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Distribution of ^{40}K, ^{238}U, ^{232}Th and Associated Radiological Risk in Quarry Soil of Chibok LGA, Borno State, Nigeria

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ABSTRACT

Effective monitoring of environmental radioactivity is essential for mitigating radiation-induced health risks such as cancer. In this study, the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were measured in soil samples collected from thirteen sample points across chibok local government area. Gamma-ray spectrometry was employed for the analysis conducted at the center for energy research and development, Obafemi Awolowo university Ile-Ife. Osun state. The results, obtained indicate average activity concentrations of approximately 14.56 $Bqkg^{-1}$ for ^{238}U, 2.73 $Bqkg^{-1}$ for ^{232}Th, and 563.58 $Bqkg^{-1}$ for ^{40}K, with ^{40}K being the dominant contributor to the overall specific activity. Furthermore, radiological parameters were evaluated, with the Absorbed dose rate (D_{Abs}), Annual Effective Dose (AEDE), Radium equivalent (Raeq), External hazard index (H_{ex}), Internal hazard index (H_{in}), Gamma activity index ($I_{\gamma r}$), and Excess lifetime cancer risk (ELCR). Were all determined to assess the radiation hazard of the quarry soil yielding average values of 31.87 $nGyh^{-1}$, 0.0391 $mSvy^{-1}$, 61.855 Bq/kg, 0.167, 0.206, 0.506, and 0.00014 respectively, the result was also compared with other study as indicate in table 1. The current radiological concentration of the soil does not pose an immediate threat to human health or the environment. However, prolonged exposure over a lifetime could result to health risks for both workers and the general public, particularly for those in close proximity to the quarry. These findings underscore the importance of continuous radioactivity monitoring to protect both human health and other components of the locality.

Keywords:
Gamma spectrometry,
Quarry soil,
Radiological Hazard,
Cancer,
Cancer.

INTRODUCTION

Monitoring levels of both natural and artificial radioactivity in the environment is essential for public safety, as exposure to these radionuclides can lead to cellular damage, impacting chromosomes and their components like genes and DNA (Nduka et al. 2022; Galadima et al. 2022). Among these natural sources, primordial radionuclides like uranium-238, thorium-232, and potassium-40, are as old as the earth itself. Minerals containing uranium-238 and thorium-232 are particularly radioactive, and studies often find significant levels of these radionuclides in rocks. Their concentrations vary depending on rock types for instance, igneous rocks like granite generally have higher radiation levels, while sedimentary rocks typically have lower levels, as these radionuclides decay, radon gas is produced. Once formed, radon diffuses and escapes into the atmosphere, with the degree of diffusion largely influenced by the permeability of the underlying bedrock (Sospeter et al. 2024; Muhammad et al. 2025).

Many studies were carried out directly linked to a significant number of radionuclides in rocks few among include (Echeweozo et al. 2020; Jegede et al. 2023; Khaleed et al. 2024). However, some shales and phosphate rocks also show relatively high radionuclide content this was reported by Olanya et al. (2022).

A similar study was conducted by Ahijjo & Baba-kutigi, (2023) investigated environmental radioactivity in soil samples from mining sites in Dange-Shuni, Sokoto State, Nigeria. The study emphasized the health risks posed by elevated radiation levels resulting from mining activities and underscored the necessity of radiological assessments in mining communities to mitigate exposure hazards. The findings revealed increased environmental

radioactivity, posing potential health concerns for local populations. However, this study differs from the present research in terms of materials analyzed, study area, and scope, as the present work covers a broader range.

Another study, also by Habu and Yusuf (2020). Studied quarry mining in Buni Gari, Yobe State, analyzing 20 soil and 20 water samples. Soil exceeded NORM safety limits, while water remained within safe levels. The highest ^{232}Th concentration in soil was linked to granitic rock crushing. However, the study lacked sampling details and does not cover up to 85–95% of the area as compare to this present study.

Also, Nduka et al. (2022). Examined radionuclide activity in quarry soil and plants from Ishiagu and Ezillo, southeastern Nigeria. Their findings revealed high excess lifetime cancer risk in some plants, posing potential health concerns. However, the study differed from the present research in location and detector type used.

