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NATURAL RADIOACTIVITY LEVELS AND RADIOLOGICAL HAZARDS INDICES OF SOIL SAMPLES FROM SELECTED MINING SITES, DANGE-SHUNI, SOKOTO STATE, NIGERIA

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ABSTRACT

Elevation of environmental radioactivity is a growing concern that requires monitoring and measurement via nuclear analytical procedures and have been conducted from Dange-Shuni in this study. The unabated mining activities whose motive is to constantly keep industries running on locally sourced minerals and raw materials often leave the host communities with heavy burden of radioactivity impacts that have be monitored in this study. this should explicitly and clearly state main objectives of the work. Hyper Pure Germanium detector coupled to a Multi-Channel Analyzer (MCA) was used for gamma-ray spectrometry to ascertain the activity concentration results of ^{226}Ra,^{232}Th,^{40}Kin 15 packs of homogenized soil samples collected from mining sites, Dange-Shuni LGA, Sokoto State, Nigeria. Mutually exclusive and collectively exhaustiveness approach of sampling was adopted in order to overcome the limitations of large and diverse nature of mining localities terrain. Results obtained from gamma-ray spectroscopy reveals a range of 30.7±2.9 to 95.6±7.2, 30.7±2.9 to 95.6±7.2 and 499.20±51.5 to 971.24±21.5$Bqkg^{-1}$ for ^{226}Ra,$^{232}Th$and ^{40}Krespectively. The mean values were calculated to be 58.04, 54.5 and 767.62 respectively. The radiological hazards of Ra_{eq}, H_{ex}, H_{in}, $D_{Abs.}$, D_{Eff}, $I_{\gamma r}$ and Σ_{elcr} were obtained for the results of activity concentration ascertained in this study. The results were found in elevations to the world mean values in comparison which is an implication of dangers of environmental radioactivity to the generality of the dwellings. These results are in good agreements with previous studies and hence, suggests for similar investigation to be conducted.

Keywords: HPGe – Detector, Gamma-rays Spectroscopy, Mining-sites, Dange-Shuni, Environmental Radioactivity

INTRODUCTION

Radioactivity measurement have long been encouraged by major world organizations such as ICRP, UNSCEAR, USEPA, WHO, and IAEA in a bid to checkmate risk exposure to inhabitants of such communities (Ahijjo & Umar, 2015). This encouragement has led to means of mitigating unnoticed impacts of exposure to radioactivity in some parts of the world. In so doing, perfect links have been established from previous studies on how some mining communities have been noticed with elevated exposure to environmental radiation due to uncontrolled mining work in their vicinities (UNSCEAR, 2013).

Hence, there is an insatiable quest for measurement of radioactivity to be conducted on the environmental samples for adequate evaluation of radiological hazard that may be posed to the dwelling communities where mining of minerals lingers unabated (Jafaru, 2009 and Ahijjo & Umar, 2015). Human insatiable demands for minerals and raw materials continued to exert more pressure in order to undermine the effects of unearthing soil particles abruptly thereby undermining the exposure of radionuclides (^{226}Ra, ^{232}Th and ^{40}K,) with potential health implications (Ahijjo, 2019).

Globally, stronger economies and industrialized nations continue to expand their acquisitions of mining capabilities for dominance over market out comes. These justling and rancour for monopoly over raw materials has recently turned the tides against mining communities where rampant mining activities has reached its peaks (Innocent, *et al.*, 2013).

Minerals such as sand, gravel, rocks, talc, asbestos, limestone, gold, silver, diamond etc. are often found in commercial quantities in the Iullemeden basin which covers an area of about 500,000 km^2 and consists of Sedimentary deposits (Shamonda, & Maduabuchi, 2014). In Nigeria, about 60,000 km^2 of Iullemeden basin occurs, which is just about 10.7% of the total stretch in West Africa on longitudes 3º40'E and 8ºE and latitudes 10º30''N and 13º 50'N (Sharu *et al.*, 2013). It harbours large gob of fresh water but with high tendencies of radioisotopes contamination (Okosun, 1989, Adeleye & Akande, 2004 & Salbu, 2012).

