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Radioactivity Concentration in Quarry mining Soil in Pulka, Gwoza 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 seventeen sample points across gwoza 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 14.01 Bq kg^{-1} for ^{238}U, 3.19 Bq kg^{-1} for ^{232}Th, and 571.72 Bq kg^{-1} for ^{40}K, with ^{40}K being the dominant contributor to the overall specific activity. Gamma hazard indices, were derived from the established equations. Furthermore, radiological parameters were evaluated, the Absorbed dose rate (D_{Abs}), Annual Effective Dose (AEDE), Radium equivalent (Ra_{eq}), 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 32.17 $nGyh^{-1}$, 0.0411 mSv y^{-1}, 62.494 Bq kg^{-1}, 0.168, 0.206, 0.506, and 0.000144 respectively, 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.

INTRODUCTION

Naturally occurring radionuclides such as uranium-238, thorium-232, and potassium-40 have been present since earth's formation (Fredrick et al., 2021). Over time, these elements have integrated into the human environment, accumulating in soil, water, sediments, plants, and food sources (UNSCEAR, 2000). Radiation exposure originates from both natural sources, including primordial radionuclide, cosmic, rays and radon gas from the Earth's crust, and artificial sources such as medical applications and nuclear energy (UNSCEAR, 2021). Ionizing radiation from these radionuclides poses significant concerns, from environmental impact to health maladies such as cancer (Ugbede, 2000).

Human exposure to ionizing radiation stems from both natural and artificial sources. Natural sources include

cosmic radiation and radon gas emitted from terrestrial rocks, whereas artificial sources arise from medical applications, nuclear weapons testing, and nuclear energy production (UNSCEAR, 2021). However, natural radionuclides remain the dominant source of radiation exposure, posing potential health risks (Ugbede, 2020).

Radionuclides released during quarry mining activities emit energy in the form of gamma rays at various stages as they seek stability. These emissions can contaminate the soil, be absorbed by plants, and eventually enter the food chain (Effiong et al., 2024). Exposure to radiation from quarry mining in nearby communities can occur through several radiological pathways, including direct contact with contaminated soil, inhalation of dust, and ingestion of long-lived alpha- and beta-emitting radionuclides (Ahijjo & Umar, 2024). Preventing the harmful effects of environmental radioactivity and reducing the incidence of radiation induced health issues or ailments, such as cancer, which requires effective monitoring. The ability to detect and measure radioactivity accurately is crucial for protecting human health, ecosystems, and the environment (Ahijjo et al., 2018).

Since radiation is invisible and cannot be detected by human senses, it is essential to maintain its levels as low as reasonably achievable. 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, this study aims to assess radionuclide concentrations in the geological formations of areas with naturally occurring radioactive rocks, providing baseline data for future environmental assessments. According to the World Health Organization (WHO, 2022), prolonged exposure to radiation increases the risk of developing certain types of cancer. Therefore, the study specifically investigates the radiological impacts of quarry soil in Pulka Community and Gwoza Town, located in southern Borno State. The goal is to generate knowledge on the potential radiological risks to inhabitants living near mining sites, which will serve as a baseline for further research. Moreover, the results were compared with established data from previous studies, as reported by (UNSCEAR, 2000).

MATERIALS AND METHODS

Study Area

The study was conducted at quarry mining sites in Pulka community and Gwoza town. which lie on longitude 13°41’45’’42E and latitude 11°04’59’’27N of Gwoza Local Government Areas, located in southern Borno State, Northeastern Nigeria (Figure 1). It is situated within the Sudan Savannah, which is characterized by short shrubs and scattered trees, a short-wet season (June – September), and a prolonged dry season (October–May). The topography features rugged terrain shaped by the Mandara Mountains (Pulka-Gwoza), with extensive occurrences of Precambrian Basement Complex rocks and some sedimentary formations. (Saidu et al., 2020).