The growing awareness of naturally occurring radioactive materials (NORMs) and their associated health implications has elicited a global response from researchers. All natural materials and the environment are inherently radioactive and subject to ionizing radiation, leading to background radiation in the ecosystem. (Amodu et al. 2024; Jauro et al. 2025; Joseph et al. 2022). This research seeks to evaluate radiation levels in soil, addressing a crucial gap in environmental safety. According to WHO, (2022), prolonged radiation exposure increases the likelihood of developing certain cancers. Quarrying, a significant livelihood for many inhabitants in the area, may contribute to long-term radiation exposure risks through inhalation, ingestion and skin contact. By measuring radiation levels and assessing potential health impacts, this study will provide vital data on ionizing radiation, particularly from primordial radionuclides such as uranium-238, thorium-232, and potassium-40.

Hence the study determined the Distribution of ^{40}K, ^{238}U, ^{232}Th and Associated Radiological Risk in Quarry Soil of Chibok LGA, the dose rate was estimated in terms of absorbed dose rate (D) and annual effective dose equivalent (AEDE). Additionally, radiation hazard indices were calculated, including radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}), gamma activity index ($I_{\gamma r}$), and excess lifetime cancer risk (ELCR), Finally, the results were compared with established data from previous studies as indicate in. Table 1, UNSCEAR, (2000).

MATERIALS AND METHODS

Study Area

This study was carried out at quarry mining sites in Chibok Local Government Area, located in the southern part of Borno State, Northeastern Nigeria, at coordinates 12°50’48"E longitude and 10°52’11"N latitude (Figure 1). The area is geologically characterized by a combination of Basement Complex rocks and sedimentary formations. The Basement Complex, which includes migmatites, gneisses, and granites, is especially prominent in the central region of Chibok. These older rocks are overlain by extensive alluvial deposits. Furthermore, the region has been significantly influenced by faulting and fracturing, particularly around the Upper Cretaceous graben structures (Abdullahi et al. 2016).

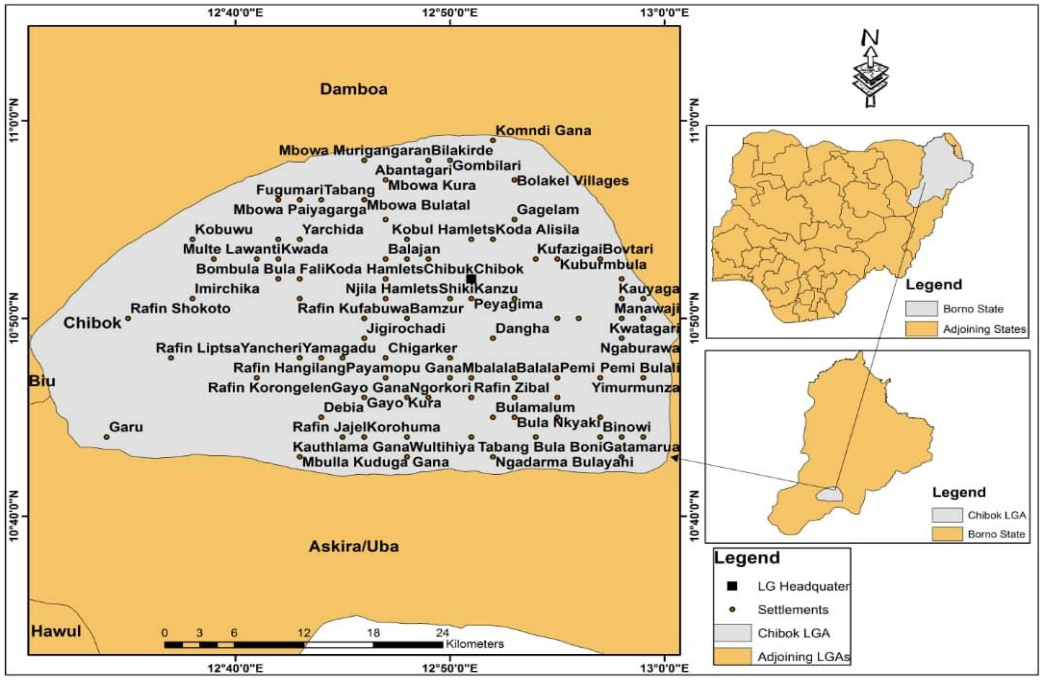

Figure 1: Map of Study Area Chibok LGA

Sampling

Soil samples were obtained from multiple locations across quarry sites and adjacent communities within Chibok Local Government Area. Sampling points were strategically chosen based on their closeness to mining activities and ease of public access. The geographic coordinates of each site were recorded using GPS, and corresponding sample numbers were clearly labeled on each sample bag for accurate identification. A purposive stratified random sampling technique was employed, segmenting the study area into defined strata to ensure comprehensive, representative, and unbiased sample collection. This approach aligns with methodologies adopted in previous studies by Ahijjo et al. (2018) and Ohakwere-Eze et al. (2024). Additionally, a geological map of the area was utilized to guide the selection process, ensuring systematic and thorough spatial coverage