However, there is need for frequent and continual evaluation of this kind to unveil potential risk of exposure to inhabitants through inhalation of dust particles and aerosols, or ingestion of water and food or absorption through the skin that may be contaminated with radionuclides such as ^{40}K, ^{238}U, ^{226}Ra, ^{232}Th, ^{137}Cs. Their decay often leads to emission of radiation such as alpha, beta or gamma radiation that could impact health maladies to organs or tissues via internal irradiation process (Kaplan *et al.*, 2013).

Prior studies have provided insights on environmental radioactivity measurement in soil samples from mining sites in order to avail the public with information on the potential elevation of exposures to inhabitants to background radiation. Nevertheless, there are very few results of such measurements to support resent scepticism and efforts for mitigations.

Hence, this paper is an attempt to present the approach taken for the measurement of radioactivity in the soil samples from mining sites and to report the results obtained. This study shall also serve as baseline data of natural radioactivity research for the study area. Also, it is expected that the results of this study will support existing results of similar studies or serves as improvement.

MATERIALS AND METHODS

This study was initially embarked upon with opinion sampling and identification of mining sites that would subsequently become sample collection points. Albeit, only

details of soil sample collected and analysis conducted shall be vividly exhausted.

The soil sampling was based on a well derived equation (see equation 1.) of proportions of the communities covered. The opinion sampling was to enable mutual conclusions on the need for the study. The equation was formulated and derived to address any discrepancies that may arise from choice of stratified random sampling by proportion. Although, similar approach was employed in the work of CWIQ Survey, (2014).

$$\Sigma_{\sigma} = \frac{S_{\rho}}{\sigma}(N_k) \quad (1)$$

Where Σ_{σ} is the sum of the instrument distributed,

S_{ρ} is the number of sample points identified and marked during opinion sampling,

σ is the sum of the sample points identified and

N_k is the sum of all the entire instrument designed before distribution for sampling.

For ascertaining the input from the real-world condition on how deserving the study was viewed by the target audience of Dange-Shuni LGA, Sokoto state. The soil samples were then basically documented based on proportion, representation of the sample type, homogeneity, sample points that were coded, GPS points location and amount of the sample collected respectively. This approach was similar to that of (Kolo, 2014 & Ahijjo *et al.,* 2018). However, the study was too clumsy and hence, the assumption of mutually exclusive and collectively exhaustive was resort to in order to avert biasness during sampling.

Soil samples were collected with the aid of a clean hand Auger from top of the hip of excavated particles, dug out of the mines. A depth of 0.0 – 5.0 cm was considered in a distance of 25 km apart between Fifteen different soil sample collection points. Therefore, five separately collected samples were carefully homogenized in order to attain at least 95% – 98% unified representation. The mass of each packed sample was gauged at 2.5 kg grossly from the field. They were packed in a 300 ml plastic container and labelled with a distinct code and then carefully stored in their sealed form awaiting laboratory characterization. However, all the samples in this study were characterized and analysed at the Centre for Advanced Studies in Physics, GC University, Lahore, Pakistan. A total number of seventy-five samples were collected, but due to cost and weight consideration for flight to Centre for Advanced Study in Physics, the size was homogenized as earlier discussed in the synopsis. Therefore, exactly fifteen packed and homogenized samples were set for analysis. Gamma-ray spectrometry of HPGe detector coupled with a multi-channel analyser was use to count all the fifteen soil samples in order to determine their activity concentrations. Prior counting, the samples were dried for seven days under the ambient temperature of the air. They were manually sorted for the removal of stones, leaves and other organic particles. They were gently dried at 75°C for 24 hours in an oven so as to carefully remove any potential residual moisture and also to avoid loss of volatile radionuclides. The approach will also assist in achieving the attainment of equilibration period of four weeks according to (Baum *et al.,* & NNDC, 2011).

In an approach similar to the one adopted by Ahijjo et al. (2018), each sample was emptied into a mortar, crushed, pulverized and homogenously mixed with the aid of pestle and later sieved through a standard mesh of 2.5 mm Size using a vibratory sieve shaker to enable uniform distribution of radionuclides in the sample.

