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Assessment of Radiation Dose Associated with Background Radionuclides in Quarry Soil at Dawakin-Kudu LGA Kano, Nigeria

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ABSTRACT

Naturally occurring radioactive materials (NORMs) are present in different concentrations in the environment as well as quarry depending on the geological formation of the soil. The assessment of any release of radioactivity into the environment is crucial for safeguarding public health, particularly when this radioactivity has the potential to enter the food chain. The quarry located in Dawakin-Kudu Kano has the potential to exhibit elevated levels of natural radioactivity due to intense mining operations. This study presents the assessment of activity concentration in quarry soil at Dawakin-Kudu with a focus on the transfer mechanism from soil to plant. Soil samples were gathered from a quarry site and farmlands situated around the quarry at Dawakin-kudu, plant samples were also collected from the same farmlands and were all analyzed for natural radioactivity, specifically for ^{226}Ra,^{232}Th, and ^{40}K. The gamma-ray spectrometry method, coupled with the Sodium thallium Iodide NaI (Tl) detector was used to measure the activity concentrations of ^{226}Ra,^{232}Th, and ^{40}K. Activity concentrations of natural radioactivity in soil were generally higher than those recorded in plants. The mean activity concentration of the radionuclides in soil ranges from Highest-to-Lowest values as follows ^{226}Ra: 65.24±1.92 Bqkg^{-1} – 42.41±1.73 Bqkg^{-1}, ^{232}Th: 182.71±1.44 Bqkg^{-1} – 114.61±1.25 Bqkg^{-1}, ^{40}K: 597.51±3.81 Bqkg^{-1} – 321.93±3.55 Bqkg$^{-1.}$ The radiological hazard indices were all determined to assess the radiation hazard of the quarry soil. The radionuclides transfer factor showed a higher value for ^{40}K in the order ^{40}K>^{232}Th >^{226}Ra, this implies high bioconcentration of ^{40}K in plants. The findings suggest that consuming plants grown around the quarry location over an extended period could pose substantial health threats to the public. Consequently, the study area may not be safe for residents in the long run, emphasizing the necessity for continuous monitoring of radioactivity concentrations to mitigate the environmental health implications of accumulated gamma dose.

Keywords:
Background Radionuclides,
Health implications,
NaI (Tl),
Quarry soil,
Plants,
Radiation dose.

INTRODUCTION

The radiation from the subsurface can threaten human life because of the uncertainty surrounding background radionuclides. These radionuclides are Naturally Occurring Radioactive Materials due to environmental changes (Joel *et al*., 2020). According to (Babatunde *et al*., 2023), there are two main sources of natural radioactivity: terrestrial (primordial radionuclides) and extra-terrestrial (cosmic rays). This means that the environment in which living things dwell is commonly radioactive, and individuals are frequently exposed to radiation from various sources, including natural radionuclides found in water, air, and soil, as well as man-made radioactivity resulting from clinical applications (Mbonu & Ben, 2021). These radionuclides can be transferred to humans through soil-plant-man pathways, with the most common routes being ingestion of contaminated crops, water, accidental soil ingestion, and inhalation of radionuclides-laden particulates (Nduka *et al*., 2022).

Naturally occurring radioactive elements and their by-products are commonly found throughout the earth's crust, including in various mining materials like quarry soil. However, these elements are not uniformly distributed within the quarry ecosystem, and their decay can release hazardous ionizing radiation that poses a risk to human health, including the potential for cancer (Nduka *et al.*, 2022). As noted by (Krishnamoorthy *et al.*, 2018), the earth's crust is comprised of solid mineral ores, rocks, and soil, which can contain these radioactive elements. Solid minerals, rocks, and soil are Naturally Occurring Radioactive Materials (NORMs) that contain radionuclides such as ^{238}U, ^{232}Th, and ^{40}K along with their various by-products. Due to the local geology of an area, these materials, as well as sediments and groundwater, can be highly enriched with NORMs, and the levels of these materials can vary from location to location. It is crucial to monitor environmental radioactivity and ensure radiation safety when exploring, mining, quarrying, crushing, and processing these materials, as the radionuclides and toxic elements they contain can become airborne and dispersed from the mining site with the dust particles.

