±2.54	59.28±2.06	44.66±2.05
ISS33	8.402736	4.654537	341	48.90±2.05	93.90±2.28	35.82±2.22	49.94±2.22
ISS34	8.402513	4.654746	342	36.30±1.55	31.30±1.82	27.17±1.20	37.76±2.07
ISS35	8.402343	4.654993	344	58.60±4.32	125.20±4.63	30.88±2.33	64.96±2.02
ISS36	8.402455	4.655218	341	49.00±2.12	62.60±2.60	35.82±1.60	49.53±2.11
ISS37	8.402545	4.654977	343	36.30±2.08	31.30±2.54	38.29±4.63	29.23±1.88
ISS38	8.402699	4.654746	342	44.30±2.37	62.60±2.21	46.93±3.32	33.70±4.22
ISS39	8.402847	4.654515	342	46.00±1.34	156.50±2.26	51.87±2.11	25.98±5.22
ISS40	8.402943	4.654354	342	58.90±2.87	187.80±4.10	58.05±2.00	41.82±2.11
ISS41	8.403065	4.654086	343	36.30±1.44	31.30±1.33	38.29±1.00	29.23±2.02
ISS42	8.403283	4.654193	342	49.30±2.21	62.60±2.60	59.28±4.20	33.70±3.22
ISS43	8.403187	4.654419	342	51.10±2.09	156.50±2.24	62.99±2.44	25.98±3.04
ISS44	8.403028	4.654687	342	61.10±4.02	187.80±2.54	62.99±2.42	41.82±2.64
ISS45	8.402816	4.654950	341	51.80±5.92	156.50±5.40	69.16±2.05	24.36±4.56
ISS46	8.402630	4.655250	339	38.80±2.21	125.20±6.20	33.35±1.08	30.86±3.04
ISS47	8.402853	4.655347	339	31.10±2.35	62.60±2.60	24.70±1.03	29.64±2.62
ISS48	8.402938	4.655052	341	44.10±2.73	31.30±1.42	30.88±2.60	48.31±2.88
ISS49	8.403092	4.654735	342	60.50±3.75	31.30±1.50	44.46±2.88	64.15±2.21
ISS50	8.403032	4.654638	340	65.50±2.01	31.30±1.00	64.22±4.23	57.65±3.01
Min			**339.00**	**30.10±2.03**	**31.30±1.00**	**21.00±0.82**	**16.65±2.66**
Max			**344.00**	**70.80±6.23**	**187.80±2.44**	**75.34±2.22**	**65.77±2.09**
Mean			**341.22**	**46.44**	**81.38**	**43.89**	**38.79**
Median			**47.05**	**62.60**	**41.37**	**35.73**	**47.05**
STDEV			**11.09**	**55.13**	**14.76**	**13.18**	**11.09**
SKEW			**0.27**	**0.60**	**0.36**	**0.33**	**0.27**
KURT			**-0.87**	**-1.19**	**-1.07**	**-0.92**	**-0.87**
Global Average			**-**	**59.00**	**420.00**	**32.00**	**30.00**

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Table 2. Summary of the estimated radiological impact parameters (RIP).