Subsequently, the samples were hermetically sealed with a pvc. tape to prevent gaseous nuclide flux in a standard 250 ml Marinelli beakers for the four weeks equilibration period that was earlier anticipated for the radionuclides progenies preservation and to minimize partial accumulations of the radionuclides after preparations. After attainment of secular equilibrium of four weeks between ^{222}Rn (radioactive noble gas), its decay products ($^{214}Pb$and ^{214}Bi) and radium (^{226}Ra), from the ^{238}Udecay series. Due to the short-lived isotope of radon (^{220}Rn) which is from the decay series of ^{232}Th , no serious problem of it is anticipated for reaching equilibration period of 55 seconds. Also, the period taken was in conformity for accounting for ^{40}K decay daughters which is not known for reaching equilibration (Umar & Ahijjo, 2022).

Gamma – ray Spectrometry

At the Centre for Advanced Studies in Physics, GCU, Lahore, a coaxial P-type HPGe detector was employed for the measurement of the activity concentrations of the radionuclides in a low background configuration. The system is made of concentric cylinders with a closed end. The peak-to-Compton ratio of the HPGe detector was ascertained at 1332.5 keV at the photopeak of ^{60}Co . The detector was protected against background interference of radiation from the surrounding to the barest minimum with the aid of a 12 cm of lead shielding. A cooling system was incorporated, aided by liquid nitrogen in a vertical Cryostat Dewar (50 Liters) in order to suppress the leakage current (Khandaker *et al.,* 2012).

In a bid to obtain optimal performance of the system, the cooling systems were sustained on a low temperature in order to achieve finest performance of the energy and detection efficiency during operation that requires cooling below 110°C. An automated multi-channel analyser was installed into the personal computer for system detection and data acquisition. A 250 ml Marinelli beaker was chosen for the Coaxial HPGe detector as a fixed geometry on order to maintain standard. An efficient pile-up ejector in the multi-channel buffer consists of an analogue – to – digital converter was incorporated to the signal processing in the gamma-ray spectrometry set up for use of main amplifier. All these were observed accordingly to the stipulated guidelines of (Isinkaye & Oyedele, 2014).

The pulse height was taken when noticed in appearance proportional to the gamma-ray energies absorbed in a sort of linearly amplified. This was met with a careful sorting of pulse height from the amplifier and then translated to a digital number which a known as channels with the aid of the analogue-to-digital converter (ADC) in the multi-channel analyser (MCA). This process was followed by identification of individual radionuclide using gamma-ray analytical software, *GENIE 2000* of Canberra Company. The spectrum signal acquisition was found dependent on this software. Although, other task achieved with *GENIE 2000* are; performance of multiple channel analysis control, spectral display, basic spectrum analysis for gamma-ray spectroscopy and quality control (Cember & Johnson, 2009).

System Calibrations

The energy and efficiency calibrations option and peak to total calibration were ascertained by the use of spectroscopic window in the MCA and therefore stored for further utility. The MCA spectral of the gamma-ray photopeak were saved and later used to obtain the spectrum results which were themselves typical radionuclide in the samples. They as well

unveiled all the interactions ranging from scattering events to photopeak being initiated by photoelectric effects.

The two well acquainted photo peaks of ^{60}Co at (1173.2 and 1332.5 keV) were identified from their direct gamma-ray emissions. Other embedded peaks of of ^{241}Am (59.54 keV), ^{109}Cd (88.03 keV), ^{57}Co (122.06 keV), ^{139}Ce (165.86 keV), ^{203}Hg (279.20 keV), ^{113}Sn (391.69 keV), ^{85}Sr (514.01 keV), and ^{88}Y (898.04 keV and 1836.1 keV) were obtained while counting the standard source. These spectral were found with additional peaks at 60.0, 88.0, 122.1 and 661.7 keV for ^{241}Am, ^{109}Cd, ^{57}Co, and ^{137}Cs respectively

The efficiency and resolution of the HPGe detector were found to be 60% at 1.85 keV in its full-width at half maximum (FWHM) of the gamma-ray energy line of ^{60}Co at 1332.5 keV. In order to achieve a varying transmission of the signal, an incorporation of Unified preamplifier was fixed instant to the terminal. A standard source for calibration containing the following radionuclides. ^{109}Cd, ^{57}Co, ^{139}Ce, ^{203}Hg, ^{113}Sn, ^{85}S, ^{137}Cs, ^{60}Co. and ^{88}Y was carefully inserted inside the detector setting for a duration of about 87,000s counting time.