Quarry activities to extract some quarry products lead to the radionuclide contamination of soil surface, food crops, and nearby aquatic environment. Unfortunately, these activities have led to environmental pollution, including the dispersal of Naturally Occurring Radioactive Materials (NORM) such as ^{238}U, ^{232}Th, and ^{40}K (Nduka *et al.*, 2022). The distribution of radionuclides in quarry soil varies based on the soil geology, geography, and physiology, which affect their migration from soil to plants on land with a possible effect on the food chain (Nduka *et al.*, 2022). Sand mining is a global environmental issue that is largely unregulated. Every year, 50 billion tons of sand are extracted worldwide, making it the most extracted material by volume and the second most used resource after water, according to the United Nations Environment Program (UNEP). The activities of sand miners along the Tamburawa River in Dawakin Kudu, which flows through several local government areas in Kano State, have raised concerns among farmers in the communities and environmentalists. Although the extent of sand mining in Nigeria is largely undocumented, the increasing population and urbanization are driving demand for the construction of sand from the Tamburawa River. Without regulations, the extraction process is causing damage, affecting water supply, and food production, and jeopardizing the livelihoods of people in the affected areas and beyond.

Numerous studies have been conducted in the past to examine the concentration and transfer mechanisms of Naturally Occurring Radioactive Materials (NORMs) to plants and humans. Despite this, there remains a significant gap in data, particularly concerning Transfer Factors, in Nigeria. A survey of earlier reported studies showed that there is no existing literature on radiation dose contamination of plants at Dawakin Kudu in Nigeria. The quarry located in Dawakin Kudu has the potential to exhibit elevated levels of natural radioactivity due to intense mining operations. Dawakin Kudu's residents primarily rely on agriculture, benefiting from the fertile lands conducive to farming. However, the ongoing quarry activities raise concerns about the possibility of increased background radiation levels, which could impact food crops cultivated in the area. This radiation transfer mechanism may occur through root uptake via waterways, as quarry soil contaminants infiltrate irrigation sources from nearby rivers, as well as through the deposition of airborne dust particles on plant surfaces (Nduka *et al.*, 2022).

Therefore, the present study tends to assess the level of radiation dose of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in quarry soil and edible plants around the quarry site at Dawakin-Kudu LGA, Kano due to intense quarry activities. The objective of this research is to analyze data on soil-to-plant transfer factors of NORMs by investigating the potential correlation between quarry activities, elevated radiation levels, and their impact on agricultural produce. It will also act as additional information to concerned authorities on the assessment of health risks of natural radionuclides in soil and bio-concentration in plants within and around the quarry site.

MATERIALS AND METHODS

Study area

This study is carried out at Dawakin Kudu densely populated community with quarry activities. Dawakin Kudu is located in Kano Northwest Nigeria, which lies at the latitude of 11.841376°N and longitude of 8.591334°E, samples were collected within latitude of 11.841343°N and longitude 8.591276°E, latitude 11.835379°N and longitude 8.633655°E, latitude 11.844535°N and 8.601081°E. The study location lies within a tropical wet and dry climate. Presently, quarrying activities are ongoing at Dawakin Kudu due to their richness in soil mineral deposits. This site was chosen because of the intense quarry activity that is ongoing in the area, and it is reputed to be one of the huge deposits of sand in Kano, Nigeria.