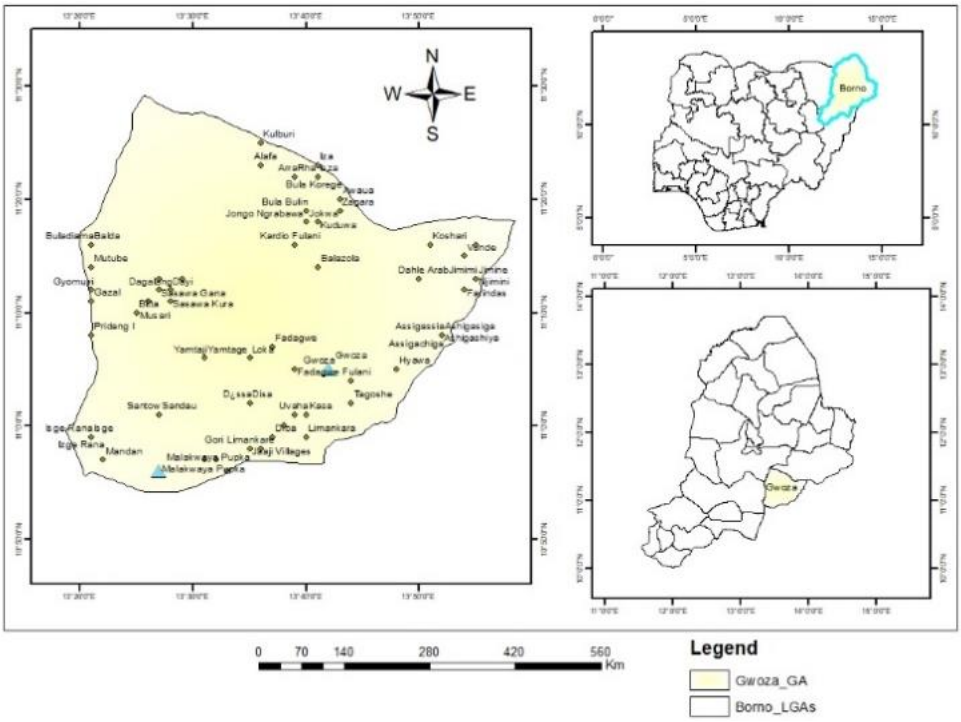

Figure 1: Map of Borno state showing the study area

Sampling

Soil samples were collected from various locations within the quarry sites and nearby communities in Pulka and Gwoza towns. Sampling sites were selected based on their proximity to the mines and their accessibility to the public. GPS coordinates were recorded for each location, and the corresponding sample numbers were labelled on each sample bag for proper identification. A stratified random sampling technique was adopted, dividing the study area into distinct strata to ensure representative and unbiased sampling. This method is consistent with the approaches used in previous studies by (Ahijjo et al., 2018; Ohakwere-Eze et al., 2024). Furthermore, a geological map of the region guided the selection of sampling sites to ensure thorough and systematic coverage of the area.

Sample Processing and Preparation

A total of 17 soil samples were collected from Gwoza Local Government Area in southern Borno State 8 from Pulka and 9 from Gwoza town mining sites. Samples were taken from the surface (0.0–5.0 *cm* depth) of mined particle heaps at 5-meter intervals. For each sample, soil weight and GPS coordinates were documented. Each 0.5 *kg* sample was 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, for further processing. At the lab, 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 (e.g., ^{222}Rn, ^{214}Pb, ^{214}Bi, and ^{226}Ra). This preparation followed established protocols from previous research (Onudibia et al., 2023; Ahijjo et al., 2018).

System Calibrations

The energy calibration of the detector was performed at the beginning before the machine was used for counting the samples. The point sources were counted for a sufficient amount of time to yield a distinct photo peak, and the system's gain was then tuned so that the photo peak of Cs was approximately one-third of the full scale. This is to ensure that all of the relevant radionuclides were covered in the energy range of 200 keV – 2 MeV. For every full energy peak (FEP) on the MCA, the multichannel number corresponding to its centroid was noted. Allocating energy to channel numbers is a part of energy calibration. Gamma ray energy emissions from ^{137}Cs and ^{60}Co were measured, yielding values of 662 keV, 1170 keV, and 1330 keV, respectively, for the energy calibration. A standard source for calibration containing the following radionuclides; ^{22}Na; ^{137}Cs; ^{60}Co; ^{22}Na; ^{60}Co, were carefully inserted inside the detector setting for a duration of about 36,000s counting time, the counting time was maintained for the soil samples. The activity concentration of ^{238}U, ^{232}Th, and ^{40}K were determined in soil sample on dry weight in *Bq kg*$^{-1}$.