Sample Processing and Preparation

A total of 13 soil samples were collected from Chibok Local Government Area in southern Borno State samples were taken from the surface (0.0–5.0 cm depth) of mined particle heaps sealed in a labeled plastic envelope, placed in a 400 ml container, and transported to the Center for Energy Research and Development at Obafemi Awolowo University, Ile-Ife Osun state Nigeria for further processing. At the laboratory, samples were cleaned of debris, crushed, mixed, and sieved through a 2.5 mm mesh for uniformity. They were oven-dried at 75°C for 24 hours to remove moisture while preserving volatile radionuclides. Subsequently, the dried samples were sealed in 250 ml Marinelli beakers with PVC tape and left undisturbed for four weeks to establish secular equilibrium, particularly for radionuclides in the uranium-238 decay series. This preparation followed established protocols from previous research (Onudibia et al. 2023 and Ahijjo et al. 2018).

Estimation of Activity Concentration of Radionuclides

The specific activity concentration of each radionuclide in the samples would be determined using equation 1, which will enable us to obtain the dose rate in equations 3 and 4 (Ahijjo et al. 2018).

$$\mathbf{A_i} = \frac{NC_i}{\varepsilon_\gamma \times p_\gamma \times t_c \times M} \quad (1)$$

where A_i is the activity concentration of a particular nuclide in $Bqkg^{-1}$. NC_i is the net count at the interest peak energy as the corrected background counts of the corresponding full energy peak, ε_γ is the absolute full energy peak detection efficiency, p_γ is the gamma-ray emission probability, t_c is the counting time in seconds, and M is the mass of the samples in kilogram (Ugbede, 2020; Abai et al. 2021; Nduka et al. 2022; Onudibia et al. 2023).

The lower limit of detection (LLD) which is the detection limit (DL) of any analytical system without a sample was determined from the background count spectrum. The detection limits, in $Bqkg^{-1}$, for each radionuclide were obtained using the relation.

$$LLD = 4.65\frac{\sqrt{C_b}}{t_b} K \quad (2)$$

where C_b is the background count in the corresponding photopeak, t_b is the background counting time (s) and k is the conversion factor from counts per second (cps) to activity concentration in $Bqkg^{-1}$ defined as;

$K = \frac{1}{\varepsilon_\gamma \times p_\gamma \times M}$, ε_γ, p_γ and M. are as defined in equation 1 (Ugbede, 2020; Karuppasamy et el. 2024)

Estimation of Absorb Dose Rate (D_{Abs})

The ionizing radiation of estimate dose rate from mean activity concentrations of ^{238}U, ^{232}Th, and ^{40}K ($Bqkg^{-1}$) in the soil samples, equation 3 was used to calculate the absorbed dose rate deposited on an individual potentially exposed at 1 m above ground level.

$$D_{Abs}(nGyh^{-1}) = 0.462\ A_U + 0.604\ A_{Th} + 0.0417A_k \quad (3)$$

where D_{Abs} is the absorbed dose rate in $nGyh^{-1}$, A_U, A_{Th}, and A_k are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K, respectively, the dose coefficients in units of $nGyh^{-1}$ per $Bqkg^{-1}$, and 0.462, 0.604, and 0.0417 is the conversion factors of uranium, thorium, and potassium, respectively.

Estimation of Annual Effective Dose (AED)

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose in the air (D_{Abs}) to effective dose (0.7 $SvGy^{-1}$) and outdoor occupancy factor (0.2 $SvGy^{-1}$) are needed. The effective dose rate in units of $mSvy^{-1}$ will be calculated from Equation 4 (Nduka et al. 2022; Jegede et al. 2023; Abdullahi et al. 2025)

$$AEDE(mSvGy^{-1}) = D_{Abs}(nGyh^{-1}) \times 8760h \times 0.2 \times 0.7SvGy^{-1} \times 10^{-3} \quad (4)$$

where 0.7 $SvGy^{-1} \times 10^{-3}$ is the conversion factor for absorbed to effective dose rate, 0.2 is the outdoor occupancy factor, at 8760 h is the number of hours around the year.