Figure 1: Map of Kano State showing study area Dawakin Kudu LGA

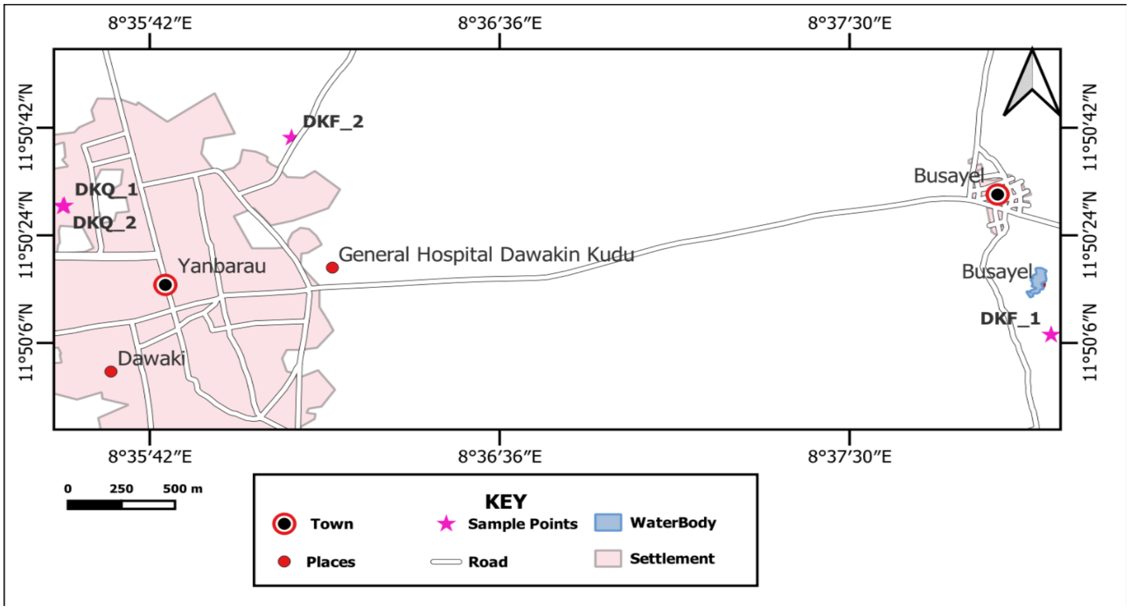

Figure 2: Geological map of Dawakin Kudu LGA Kano State showing locations of samples collection

Sample collection

Eleven (11) soil samples were collected from both the quarry site as well as the farmlands situated around the quarry. Seven (7) plant samples were collected from the farmlands. Four soil samples (quarry soil), seven soil samples from farmlands making a total of eleven soil samples. The samples were collected into a very clean polythene bag and well-labeled to avoid mixed samples. The samples were transported to the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. The majority of the local dwellers are mostly farmers and there could be migration of radionuclides to nearby farmlands leading to radiation and public health implications.

Sample preparation and processing (Gamma-ray spectroscopy)

The soil and plant samples along with the extraneous materials were dried at ambient temperature until there was no detectable change in the mass of the sample. The dried samples were thoroughly crushed, grounded, and pulverized to powder. The powder was passed through a 2mm sieve, due to the limited space of the detector shield. Only 200g - 300g of the soil and plant samples (dry–weight) were used for analysis since this is the quantity it could conveniently take.

The samples after weighing were transferred to radon-impermeable cylindrical plastic containers of uniform size (60mm height by 65mm diameter) and sealed for about 30 days. This was done to allow for Radon and its short-lived progenies to reach secular radioactive equilibrium before gamma spectroscopy (Veiga *et al.*, 2006).

Estimating activity concentration of radionuclides

The activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in the soil and plant samples were determined using a gamma spectrometer coupled with a lead-shielded 76×76 mm NaI (TI) detector crystal (Model No. 727 series, Canberra Inc.) available at the Centre for Energy Research and Training (CERT) Ahmadu Bello University Zaria, Nigeria. The detector is coupled to a Canberra Series 10 plus Multichannel Analyzer (MCA) (Model No.1104) through a preamplifier that was used for the radioactivity measurements. It has a resolution (FWHM) of about 8% at the energy of 662.0keV (^{137}Cs) which is considered adequate to distinguish the gamma-ray energies of interest in the present study. The choice of gamma-ray peaks of the radionuclides to be used for measurements was made because the NaI (Tl) detector used in this study had a modest energy resolution. This was to ensure that the photons emitted by the radionuclides would only be sufficiently discriminated if their emission probability and their energy were high enough, and the surrounding background continuum low enough. Therefore, the activity concentration of ^{214}Bi (determined from its 1760 KeV □ - ray peak) was chosen to provide an estimate of ^{226}Ra (^{238}U) in the samples, while that of the daughter radionuclide ^{208}Ti (determined from its 2615 KeV □ -ray peak) was chosen as an indicator of ^{228}Th (^{232}Th). Potassium-40 was determined by measuring the 1.460 MeV □ -rays emitted during its decay.