Activity Concentration (A_i)

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 2.8 and 2.9 (Ahijjo et al., 2018).

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

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 (Abai et al., 2021; Nduka et al., 2022; Onudibia et al., 2023).

Radiation Hazards

Dose Rate (D_{Abs})

To estimate the dose rate from mean activity concentrations of ^{238}U, ^{232}Th, and ^{40}K (Bqkg^{-1}) in the samples equation 2, was used to calculate the absorbed dose rate deposited on an individual.

$$D_{Abs}(nGyh^{-1}) = 0.462\ A_U + 0.604\ A_{Th} + 0.0417 A_k \quad (2)$$

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.

Annual Effective Dose Equivalent (AEDE)

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose in the air (D_{Abs}) to effective dose (0.7 *SvG y*$^{-1}$) and outdoor occupancy factor (0.2 *SvGy*$^{-1}$) are needed. The effective dose rate in units of *mSvy*$^{-1}$ will be calculated from Equation 3. (Nduka et al., 2022; Jegede et al., 2024; Abdullahi et al., 2025).

$$AEDE(mSvGy^{-1}) = D_{Abs}(nGy\ h^{-1}) \times 8760h \times 0.2 \times 0.7\text{SvG}\ y^{-1} \times 10^{-6} \quad (3)$$

where 0.7SvG y^{-1}× 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.

Hazard Index

Radium equivalent activity (Ra_{eq}) is for the purpose of comparing the radiological effect of the 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 4 (Obasi et al., 2020).

$$Ra_{eq} = A_U + 1.430A_{Th} + 0.077A_K \quad (4)$$

where: A_U, A_{Th}, and A_K are the radioactivity concentration of ^{238}U, ^{232}Th, and ^{40}K respectively in the sample. Hazard indices are due to the assumption that radiologically contaminated materials such as stones produced by local quarry production may be used for the construction of houses, hence the external hazard index (H_{ex}) and. Internal hazard index (H_{in}) could be calculated from equation 5 and 6, as stated by (Idris et al., 2020).

$$H_{ex} = \frac{A_U}{370Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \quad (5)$$

$$H_{in} = \frac{A_U}{185Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \quad (6)$$

where, A_U, A_{Th}, and A_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively Bq/kg. Gamma activity index ($I_{\gamma r}$) is 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 value (Obasi et al 2020; Vesna et al., 2021). The equation is as follow:

$$I_\gamma = \frac{A_U}{150Bqkg^{-1}} + \frac{A_{Th}}{100Bqkg^{-1}} + \frac{A_K}{1500Bqkg^{-1}} \quad (7)$$

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 (Obasi et al 2020; Agbalagba et al., 2024).

Excess lifetime cancer risk is the augmented likelihood of the quarry site workers and other people developing cancer due to exposure to precise doses of radiation over an extended period. The ELCR was calculated using this equation 8.

$$ELCR = AEDE \times DL \times RF \quad (8)$$

where AEDE is the annual effective dose equivalent obtained inequation in $mSv\ y^{-1}$, [7]. while DL is the required average lifespan of (70 years), and RF is the risk factor (0.05 Sv^{-1}) per Sv (Effiong et al., 2024).