The counting time was maintained for the soil samples on the HPGe detector exactly as it was for system calibration. The activity concentration for the radionuclides of interest were therefore determined in the soil samples on a dry weight basis in $Bqkg^{-1}$.

The soil activity concentration was carefully observed so that peak selection were manually obtained in a somewhat calibration pattern by a process of entering and matching the identified energies that corresponds to a Region of Interest (ROI) for the study (^{226}Ra,^{232}Th,$^{40}K$and ^{137}Cs) were set through the standard source channel range that were earlier obtained. Although, $137Cs$ and ^{40}K are known to decay directly in gamma-ray by their common emission lines of 661 KeV and 1460 KeV respectively. A line of best fit was obtained modelling the energy Calibration parameters. One spectrum channel corresponds to 0.5 KeV on the amplifier gains. The obtained model from the line of best fit between the gamma-ray (0 – 2000) and channel numbers (0-6000) was set within the ROI which has earlier been obtained from the linear relationship in equation (2) below by the computer (Gilmore, 2008 & Faanu, 2011).

$$E = A_1 + A_2 Channel.Number \quad (2)$$

Where E is the energy in keV, A_1 and A_2 are calibration constants for a given geometry. Hence, a linear relationship was obtained between the energy in keV and the respective channel number. The outcome of the above laboratory exercise shows that the activity concentrations of the radionuclides were obtained from the soil samples by establishing the physical relationship of equation (3) below;

$$A_c = \frac{N_E}{\varepsilon_\gamma p_\gamma t_c m} \quad (3)$$

Where, A_c is the activity concentration of a particular radionuclide in $Bqkg^{-1}$,

$N_E$is the net count rate at the energy peak of interest as the corrected background counts of the corresponding full energy peak,

$\varepsilon_\gamma$is the absolute full-energy peak detection efficiency,

$p_\gamma$is the gamma-ray emission probability,

$t_c$is the counting time in 86,400 S ,

m is the mass of the samples in kilogram.

The analytical set up was found with limitations for detection which is known as the minimum detectable activity (MDA) for each radionuclide. The MDA was determined with the perfect application of equation (4) according to Gilmore and Hermingway (1995).

$$MDA = \frac{DL}{\varepsilon_\gamma p_\gamma t_c m} \quad (4)$$

Where DL is the detection limit under the background counts B , such that;

$$DL = 2.71 + 465\sqrt{B} \quad (5)$$

Since it is natural that every measurement has some element of errors, the measurement of activity concentrations' error was expressed in terms of standard deviation $(\pm\sigma)$, where σ is expressed as illustrated below in equation (6) (Gilmore, 2008 & Faanu, 2011);

$$\sigma = \left[\frac{N_s}{T_s^2} + \frac{N_b}{T_b^2}\right]^{1/2} \quad (6)$$

Where, $N_s$is the sample count measured in time T_s^2 and $N_b$is the background counts measured in time T_b^2,

$\pm\sigma$ is measured in cps and was converted to activity concentration in $Bqkg^{-1}$ according to the approach of Gilmore and Hermingway (1995) in equation (5).

Radiation Hazards

Radium Equivalent Activity

Based on the measurement conducted and the detected values of the radionuclides of interest (^{226}Ra , ^{232}Th and ^{40}K) for all the samples in this study, the radium equivalent activity was obtained through calculations from equation (7);

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (7)$$

Where, A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in $Bqkg^{-1}$ respectively. Based on the assumption that holds radiological contaminated materials from the mining communities are frequently harnessed in local crafts and domestic construction of homes and other dwelling structures in most times, hence, the external hazard index (H_{ex}) and internal hazard index (H_{in}) could be calculated from equations (8) and (9) below;

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (8)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (9)$$

Where, A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra , ^{232}Th and^{40}Kin $Bqkg^{-1}$respectively.

This was performed in conformity with the guidelines of Kogbe (1979) for the assessment of radiological hazards in dwellings where mining activities are undertaking. There could be related exposure of the inhabitants of such dwellings to elevated dangers of ionizing radiation from commonly occurring radionuclides in such environment.