The soil and plant samples were placed symmetrically on top of the detector and measured for 29000 seconds (8 hours). The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and other background sources from the total area of the peaks.

Estimating soil-to-plant transfer factor (TF) of radionuclides

The rate of transfer of natural radionuclides from soil to plants was determined using the following (Nduka *et al.*, 2022):

$$TF = \frac{Concentration\ of\ radionuclides\ in\ plant\ (\frac{Bq}{kg} dry\ weight)}{Concentration\ of\ radionuclides\ in\ soil\ (\frac{Bq}{kg} dry\ weight)} \qquad (1)$$

Radiation hazard indices calculation (Gamma Ray Spectroscopy)

The radiological measurement of potassium-40, thorium-232, and Radium-226 was carried out using a sodium iodide (Thallium doped) Gamma-ray detector. It is justifiable to exploit as many as possible known radiation health hazard indices analyses to arrive at a better and safer conclusion on the health status of a radiated or irradiated person and environment. To assess the radiation hazards associated with the soil samples, six quantities have been defined (Zarie and Al Mugren, 2010).

Radium equivalent activity index (Ra_{eq})

To represent the activity levels of ^{226}Ra, ^{232}Th, and ^{40}K by a single quantity, that takes into account the radiation hazards associated with them, a common radiological Index has been introduced (Diab *et al*., 2008). The index otherwise known as Radium equivalent (Ra_{eq}) activity is mathematically defined by (UNSCEAR, 2000) as shown below:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_{K}. \qquad (2)$$

A_{Ra}, A_{Th}, and A_{K} are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K respectively. In the above relation, it has been assumed that 10 $Bqkg^{-1}$ of ^{226}Ra, 7 $Bqkg^{-1}$ of ^{232}Th, and 130 $Bqkg^{-1}$ of ^{40}K produce equal gamma dose. The maximum value of Ra_{eq} in the soil must be less than 370 $Bqkg^{-1}$.

Representative level index (I_{γ}) & (I_{α});

This is another radiation hazard index used for the estimation of gamma radiation and alpha radiation associated with the natural radionuclides in the soil called the representative level index (I_{γ}) (I_{α}), defined according to (Alam *et al*. 1999; Ashraf *et al*. 2010).

$$I\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_{K}}{1500} \qquad (3)$$

$$I\alpha = \frac{A_{Ra}}{200} \qquad (4)$$

The safety value for this index is ≤1.

External hazard index (H_{ex})

A widely used hazard Index (reflecting external exposure) called the External hazard index H_{ex} is defined as follows (UNSCEAR, 2000).

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810} \qquad (5)$$

Internal Hazard Index (H_{in})

In addition to the external hazard index, radon and its short-lived products are also hazardous to the respiratory organs. The internal hazard index is defined to reduce the acceptable maximum concentration of ^{226}Ra to half the value appropriate external exposures alone. The internal exposure to radon and its daughter progenies is quantified by the internal hazard index H_{in}, which is given by the equation:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (6)$$

The values of the indices (H_{ex}, H_{in}) must be less than unity for the radiation hazard to be negligible (Diab *et al*., 2008).