RESULTS AND DISCUSSION

Activity Concentration in Soil

The study employed a gamma-ray spectroscopy-based radioactive counting system to measure the activity concentrations of radionuclides ^{238}U, ^{232}Th, and ^{40}K in quarry mining areas, as presented in Tables 1 and 2. The results indicate consistent and reliable detection of radiation levels across all collected samples. In the Pulka community quarry site, the activity concentrations ranged from 10.01 ± 0.07 to 18.71 ± 0.09 Bq/kg for ^{238}U, 2.9 ± 0.07 to 6.05 ± 0.15 Bq/kg for ^{232}Th, and 604.41 ± 4.76 to 688.25 ± 4.68 Bq/kg for ^{40}K. In Gwoza town, the corresponding values ranged from 9.91 ± 0.08 to 16.76 ± 0.09 Bq/kg for ^{238}U, 1.56 ± 0.16 to 3.69 ± 0.05 Bq/kg for ^{232}Th, and 460.95 ± 4.62 to 688.28 ± 4.68 Bq/kg for ^{40}K. In both regions, the activity concentrations followed the order: $^{232}Th < ^{238}U < ^{40}K$. Despite being different locations, the similarity in measured values suggests that the regions share comparable geological characteristics.

Table 1: Activity Concentration of Radionuclides in Soil Samples of Pulka

Sample Code	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
PS001	686.31 ± 4.45	18.71±0.09	5.68 ± 0.05
PS002	676.74±4.13	18.1 ± 0.08	3.83 ±0.05
PS003	616.35 ± 4.59	13.92±0.09	3.69 ± 0.12
PS004	688.28 ± 4.68	10.31 ± 0.07	6.05 ± 0.15
PS005	604.41±4.76.	15.19±0.13	2.9±0.07
PS006	631.26 ± 4.85	18.6 ± 0.09	3.99 ± 0.06
PS007	687.43 ± 4.67	10.01±0.11	5.98 ± 0.69
PS008	632.22 ± 4.88	13.39 ± 0.09	3.49 ± 0.17
Average	647.58 ± 4.85	14.695 ± 0.13	4.456±0.06

PS: PULKA SOIL

Table 2: Activity Concentration of Radionuclides in Soil Samples of Gwoza Town

Sample Code	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
GS001	546.89 ± 4.87	15.19 ± 0.09	1.63 ± 0.02
GS002	614.83 ± 4.25	16.76 ± 0.09	3.57 ± 0.05
GS003	460.95 ± 4.62	15.19 ± 0.09	1.56 ± 0.16
GS004	522.24 ± 4.16	14.59 ± 0.11	3.69 ± 0.05
GS005	6575.09 ± 4.87	15.50 ± 0.09	2.93 ± 0.06
GS006	529.50 ± 4.58	14.08 ± 0.12	2.35 ± 0.01
GS007	467.48 ± 4.68	9.91 ± 0.08	2.98 ± 0.06

GS008	567.21 ± 4.80	15.13 ± 0.09	2.23 ± 0.05
GS009	534.68 ± 4.75	14.03 ± 0.07	3.18 ± 0.05
Average	592.02 ± 5.33	14.622 ± 0.12	3.56 ± 0.13

GS: GWOZA SOIL

The activity concentration values measured in the study area and its environs were found to be below the global safety thresholds recommended by (Abd El Azeema and Mansour, 2021), which are 33.0 *Bqkg*$^{-1}$ for ^{238}U and 45.0 *Bqkg*$^{-1}$ for ^{232}Th. However, the concentration of ^{40}K, with a recommended upper limit of 420 *Bqkg*$^{-1}$, exceeded this value in most sampling locations. This suggests a localized enrichment of ^{40}K in the geological matrix of the area.

Table 3, summarizes the average radiological parameters for the quarry mining sites in Pulka and Gwoza. The absorbed dose rates, computed using Equation 2, ranged from 33.97 to 40.69 *nGyh*$^{-1}$ in Pulka, with a mean value of 37.04 *nGyh*$^{-1}$. In Gwoza, the dose rates ranged between 25.87 and 35.54 *nGyh*$^{-1}$, yielding an average of 30.63 nGy/h. All recorded dose rates are below the recommended global limit of 57.00 *nGyh*$^{-1}$ (Abd El Azeema and Mansour, 2021), indicating that the radiological risk associated with external exposure in these quarry sites is minimal and within acceptable safety margins. These findings suggest that, despite the elevated levels of ^{40}K, the overall radiological hazard in the study area remains low, likely due to the relatively low concentrations of the more radiotoxic nuclides, ^{238}U and ^{232}Th. The data further support the inference that the geological characteristics of the Pulka and Gwoza regions contribute to a natural background radiation environment that does not pose significant health risks to the local population or workers in the quarrying industry.