Estimation of Radium Equivalent Activity (Ra_{eq})

Is for the purpose of comparing the radiological effect, it is also the weight sum activity of materials that contain ^{238}U, ^{232}Th, and ^{40}K by a single quantity which takes into account the radiation hazards associated with them, a common index termed Radium equivalent activity (Ra_{eq}), it provides a very useful guideline in regulating the safety standards in radiation protection for a human population, the index will be calculated using equation 5 (Idris et al. 2023; Ofomola et al. 2023).

$$Ra_{eq} = A_U + 1.430A_{Th} + 0.077A_K \quad (5)$$

where: A_U, A_{Th}, and A_K are the radioactivity concentration of ^{238}U, ^{232}Th, and ^{40}K respectively in the sample.

Estimation for External and Internal Hazard Index

To assess both external and internal radiation exposure from ^{238}U, ^{232}Th, and ^{40}K present in quarry soil, calculations were carried out using equation 6 and 7 as stated by (Idris et al. 2023).

$$H_{ex} = \frac{A_U}{370Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \quad (6)$$

$$H_{in} = \frac{A_U}{185Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \quad (7)$$

where, A_U, A_{Th}, and A_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively Bq/kg.

Estimation of Gamma Index ($I_{\gamma r}$)

Generally used to assess the hazardous level of radionuclides in the human body when exposed to external and internal annual effective doses of γ - radiation decayed from radioactive nuclides in a sample. This index is very important for the quality control I_γ of radiation annual effective doses and in monitoring radiation inside the human body, to ensure that such radiation does not exceed the worldwide permissible high dose values (Obasi et al. 2020; Vesna et al. 2021). The equation is as follow:

$$I_\gamma = \frac{A_U}{150Bqkg^{-1}} + \frac{A_{Th}}{100Bqkg^{-1}} + \frac{A_K}{1500Bqkg^{-1}} \quad (8)$$

The assessed values of I_γ must be less than or equal to 1 for the soil and water within the environment to be generally safe or hazard-free (Agbalagba et al. 2021; Obasi et al. 2020).

Estimation of Excess Lifetime Cancer Risk (ELCR)

Excess lifetime cancer risk is used in radiation protection assessments to estimate the likelihood of an individual developing cancer over their lifetime as a result of low-level radiation exposure. (Omonokhua et al. 2022; Kareemah et al. 2024). To assess this equation 9 is used.

$$ECLR = AED \times DL \times RF \quad (9)$$

where AED is the total annual effective dose, DL is average lifetime duration assumed to be 70 years (Aborisade et al. 2018), and RF represents fatal cancer risk factor per Sievert taken to be 0.05 Sv^{-1} as contained in ICRP, (2007).

RESULTS AND DISCUSSION

The spectrometric results revealed a wide range of spectra from the counting of the samples. The spectral signals were used for the identification of different radionuclides from the soil samples. The results of activity concentrations of ^{238}U, ^{232}Th and ^{40}K from quarry soil samples in chibok LGA are presented on graphically in Figure 2.

Figure 3 displayed the combined activity concentration and radiological parameters of the study location the radiological from the graph the radiological parameters include absorb dose rate ($nGyh^{-1}$), annual effective dose ($mSvGy^{-1}$), radium equivalent activity ($Bqkg^{-1}$), external hazard index (H_{ex}), internal hazard index (H_{in}), gamma index ($I_{\gamma r}$) and excess lifetime cancer risk.

From the result of the analysis found using gamma ray scintillation the mean activity obtains using equation 3.8 is 14.555, 2.73 and 563.583 in $Bqkg^{-1}$ respectively. Similarly, the highest activity concentration found were in following order 18.74, 4.54 and 661.09 $Bqkg^{-1}$. The minimum values were also found to be in order of 4.99, 1.59 and 485.21 $Bqkg^{-1}$ respectively, for ^{238}U, ^{232}Th, and ^{40}K.