Absorbed dose rate (D)

The absorbed dose rates in outdoor (D) due to gamma radiations in the air at 1m above the ground surface for the uniform distribution of the naturally occurring radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) when calculated based on guidelines provided by (UNSCEAR, 2000). The conversion factors used to compute absorbed gamma (γ) dose rate (D) in air per unit activity concentration in Bq/kg (dry-weight) corresponds to 0.462 ηGyh^{-1} for ^{226}Ra (of U series), 0.621 ηGyh^{-1} for ^{232}Th and 0.0417 ηGyh^{-1} for ^{40}K (UNSCEAR, 2000; Ashraf *et al*., 2010).

$$D\ (\eta Gyh^{-1}) = 0.462A_{Ra} + 0.621A_{Th} + 0.0417A_k \qquad (7)$$

Annual Effective Dose Rate

To estimate the annual effective dose rates outdoors, one has to take into account the conversion coefficient from absorbed dose in the air to effective dose (0.7 Sv Gy^{-1}) and outdoor occupancy factor (0.2) proposed by (UNSCEAR, 2000). The indoor and outdoor annual effective dose rates in ($mSvyr^{-1}$) were calculated using the equations (UNSCEAR, 2000):

$$AEDRoutdoor\ (mSvyr^{-1}) = D\ (\eta Gyh^{-1}) \times 8760\ hyr^{-1} \times 0.7 \times (103mSv/10^9)\ \eta Gy \times 0.2$$

$$AEDRoutdoor\ (mSvyr^{-1}) = D \times 1.2264\ x10^{-3} \qquad (8)$$

$$AEDRindoor\ (mSvyr^{-1}) = D\ (nGyh^{-1}) \times 0.7\ (SvGy^{-1}) \times 0.8 \times 8760\ (hyr^{-1}) \times 10^{-6}$$

$$AEDRindoor\ (mSvyr^{-1}) = D \times 4.9056 \times 10^{-3} \qquad (9)$$

The worldwide annual effective dose from the natural sources of radiation in areas of normal background is estimated to be 1mSvy^{-1} (UNSCEAR, 1993).

Annual effective ingestion dose of plants (AEDing)

The annual ingestion of radionuclides to humans from plants was estimated from the activity concentration of individual radionuclides as shown in equation (10) (UNSCEAR, 2000).

$$AEDing\ (mSv.y^{-1}) = AR \times IRing \times DCFing \qquad (10)$$

Where **AR** is the activity concentration of the radionuclides in a sample, **IRing** is the consumption rate per year, and **DCFing** is the effective dose coefficient for the ingestion of ^{226}Ra (3.58×10^{-4} mSvBq^{-1}), ^{232}Th (2.30×10^{-4} mSvBq^{-1}) and ^{40}K (6.20×10^{-6} mSvBq^{-1}) (UNSCEAR,2000; ICRP,2012). An average consumption rate of 40 kg/year was used for leafy vegetable samples (UNSCEAR, 2000).

Excess Lifetime Cancer Risk

Excess lifetime cancer risk is the increased probability of the quarry site workers and other inhabitants developing cancer due to exposure to specific doses of radiation over a long period. The ELCR was calculated using this equation (ICRP, 2007) (Ugbede, 2021):

$$ELCR = AED\ x\ DL\ x\ RF \qquad (11)$$

where **AED** is the annual effective dose, **DL** is the average duration of life taken and **RF** stands for risk factor.

RESULTS AND DISCUSSION

Activity concentration of radionuclides in soil

The results of gamma-ray measurements of ^{40}K, ^{232}Th, and ^{226}Ra activity concentrations of the soil samples are shown in Table 1. The activity concentration of ^{40}K, ^{232}Th, and ^{226}Ra in soil samples ranges from a maximum value of 597.51 ± 3.81 Bq/kg to a minimum value of 321.93 ± 3.55 Bq/kg in potassium, maximum value of 182.71 ± 1.44 Bq/kg to minimum value of 114.61 ± 1.25 Bq/kg in thorium, maximum value of 65.24 ± 1.92 Bq/kg to minimum value of 42.41 ± 1.73 Bq/kg in radium. The mean activity concentration values of ^{40}K, ^{232}Th, and ^{226}Ra in soil were 502.60 ± 3.43, 162.30 ± 1.62, and 53.76 ± 1.62 Bq/kg. The activity concentration for soil is in this order ^{40}K > ^{232}Th > ^{226}Ra. The results showed that the activity concentration of natural radionuclides in 40_K are higher in soil at Dawakin Kudu