Absorbed dose rate is a factor of radiological hazard. It could be deposited on an individual at such, it was obtained using the mean activity concentrations values of ^{226}Ra , ^{232}Th and ^{40}K ($Bqkg^{-1}$) determined from the counting process of the soil samples via equation (10);

$$D_{Abs.} = (0.462A_{R_a} + 0.604A_{Th} + 0.0417A_K). \quad (10)$$

Where, $D_{Abs.}$ is the absorbed dose rate in units of $nGyh^{-1}$, A_{Ra} , A_{Th} and A_K are the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in $Bqkg^{-1}$ respectively.

The dose coefficient is in units of $nGyh^{-1}$per $Bqkg^{-1}$.

In a bid to calculate the annual effective dose rates, the approach in the work of Ahijjo et al, (2015) have it that the conversion coefficient from absorbed dose in air ($D_{Abs.}$)to

effective dose $(0.7SvGy^{-1})$ and outdoor occupancy factor $(0.2SvGy^{-1})$ should be used. The effective dose rate in units of $\mu Svyr^{-1}$ was therefore calculated via equation (11);

$$D_{Eff} = D_{Abs.} \times 8760h \times 0.2 \times 0.7SvGy^{-1} \times 10^{-3} \quad (11)$$

Where, $0.7SvGy^{-1} \times 10^{-1}$ is the conversion factor for absorbed dose to effective dose rate, 0.2 is the outdoor occupancy factor for 20% time spent by in individual,
$8760\,h$ is the amount of time in hours around the year for every individual.

This study was tailored on the path to determine the dangers of radiation exposure to the inhabitants of the mining communities where heavy exploration of solid minerals is unabated. Hence, the representative level index rather called gamma radiation hazard index ($I_{\gamma r}$) was calculated from the values of the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K respectively. It was obtained using equation (12) stated below;

$$I_{\gamma r} = 0.0067A_{Ra} + 0.01A_{Th} + 0.00067 \quad (12)$$

Taking individual dwelling in the mining community into consideration, the absorbed dose rate and the average lifetime expectancy were used to calculate excess lifetime Cancer risk ($ELCR$) using equation (13) given below;

$$ELCR = D_{Abs.}(nGy.h^{-1}) \times ALE \times RF \quad (13)$$

Where, $D_{Abs.}(nGy.h^{-1})$ is the absorbed dose rate,
ALE is the average life expectancy in the range of 30 – 70 years = 50,
RF is the risk factor recommended by ICRP 60 which was standardized at RF =0.05 for public.

RESULTS AND DISCUSSION

The values of the measured activity concentration of ^{226}Ra , ^{232}Th and ^{40}K in this study with their respective uncertainties are presented on Table 1 below. The sample codes were all in the form DAN_{SOK1} which means that this first sample was collected from Dange-Shuni Local Government Area, Sokoto state. Progressively, this mode of coding was maintained. This approach was adopted so as to distinctively identify each sample based on its collection point. Therefore, each result was identified based on the code as a reference identity. The ^{226}Ra concentrations in all the samples were found in the range of 30.7 ± 2.9 to 95.6 ± 7.2 $Bqkg^{-1}$. Also, ^{232}Th activity concentrations were found ranging from 25.2 ± 0.1 to 84.8 ± 3.2 $Bqkg^{-1}$. While the activity concentrations of ^{40}K was between 499.20 ± 51.5 to 971.24 ± 21.5 $Bqkg^{-1}$ respectively. The results on Table 1 shows that the activity concentrations of ^{226}Ra and that of ^{232}Th are lesser contributors to the specific activities when compared to the activity concentration of ^{40}K in all the soil samples. Generally, the mean activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K were found to be 58.04, 54.5 and 767.62 $Bqkg^{-1}$.

Table 1: Test model specifications and test conditions.