Table 3: Average Radiological Parameters for Soil Samples Collected from Pulka and Gwoza

S/No	Location	D_{Abs} (*nGy h*$^{-1}$)	Ra_{eq}(*Bq kg*$^{-1}$)	AEDE(mSv y^{-1})	H_{ex}	H_{in}	I_y	ELCR
1.	Pulka	37.04	72.04	0.045	0.194	0.235	0.582	0.000158
2.	Gwoza	30.63	59.52	0.037	0.160	0.20	0.480	0.00013
3.	Minimum	25.87	50.17	0.031	0.135	0.162	0.480	0.000111
4.	Maximum	40.69	79.68	0.041	0.177	0.218	0.583	0.000175
5.	World Average	57.00	370.00	<= 1	<= 1	<= 1	<= 1	<= 1

The radium equivalent activity (Ra_{eq}), calculated using Equation 4, ranged from 65.88 to 79.68 *Bq kg*$^{-1}$ in the Pulka community, with a mean value of 72.04 *Bq kg*$^{-1}$. In Gwoza town, Ra_{eq} values varied between 50.17 and 69.21 *Bq kg*$^{-1}$, with an average of 59.52 *Bq kg*$^{-1}$. All measured values are significantly below the internationally recommended world average of 370 *Bq kg*$^{-1}$, as established by (UNSEAR, 2002).

Similarly, the annual effective dose equivalent (AEDE), calculated using Equation 3, ranged from 0.042 to 0.049 *mSv y*$^{-1}$in the Pulka community, with an average value of 0.0454 *mSv y*$^{-1}$. In Gwoza town, AEDE values ranged from 0.032 to 0.044 *mSv y*$^{-1}$, yielding an average of 0.037 *mSv y*$^{-1}$ across the entire quarry mining site.

The calculated radiological hazard indices including the external hazard index (H_{ex}), internal hazard index (H_{in}), and the gamma radiation activity index derived from Equations 5, 6, and 7, respectively, were all found to be below the safety threshold of unity (1), as recommended by (UNSEAR, 2002). Figures 2 and 3 present bar chart illustrations of these radiological parameters for both study locations.

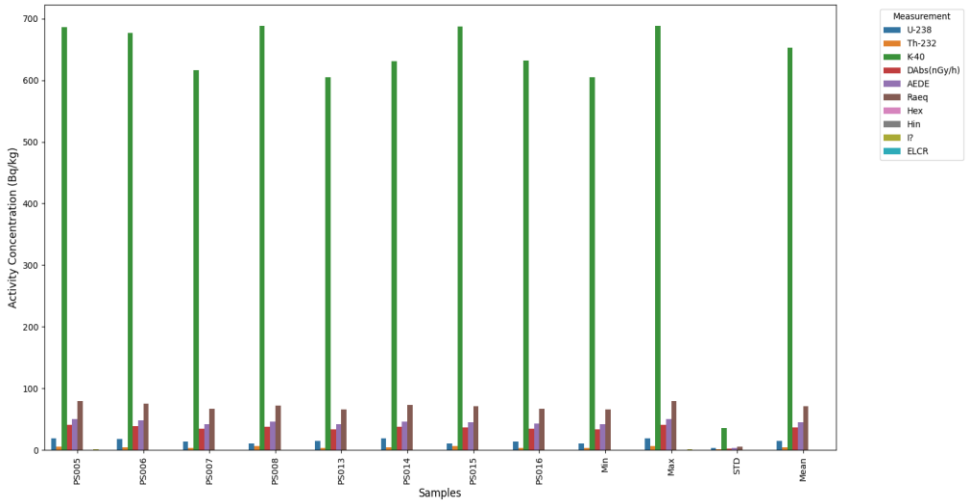

Figure 2: A combined graph of radionuclides activities and radiological parameters for soil samples from Pulka community of Gwoza LGA, Borno state, Nigeria