Table 1: Activity concentrations of radionuclides in sampled quarry and Farmland soil from Dawakin Kudu

	SAMPLE CODE	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})
1	DKQ1	65.24 ± 1.92	169.78 ± 1.49	517.57 ± 3.70
2	DKQ2	55.74 ± 1.89	179.70 ± 1.32	577.92 ± 4.03
3	DKQ3	42.64 ± 1.32	167.27 ± 1.19	418.35 ± 2.21
4	DKQ4	65.12 ± 1.23	144.24 ± 1.63	488.18 ± 4.85
5	DKF1	52.03 ± 1.90	170.01 ± 1.52	475.89 ± 3.23

6	DKF2	54.69 ± 1.56	180.05 ± 3.89	407.15 ± 2.41
7	DKF3	52.49 ± 1.44	157.24 ± 1.51	546.81 ± 2.67
8	DKF4	53.88 ± 1.74	166.02 ± 1.31	321.93 ± 3.55
9	DKF5	61.65 ± 1.40	114.61 ± 1.25	671.38 ± 3.37
10	DKF6	42.41 ± 1.73	153.71 ± 1.28	597.51 ± 3.81
11	DKF7	48.47 ± 1.69	182.71 ± 1.44	505.91 ± 3.94
	MEAN	53.76 ± 1.62	162.30 ± 1.62	502.60 ± 3.43

N=11, DKQ= Dawakin Kudu Quarry, DKF= Dawakin Kudu Farmland

Activity concentration of radionuclides in plants

The results of ^{40}K, ^{232}Th, and ^{226}Ra activity concentrations for plant samples are shown in Table 2. The activity concentration of potassium has a maximum value of 282.74 ± 3.27 Bq/kg and a minimum value of 82.43 ± 2.08 Bq/kg, thorium has a maximum value of 152.57 ± 1.22 Bq/kg and a minimum value of 41.96 ± 1.15 Bq/kg, and radium has a maximum value of 78.91 ± 2.32 Bq/kg and a minimum value of 33.37 ± 1.74 Bq/kg. The mean activity concentration values of ^{40}K, ^{232}Th, and ^{226}Ra in plants were 197.51 ± 2.81, 85.15 ± 1.80 and 51.05 ± 2.80 Bq/kg. The activity concentration of radionuclides in plants are in this order ^{40}K > ^{232}Th > ^{226}Ra. The results showed that the activity concentration of natural radionuclides in ^{40}K are higher in plants at Dawakin Kudu

Table 2: Activity concentrations of radionuclides in sampled Plants from Dawakin Kudu

S/N	Plants	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})
1	Maize	42.06 ± 1.54	83.24 ± 3.76	168.89 ± 2.33
2	Tomato	55.39 ± 2.67	53.48 ± 1.48	82.43 ± 2.08
3	Onion	78.91 ± 2.32	67.96 ± 1.51	84.60 ± 2.32
4	Green beans	45.19 ± 4.98	41.96 ± 1.15	130.95 ± 1.77
5	Pepper	33.37 ± 1.74	152.57 ± 1.22	381.49 ± 3.92
6	Okro	60.72 ± 1.62	129.99 ± 1.39	251.47 ± 3.95
7	Spinach	41.71 ± 4.75	66.82 ± 2.09	282.74 ± 3.27
	Mean	51.05 ± 2.80	85.15 ± 1.80	197.51 ± 2.81

N=7

Soil-to-plant Transfer Factor (TF) of Radionuclide Concentration

Table 3 shows the soil-to-plant transfer factor of radionuclides. Ra-266 has a maximum value of 1.503 in tomato plant with a minimum value of 0.541 in pepper plant, Th-232 has a maximum value of 1.331 in pepper plant with a minimum value of 0.253 in green beans plant, and K-40 has a maximum value of 0.568 in pepper plant with a minimum value of 0.202 in tomato plant as shown in figure (3). Figure (3) showed that the Concentration of Ra-266 in a tomato plant, onion plant, okro plant, and Th-232 in a pepper plant was found to be higher than the value recommended by International Commission on Radiation Protection “unity” (TF > 1), while the concentration of K-40 in all plants was found to be less than the value recommended by International Commission on Radiation Protection “unity” (TF < 1). The low values of the transfer factor for K-40 were observed in the case where the concentration of K-40 in the soil samples was extremely high.