SAMPLE Code	D_{in} ($nGyh^{-1}$)	D_{out} ($nGyh^{-1}$)	$AED_{outdoor}$ ($mSvy^{-1}$)	AED_{indoor} ($mSvy^{-1}$)	Ra_{eq} ($Bqkg^{-1}$)	H_{ext}	H_{int}	RLI	ELCR ($X\ 10^{-3}$)	AGED ($mSvy^{-1}$)
ISS1	84.03	44.85	0.06	0.41	102.11	0.28	0.34	0.72	1.44	0.31
ISS2	69.03	36.64	0.04	0.34	83.57	0.23	0.30	0.58	1.19	0.25
ISS3	92.46	49.07	0.06	0.45	110.77	0.30	0.38	0.78	1.59	0.34
ISS4	92.44	49.03	0.06	0.45	111.47	0.30	0.40	0.78	1.59	0.34
ISS5	69.88	36.63	0.04	0.34	82.50	0.22	0.33	0.57	1.20	0.25
ISS6	61.39	32.62	0.04	0.30	74.00	0.20	0.26	0.52	1.05	0.23
ISS7	126.98	66.49	0.08	0.62	148.26	0.40	0.58	1.04	2.18	0.46
ISS8	118.97	62.06	0.08	0.58	137.25	0.37	0.54	0.97	2.04	0.43
ISS9	93.85	48.52	0.06	0.46	106.17	0.29	0.45	0.75	1.61	0.33
ISS10	74.64	39.18	0.05	0.37	87.11	0.24	0.33	0.62	1.28	0.27
ISS11	60.33	31.88	0.04	0.30	71.90	0.20	0.26	0.50	1.04	0.22
ISS12	84.05	44.73	0.05	0.41	102.37	0.28	0.36	0.71	1.44	0.31
ISS13	98.79	52.23	0.06	0.48	118.86	0.32	0.44	0.82	1.70	0.36
ISS14	98.39	52.49	0.06	0.48	120.52	0.33	0.42	0.84	1.69	0.36
ISS15	58.68	30.68	0.04	0.29	67.58	0.18	0.26	0.48	1.01	0.21
ISS16	59.12	30.83	0.04	0.29	69.00	0.19	0.28	0.48	1.02	0.21
ISS17	67.77	35.15	0.04	0.33	78.30	0.21	0.34	0.54	1.16	0.24
ISS18	63.99	33.02	0.04	0.31	73.14	0.20	0.32	0.50	1.10	0.22
ISS19	113.97	60.08	0.07	0.56	135.10	0.37	0.50	0.95	1.96	0.41
ISS20	107.00	56.34	0.07	0.52	126.88	0.34	0.48	0.89	1.84	0.39
ISS21	106.17	55.65	0.07	0.52	125.55	0.34	0.50	0.86	1.82	0.38
ISS22	63.06	33.20	0.04	0.31	75.09	0.20	0.29	0.52	1.08	0.23
ISS23	96.99	50.07	0.06	0.48	111.20	0.30	0.49	0.76	1.67	0.34
ISS24	63.43	33.62	0.04	0.31	76.53	0.21	0.28	0.53	1.09	0.23
ISS25	135.68	71.16	0.09	0.67	160.77	0.44	0.64	1.11	2.33	0.49
ISS26	90.09	46.82	0.06	0.44	104.65	0.28	0.44	0.72	1.55	0.32
ISS27	76.41	39.47	0.05	0.37	87.59	0.24	0.39	0.60	1.31	0.27
ISS28	77.99	40.44	0.05	0.38	88.44	0.24	0.36	0.63	1.34	0.28
ISS29	93.42	49.45	0.06	0.46	110.93	0.30	0.39	0.79	1.60	0.34
ISS30	76.90	40.38	0.05	0.38	89.45	0.24	0.33	0.64	1.32	0.28
ISS31	125.31	66.40	0.08	0.61	150.68	0.41	0.54	1.05	2.15	0.46
ISS32	106.17	55.65	0.07	0.52	125.55	0.34	0.50	0.86	1.82	0.38
ISS33	95.39	50.56	0.06	0.47	114.46	0.31	0.41	0.80	1.64	0.35
ISS34	69.03	36.64	0.04	0.34	83.57	0.23	0.30	0.58	1.19	0.25
ISS35	109.88	58.63	0.07	0.54	133.41	0.36	0.45	0.94	1.89	0.41
ISS36	92.44	49.03	0.06	0.45	111.47	0.30	0.40	0.78	1.59	0.34
ISS37	69.88	36.63	0.04	0.34	82.50	0.22	0.33	0.57	1.20	0.25
ISS38	85.25	44.60	0.05	0.42	99.94	0.27	0.40	0.69	1.46	0.31
ISS39	88.82	46.07	0.06	0.44	101.08	0.27	0.41	0.71	1.53	0.32
ISS40	114.43	59.77	0.07	0.56	132.31	0.36	0.52	0.93	1.96	0.41
ISS41	69.88	36.63	0.04	0.34	82.50	0.22	0.33	0.57	1.20	0.25
ISS42	96.61	50.31	0.06	0.47	112.29	0.30	0.46	0.78	1.66	0.34
ISS43	99.05	51.21	0.06	0.49	112.19	0.30	0.47	0.79	1.70	0.35
ISS44	118.97	62.06	0.08	0.58	137.25	0.37	0.54	0.97	2.04	0.43
ISS45	102.94	53.08	0.07	0.50	116.05	0.31	0.50	0.81	1.77	0.36
ISS46	74.64	39.18	0.05	0.37	87.11	0.24	0.33	0.62	1.28	0.27
ISS47	60.33	31.88	0.04	0.30	71.90	0.20	0.26	0.50	1.04	0.22

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Continuation of Table 2. Summary of the estimated radiological impact parameters (RIP).