S/n	Sample Code	Activity Concentration $Bqkg^{-1}$			Ra_{eq}
		^{226}Ra	^{232}Th	^{40}K	
1.	DAN_{SOK1}	95.6±7.2	48.2±1.2	929.19±31.4	236.1
2.	DAN_{SOK2}	32.8±4.2	39.8±0.2	971.24±21.5	164.5
3.	DAN_{SOK3}	73.2±3.0	25.2±0.1	675.09±26.6	161.2
4.	DAN_{SOK4}	53.6±8.3	84.8±3.2	871.13±20.7	241.9
5.	DAN_{SOK5}	46.3±0.9	53.4±0.3	549.02±11.8	164.9
6.	DAN_{SOK6}	61.2±0.2	60.3±2.2	764.19±21.6	206.3
7.	DAN_{SOK7}	39.8±2.1	49.5±9.1	918.72±18.9	181.3
8.	DAN_{SOK8}	70.3±0.3	33.0±2.4	499.20±51.5	155.9
9.	DAN_{SOK9}	84.6±3.9	71.2±0.2	880.07±20.7	254.2
10.	DAN_{SOK10}	57.6±2.0	54.1±0.1	697.10±22.0	188.6
11.	DAN_{SOK11}	29.2±0.4	69.0±0.4	719.33±10.3	183.3
12.	DAN_{SOK12}	44.8±5.5	80.4±3.2	600.91±41.5	206.0
13.	DAN_{SOK13}	30.7±2.9	49.3±1.1	921.32±16.9	172.1
14.	DAN_{SOK14}	81.1±1.9	54.8±2.9	802.70±40.7	221.3
15.	DAN_{SOK15}	69.8±0.3	44.5±3.0	715.16±31.5	188.5
Minimum		29.2±0.2	25.2±0.1	499.2±10.3	155.9
Maximum		95.6±8.3	84.8±9.1	971.24±51.5	254.2
Mean		58.04	54.5	767.62	195.07
World Mean		35.02	45.03	420.12	370.00

Their world mean activity concentrations were calculated to be 35.02, 45.03 and $420.12Bqkg^{-1}$ respectively. For the sake of this assessment, these results could be an indication that these communities are at risk of exposure to some elevated environmental radioactivity due to mining of minerals. Also, this indicates that some primordial sources of radionuclides embedded beneath the soil may have been unearthed during mining activities. Hence, common exposure becomes inevitable to the public.

Furthermore, the mean Ra_{eq} in $Bqkg^{-1}$ was calculated to be 195.07 $Bqkg^{-1}$ which is fairly below the world mean value of 370.00 $Bqkg^{-1}$. This in shows that the accumulated amount of radioactivity concentration has their potential pathways that may be available for either ingestion, inhalation or skin absorption. The external hazard and the internal hazard indices were found approaching unity. This means that these results are in fair conformity with the global thresholds. The mean values of absorbed dose and the annual effective dose

were found to be 91.74 $nGy.h^{-1}$ and 112.51 $\mu Svyr^{-1}$. In comparison with the global threshold mean values of 57.00 $nGy.h^{-1}$ and 100.00 $\mu Svyr^{-1}$ respectively. This result portrays evidences that the inhabitants of these mining communities may be receiving some elevated doses in the ambient air due to terrestrial gamma-rays. Further implications could point out that most minerals usually mined in some parts of the Iullumeden basin are mostly found clustered with with quartz-mica rocks, younger granites rocks and seldom monazites which have been implicated for their higher radioactivity contents in the ground. Therefore, enhanced doses of environmental radioactivity to the inhabitants of mining communities from the presumed embedded primordial content must be curtailed (Umar *et al*., 2012 & Ahijjo *et al*., 2018).

Gamma index and Excess Life-time Cancer Risk

The calculations for the gamma index for the results of activity concentrations of ^{226}Ra and $^{232}Th$was obtained from equation (12) above, and the results are presented in Table 2 below.

They are all referenced to the sample points. The values of the result ranges from 0.618 mSv to 1.279 mSv which indicates that gamma radiation index in this study was found fairly above the global threshold of 1.0 mSv for an individual in these communities. Also, excess life-time Cancer risk was obtained from the calculation with equation (13). The values were found in the range of 183.08 $\mu Svyr^{-1}$ and 296.98 $\mu Svyr^{-1}$respectively. Which portrays an elevation level of potential exposure to excess gamma radiation and higher risk of cancer to the public of the mining communities around Dange-Shuni LGA.

In respect to the results obtained in this study, Tchokossa et al. (1999) deduced from such result that prominent values acquired via nuclear instrumentation could be due to some specific rocks that are rich in Felspars, Younger granites and Phosphates. Also, that certain level of accumulation of such rocks and compounds were found in abundance in the Iullumeden basin where Dange-Shuni localities forms apart. Moreso, these results were noticed in conformity with other findings in Nigeria and other parts of the world as summarily presented on Table 3 below.