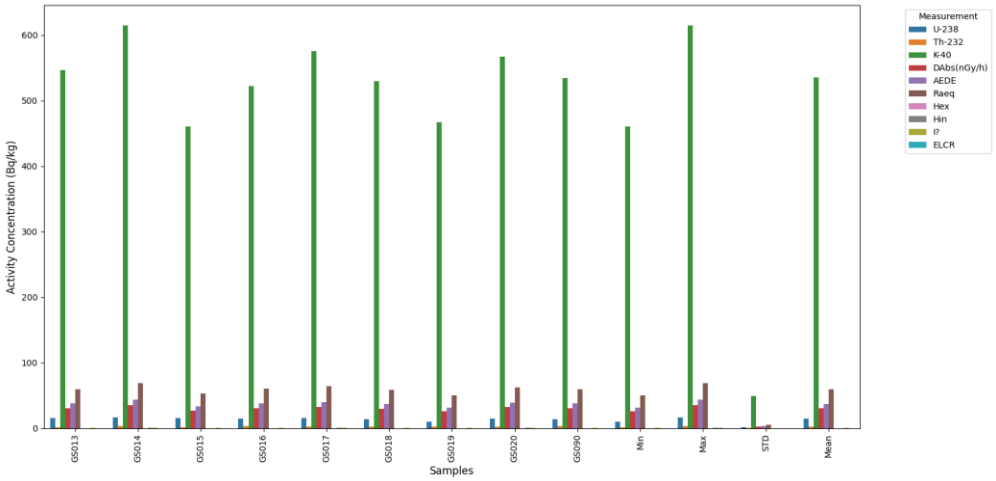

Figure 3: A combined graph of radionuclides activities and radiological parameters for soil samples from Gwoza LGA, Borno state, Nigeria

The results of this study show strong consistency with findings reported by other researchers both within Nigeria and internationally. A comparative analysis of these results is provided in Table 4.

Table 4: Comparison Of the Result Obtained in This Study with Previous Studies

S/No	Country/State	^{238}U	^{232}Th	^{40}K	Reference
1.	Tuckey	13.8	10.24	680	Nduka et al., (2022)
2.	Saudi Arabia	27.03	19.76	193.8	Abd and Mansour, (2021)
3.	Nigeria/west	35.0	385	823.2	Fredrick et al., (2021)
4.	Nigeria/south south	30.64	12.24	1167.12	Effiong et al., (2024)
5.	Nigeria/northeast	45.1	146.5	512.65	Habu and Yusuf, (2020)
6.	Borno	**14.01**	**3.11**	**571.70**	This study

CONCLUSION

This study employed gamma-ray spectrometry to determine the concentration of naturally occurring radionuclides in soil samples collected from quarry mining sites in Pulka and Gwoza. The results revealed that potassium 40 (^{40}K) exhibited the highest activity concentration, followed by uranium-238 (^{238}U) and thorium-232 (^{232}Th), establishing a consistent activity trend across all sampled locations: ^{40}K > ^{238}U > ^{232}Th. Although all measured activity concentrations remained within internationally accepted safety limits, ^{40}K levels in some areas were found to be marginally elevated, approaching

regulatory thresholds. Despite this, the current radiological profile of the soil does not present an immediate risk to human health or the surrounding environment. However, continuous or long-term exposure particularly for quarry workers and nearby residents may pose potential health concerns over time. Overall, the quarry soil is classified as minimally radioactive with a low radiological hazard index, indicating that the environmental and health implications of quarrying activities in the region are not presently alarming. Furthermore, the ^{40}K concentrations observed are consistent with values reported in similar studies, reinforcing the validity of the results. This investigation thus provides a valuable baseline for future radiological assessments and related studies within the region.

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