SAMPLE Code	D_{in} ($nGyh^{-1}$)	D_{out} ($nGyh^{-1}$)	$AED_{outdoor}$ ($mSvy^{-1}$)	AED_{indoor} ($mSvy^{-1}$)	Ra_{eq} ($Bqkg^{-1}$)	H_{ext}	H_{int}	RLI	ELCR ($X\ 10^{-3}$)	AGED ($mSvy^{-1}$)
ISS48	84.05	44.73	0.05	0.41	102.37	0.28	0.36	0.71	1.44	0.31
ISS49	113.97	60.57	0.07	0.56	138.60	0.38	0.50	0.96	1.96	0.42
ISS50	125.00	65.77	0.08	0.61	149.07	0.40	0.58	1.03	2.15	0.45
Min	58.68	30.68	0.04	0.29	67.58	0.18	0.26	0.48	1.01	0.21
Max	135.68	71.16	0.09	0.67	160.77	0.44	0.64	1.11	2.33	0.49
Mean	89.56	47.04	0.06	0.44	105.63	0.29	0.41	0.74	1.54	0.32
Median	**91.27**	47.67	0.06	0.45	105.41	0.29	0.40	0.73	1.57	0.33
STDEV	**20.91**	11.00	0.01	0.10	24.81	0.07	0.10	0.17	0.36	0.08
SKEW	0.27	0.28	0.28	0.27	0.29	0.29	0.32	0.27	0.27	0.27
KURT	-0.87	-0.88	-0.88	-0.87	-0.85	-0.85	-0.76	-0.91	-0.87	-0.91
Acceptable LIMIT	84.00	59.00	0.07	0.41	370.00	≤1	≤1	≤1	3.75	0.30

DISCUSSION

A well calibrated Super-Spec (RS-125) gamma spectrometer was used to measure the activity concentrations of ^{40}K, ^{238}U, ^{232}Th and gamma doses rate at 1 m above the ground level over a laterite mining field in Ilorin, Kwara State, North-central Nigeria. Measurements were carried out in 50 randomly selected sample points. The overall mean activity concentrations of ^{40}K, ^{238}U, ^{232}Th and gamma dose are $^{2}5.7^{2}$, 43.89, 38.79 $Bqkg^{-1}$, and 46.44 $nGyh^{-1}$ respectively. To further study the distribution of these measured radionuclides and the gamma dose rate, isopotassium, isouranium, isothorium and isodose maps of the laterite mining field were plotted using Surfer 15 software and presented in figures 2 to 5 respectively. Two colors (green and red) were used to project areas with values greater than the recommended limits provided by UNSCEAR. Green field represents areas within the recommended limits while red which is universally used for caution/danger, represent areas whose values are above the recommended average. The iso-maps revealed that the mine field is blessed with uranium and thorium which in turn contributes to the dose rate. The enhancement of the dose rate caused by these radionuclides is evident in figure 5 as some red fields can be seen.

Correlation analysis was further conducted to study the relationship between these measured radionuclides and the gamma dose rate and the result are presented in table 3. The results were classified according to the correlation coefficient R [49], as follows:

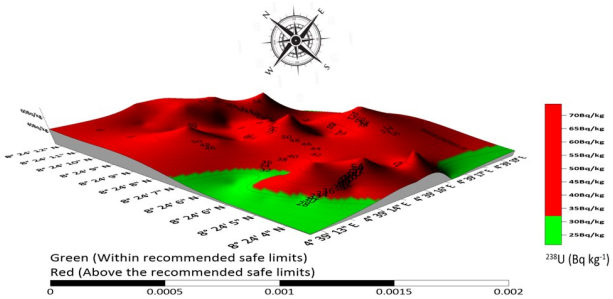

Figure 3. Isouranium map of the laterite mining field.

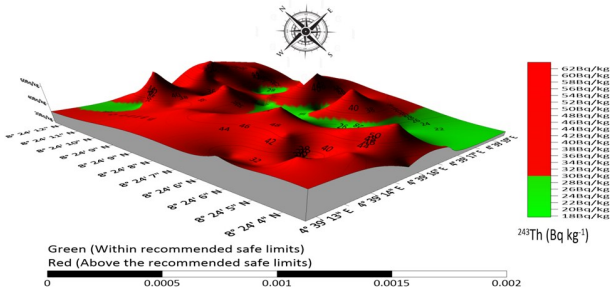

Figure 4. Isothorium map of the laterite mining field.