Table 2: Results of the Radiological Hazard Calculated from Activity Concentration (^{226}Ra , ^{232}Th and ^{40}K)

S/Code	H_{ex}	H_{in}	$D_{Abs}(nGy.h^{-1})$	$D_{Eff}(\mu Svyr^{-1})$	$I_{\gamma r}$	$\sum_{elr}$
DAN_{SOK1}	0.6	0.9	112.02	137.39	1.12	280.05
DAN_{SOK2}	0.4	0.5	79.69	97.736	0.62	199.23
DAN_{SOK3}	0.4	0.6	77.19	94.67	0.74	192.98
DAN_{SOK4}	0.7	0.8	112.31	137.74	1.21	280.78
DAN_{SOK5}	0.4	0.6	76.54	93.87	0.84	191.35
DAN_{SOK6}	0.6	0.7	96.56	118.42	1.01	241.40
DAN_{SOK7}	0.5	0.6	86.60	106.20	0.76	216.50
DAN_{SOK8}	0.4	0.6	73.23	89.81	0.80	183.08
DAN_{SOK9}	0.7	0.9	118.79	145.68	1.28	296.98
DAN_{SOK10}	0.5	0.7	88.36	108.36	0.93	220.90
DAN_{SOK11}	0.5	0.6	85.16	104.44	0.89	212.90
DAN_{SOK12}	0.6	0.7	94.32	115.67	1.10	235.80
DAN_{SOK13}	0.5	0.5	82.38	101.03	0.70	205.95
DAN_{SOK14}	0.6	0.8	104.04	127.59	1.09	260.10
DAN_{SOK15}	0.5	0.7	88.95	109.09	0.91	222.38
Min	0.4	0.5	73.23	89.81	0.62	183.08
Max	0.7	0.9	118.79	145.68	1.28	296.98
Mean	0.53	0.68	91.74	112.51	0.93	229.37
W/Mean*	≤ 1	≤ 1	57.00	100.00	1.00	-

*W/Mean = World Mean

Table 3. Summary and Comparison of Activity Concentration of this study with Prior ones

S/n	Country/State	Activity Concentration $Bqkg^{-1}$			Reference
		^{226}Ra	^{232}Th	^{40}K	
1.	Algeria	53.2	50.03	311	Boukhenfouf et al, (2011)
2.	Nigeria (Sokoto)	720	33.5	315.3	Kolo (2014)
3.	Greece	90	190	960	Avgerinos et al, (2023)
4.	Madagascar	-	123	730	Rahelivao et al, (2023)
5.	India	64.60	109.03	972.67	Vishnu & Antony, (2022)
6.	Namibia	81.24	72.10	682.00	Munyaradzi et al, (2023)
7.	Nigeria, Imo state	-	75	783	Charles et al, (2021)
8.	This study, Dange-Shuni	58.04	54.5	767.62	

CONCLUSION

A total of Seventy-five sample points were covered in this study and were later merged into Fifteen samples in the fashion earlier presented for sampling approach for cost minimization. The Fifteen soil samples were successfully characterized and measured which produced the results presented and discussed above. Gamma-ray spectroscopy system was used to acquire a dependable result of natural

radioactivity due to ^{226}Ra, ^{232}Th and ^{40}K. The approach was conducted under a very careful and strict conditions. A constant calibration and re-calibration were performed for each sample measurement in order to ensure fairly accurate and error mitigated results. The results obtained shows that over 50% of all the soil samples have higher contents of radioactivity levels when compared with the acceptable limits. Furthermore, the mean values of the radiological hazards' indices were fairly higher than the global threshold except the Ra_{eq}.

Hence, the inhabitants of mining communities in Dange-Shuni LGA might be potentially exposed to higher risk of radioactivity from their immediate environment which should be a public concern. Considering the elevated values of gamma index obtained from the calculations in this study. It could also be a response of higher background radiations contribution from ^{226}Ra and ^{232}Th that were found in the soil samples that must nip in the bud. Any future study could be referenced to this study in case of unwarranted future enhancement.

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