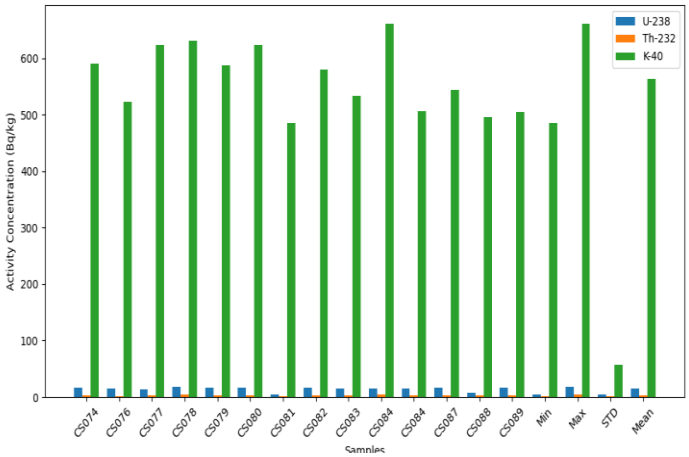

Figure 2: Activity Concentration in Quarry Soil in Chibok LGA

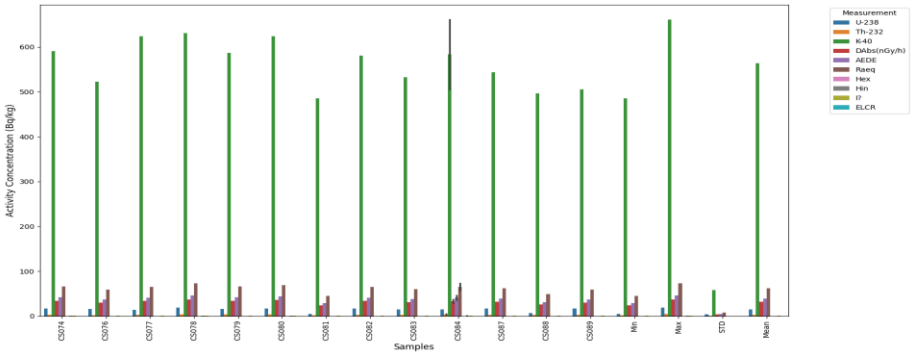

Figure 3: Activity Concentration and Radiological Parameters in Quarry Soil in Chibok LGA

Overall, the average activity concentrations of soil samples from Chibok Local Government Area were observed to be below the recommended safety thresholds of 35.02 Bqkg^{-1} for ^{238}U and 45.03 Bqkg^{-1} for ^{232}Th, were found in increasing order of ^{40}K > ^{238}U > ^{232}Th. However, the activity concentration of ^{40}K exceeded the acceptable limit of 420.12 Bqkg^{-1} as set by WHO (2005) and UNSCEAR (2000). Notably, the elevated levels of ^{40}K in the samples may be attributed to the natural abundance of potassium in soil forming minerals, as reported by Ahijjo et al. (2018) and Guagliardi et al. (2020).

For the radiological parameters found in quarry soil of Chibok LGA the mean average values of $D_{Abs,}$ (nGyh^{-1}) $Ra_{eq,}$ (Bqkg^{-1}) AEDE (mSvGy^{-1}), H_{ex}, $H_{in,}$ $I_{\gamma r}$, and ELCR, are 31.875, 0.0390, 61.855, 0.1671, 0.2064, 0.5006 and 0.00014 respectively, the current radiological parameters of quarry soil does not pose an immediate threat to human health or the environment. However, prolonged exposure over a lifetime could result to health risks for both workers and the general public, particularly for those in close proximity to the quarry. These findings underscore the importance of continuous radioactivity monitoring to protect both human health and other components of the locality.

Table 1: Summary and Comparison of Activity Concentration of the Study with other Studies

S/No	Country/State	Activity Concentration Bqkg^{-1}			Reference
		^{238}U	^{232}Th	^{40}K	
1	Turkey	13.8	10.24	680	Manisa et al. (2021)
2	Indian	19.9	33.5	335	Yadav et al. (2023)
3	Armenia	111.0	109.3	531.04	Belyaeva et al. (2019)
4	Nigeria (west)	61.55	72.65	381.04	Amodu et al. (2024)
5	Nigeria (south east)	35.0	38.5	482.04	Abai et al. (2021)
6	Nigeria (north east)	15.0	43.0	512.0	Abba et al. (2025)

CONCLUSION

This study examined 13 quarry soil sample points in Chibok (CS) Local Government Area, Borno state. The measured quarry soil activity concentrations were within globally accepted safety limits, although ^{40}K levels were slightly elevated above the threshold in some locations, with the activity ranking as ^{40}K > ^{238}U > ^{232}Th across all regions. The result was compared with other study as indicate in Table 1. The current radiological concentration of the soil does not pose an immediate threat to human health or the environment. However, prolonged exposure over a lifetime could result to health risks for both workers and the general public, particularly for those in close proximity to the quarry. Finally, the quarry soil may be termed as minimally radioactive with a low radiological risk index, which suggests that the environmental impact of rock quarrying in the presence of these toxic components may not call for immediate concern. The values of ^{40}K, in particular, are in line with those reported in similar studies, highlighting the consistency of the findings. Even though the soil does not currently present significant radiological concerns, continuous monitoring could be necessary to assess any abrupt potential elevation effects.

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