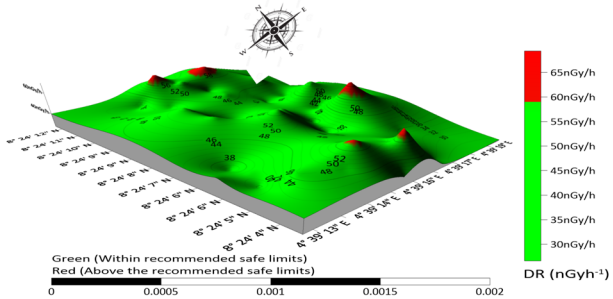

Figure 5. IsoDose-rate map of the laterite mining field.

Table 3. Pearson's correlation matrix showing the relationship between the measured radionuclides and dose rate.

	DR ($nGyh^{-1}$)	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)
DR ($nGyh^{-1}$)	1.0000			
^{40}K ($Bqkg^{-1}$)	0.3130	1.0000		
^{238}U ($Bqkg^{-1}$)	0.6633	0.1975	1.0000	
^{232}Th ($Bqkg^{-1}$)	0.7225	0.0000	0.0071	1.0000

$0.8 \leq |R| \leq 1$ suggests a strong correlation;
$0.5 \leq |R| \leq 0.8$ suggests a significant correlation;
$0.3 \leq |R| \leq 0.5$ suggests a weak correlation; and
$|R| < 0.3$ suggests an insignificant correlation.

A somewhat weak correlation of 0.3130 exists between gamma dose rate (*DR*) and ^{40}K, a moderately significant correlation of 0.6633 exists between *DR* and ^{238}U and a significant correlation of 0.7225 as found to exist between *DR* and ^{232}Th. The correlation results showed that the mine field is loaded with uranium and thorium, with ^{232}Th contributing more signi significant to the gamma dose received from the field than ^{238}U and ^{40}K. These radionuclides have been noted for their notorieties and contributions to background ionizing radiation which is linked with various kinds of cancers, liver diseases and ruthless health related harms which could eventually lead to death [16, 17, 19, 50, 51, 52].

In general, comparative analysis of these mean values of ^{40}K, ^{238}U, ^{232}Th and *DR* for the Laterite mine field under study with some selected studies from literatures across the world is given in table 4. It was observed that the mean values of ^{238}U obtained in this study is only higher than the values obtained by [41] in India, [42] in Turkey for Clay soil, [48] in Ghana and the findings of [19] and [14] from Nigeria. The values of ^{40}K even though lower than recommended limit of 420 $Bgkg^{-1}$, it compares well with the values reported by most of the authors (see table 4). The mean values of ^{238}U obtained in this study compares relatively with works reported by most authors except for [44] and few others whose values are much higher. The variation observed in the activity concentrations of these radionuclides when compared with other studies was believed to be because these radio-elements are not evenly spread in the earth crust. So their concentration level depends mostly on the local geology.

The results of the activity concentrations of these radionuclides were used to estimate the corresponding radiation hazard parameters to assess the suitability of the granite for building and construction purposes. The estimated radium equivalent (Ra_{eq}) ranges between 160.77 and 67.58 $Bqkg^{-1}$ with average value of 105.63 $Bqkg^{-1}$. These estimated values of Ra_{eq} are below the limit of 370 $Bqkg^{-1}$ [31] for the use of materials in the construction of buildings. The external radiation hazards (H_{ext}) and the internal radiation hazard (H_{int}) calculated were below unity as recommended by UNSCEAR. The representative level index (*RLI*), a radiological hazard parameter used as screening tool for identifying building materials that may possibly be of radiological concern to be used as construction materials. The estimated *RLI* ranged from 0.48 to 1.11 with an average value of 0.78. About 12% of the estimated values are greater than the recommended value of 1. Even though the mean value is less than unity but the fact that some values are higher than 1, care should be taken in the use of the lateritic soil from this mine field for building and construction. The estimated values for the *ELCR* were below the recommended limits of 3.75×10^{-3}. While estimated mean values of *AGED* for the residents using the laterite for building was evaluated and found to be higher than the recommended limit of 0.3 $mSvy^{-1}$ (i.e 0.32 $mSvy^{-1}$). The high values of AGED further amplified our concerns in the use of the lateritic soil from this mine field for building and construction purposes. The contributions of ^{40}K, ^{238}U and ^{232}Th to the hazard parameters (D_{out}, D_{in}, Ra_{eq}, H_{in}, H_{ext}, *RLI* and *AGED*) are presented in figure 6 and 7. It's evident from these plots that ^{234}Th is the principal contributor to the radiation hazards.