Table 3: Soil to plant transfer factor of radionuclides from Dawakin Kudu

S/N	Plants	Quantities	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})
1	Maize	Activity in plant	42.06 ± 1.54	83.24 ± 3.76	168.89 ± 2.33
		Activity in soil	52.03 ± 1.90	170.01 ± 1.52	475.89 ± 3.23
		TF	0.808	0.489	0.355
2	Tomato	Activity in plant	55.39 ± 2.67	53.48 ± 1.48	82.43 ± 2.08
		Activity in soil	54.69 ± 1.56	180.05 ± 3.89	407.15 ± 2.41
		TF	1.013	0.297	0.202
3	Onion	Activity in plant	78.91 ± 2.32	67.96 ± 1.51	84.60 ± 2.32
		Activity in soil	52.49 ± 1.44	157.24 ± 1.51	546.81 ± 2.67
		TF	1.503	0.432	0.155
4	Green beans	Activity in plant	45.19 ± 4.98	41.96 ± 1.15	130.95 ± 1.77
		Activity in soil	53.88 ± 1.74	166.02 ± 1.31	321.93 ± 3.55

		TF	0.839	0.253	0.407
5	Pepper	Activity in soil	33.37 ± 1.74	152.57 ± 1.22	381.49 ± 3.92
		Activity in plant	61.65 ± 1.40	114.61 ± 1.25	671.38 ± 3.37
		TF	0.541	1.331	0.568
6	Okro	Activity in plant	60.72 ± 1.62	129.99 ± 1.39	251.47 ± 3.95
		Activity in soil	42.41 ± 1.73	153.71 ± 1.28	597.51 ± 3.81
		TF	1.432	0.846	0.421
7	Spinach	Activity in plant	41.71 ± 4.75	66.82 ± 2.09	282.74 ± 3.27
		Activity in soil	48.47 ± 1.69	182.71 ± 1.44	505.91 ± 3.94
		TF	0.861	0.366	0.559