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Table 4. Comparison of the mean activity concentration and dose rate with some selected studies.

Case Study	*U-238 (Bq kg^{-1})*	*Th-232 (Bq kg^{-1})*	*K-40 (Bq kg^{-1})*	*Dose rate (nGy h^{-1})*	Country	References
Soil	19.16	48.56	1146.88	89.60	India	(41)
Kaolin (soil)	82.00	94.80	463.60	117.70	Turkey	(42)
Clay (soil)	39.30	49.60	569.50	74.10	Turkey	(42)
Floor ceramic	101.22	87.53	304.57	213.98	Iraq	(43)
Wall ceramic	102.12	70.90	328.60	178.40	Iraq	(43)
Kaolin (soil)	964.70	251.60	58.90	58.10	Egypt	(44)
Phosphogypsum	206.80	99.10	15.10	154.60	Brazil	(45)
Kaolin (soil)	38.20	65.10	93.90	59.60	Nigeria (Ifonyintedo)	(19)
Building materials	51.50	48.10	114.70	-	Australia	(46)
Sands (soil)	78.00	33.00	337.00	-	Egypt	(47)
Soil Samples	55.30	26.40	505.10	66.30	Nigeria (Itagunmodi)	(15)
Soil and Rock	13.60	24.20	162.10	-	Ghana	(48)
Laterite (soil)	30.00	41.00	65.00	17.510	Nigeria (Obajana)	(14)
Laterites (Soil)	**43.89**	**38.79**	**81.38**	**46.44**	**Nigeria (Ilorin)**	**Present Study**
Soil and Rock	32.00	30.00	420.00	59.00	Global Limit	(31)

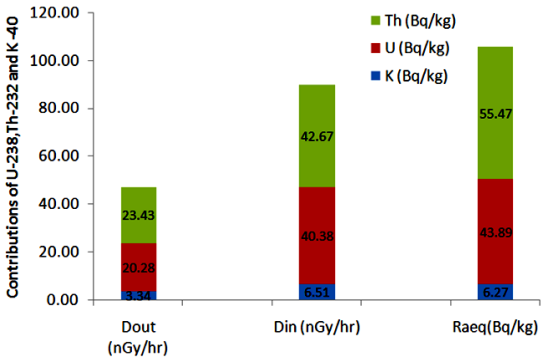

Figure 6. Contributions of ^{40}K, ^{238}U and ^{232}Th to D_{out}, D_{in} and Ra_{eq}.

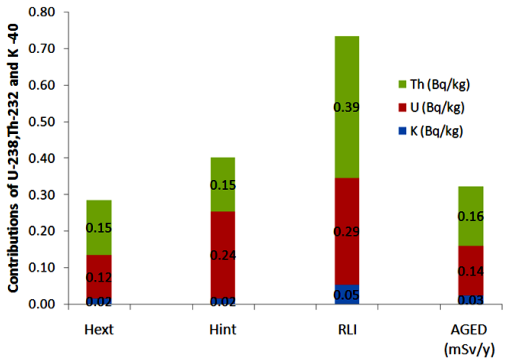

Figure 7. Contributions of ^{40}K, ^{238}U and ^{232}Th to H_{ext}, H_{in}, RLI and AGED.

CONCLUSIONS

The measured radionuclides and the estimated hazard indices are mostly higher than the recommended limits, which implies that the risk of radiation exposure is high for this lateritic soil. The research hereby recommends that radionuclide monitoring and assessment of all mined minerals used as building materials in Kwara State and the country at large carried out on a regular basis, and appropriate authority should implement specific statutory requirements and laws to regulate the high rate of mining activities. Also, in accordance with international recommendations quoted in the Basic Safety Series No.115 from the IAEA, the use of building materials containing enhanced concentrations of NORM should be controlled and restricted under the application of the radiation safety standards.

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Conflicts of interest*: *Declared none.

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