N=7, TF= Transfer Factor

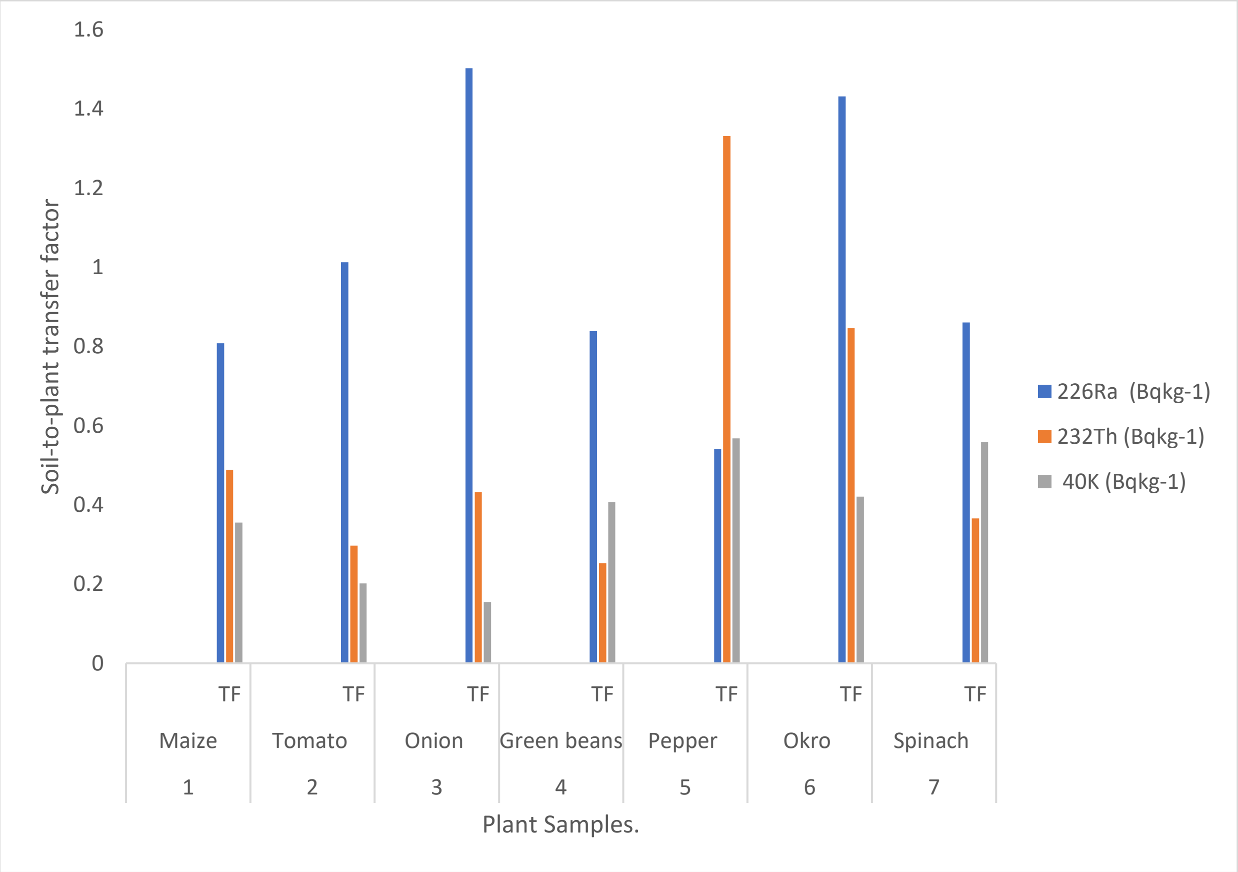

Figure 3**:** Soil-to-plant transfer factor (TF) of radionuclides concentration

Comparison of mean activity concentration (Bq/kg) with other studies.

In this section, the results presented in Table 4 were used to compare the present study with the United Nations Scientific Committee on the Effects of Atomic Radiation. The mean value Concentration of Ra-226 in Soil was found to be higher than the value recommended by UNSCEAR (32 Bq/kg), the mean value Concentration of Th-232 in Soil was found to be higher than the value recommended by UNSCEAR (45 Bq/kg), and the mean value Concentration of K-40 was also found to be higher than the value recommended by UNSCEAR (420 Bq/kg).

Table 4: Comparison of mean activity concentration (Bqkg^{-1}) with other studies

S/N	STUDY SAMPLES	^{226}RA (BQKG^{-1})	^{232}TH (BQKG^{-1})	^{40}K (BQKG^{-1})	COUNTRY	REFERENCES
1	Soil	52.91	76.79	393.73	Nigeria	Ibikunle *et al.*, 2019
2	Soil	35	41	143	Pakistan	Tahir *et al.*, 2005
3	Soil	15.4	14.8	493.0	Saudi Arabia	Aydarous *et al.*, 2022
4	Soil	101	1310	583	India	Yadav *et al.*, 2015
5	Granite soil	131	352	412	Nigeria	Oludunjoye *et al.*, 2022
6	Quarry soil	32.71	68.32	220.0	Ethiopia	Regassa *et al.*, 2022
7	Soil	15.66	16.22	110.54	Nigeria	Rilwan et al., 2022
8	Soil	16.92	21.96	505.92	Egypt	Harb *et al.*, 2014
9	Quarry soil	53.76	162.30	502.60	Nigeria	Present study
10	Soil and rock	32	45	420	Global limit	UNSCEAR

N=10

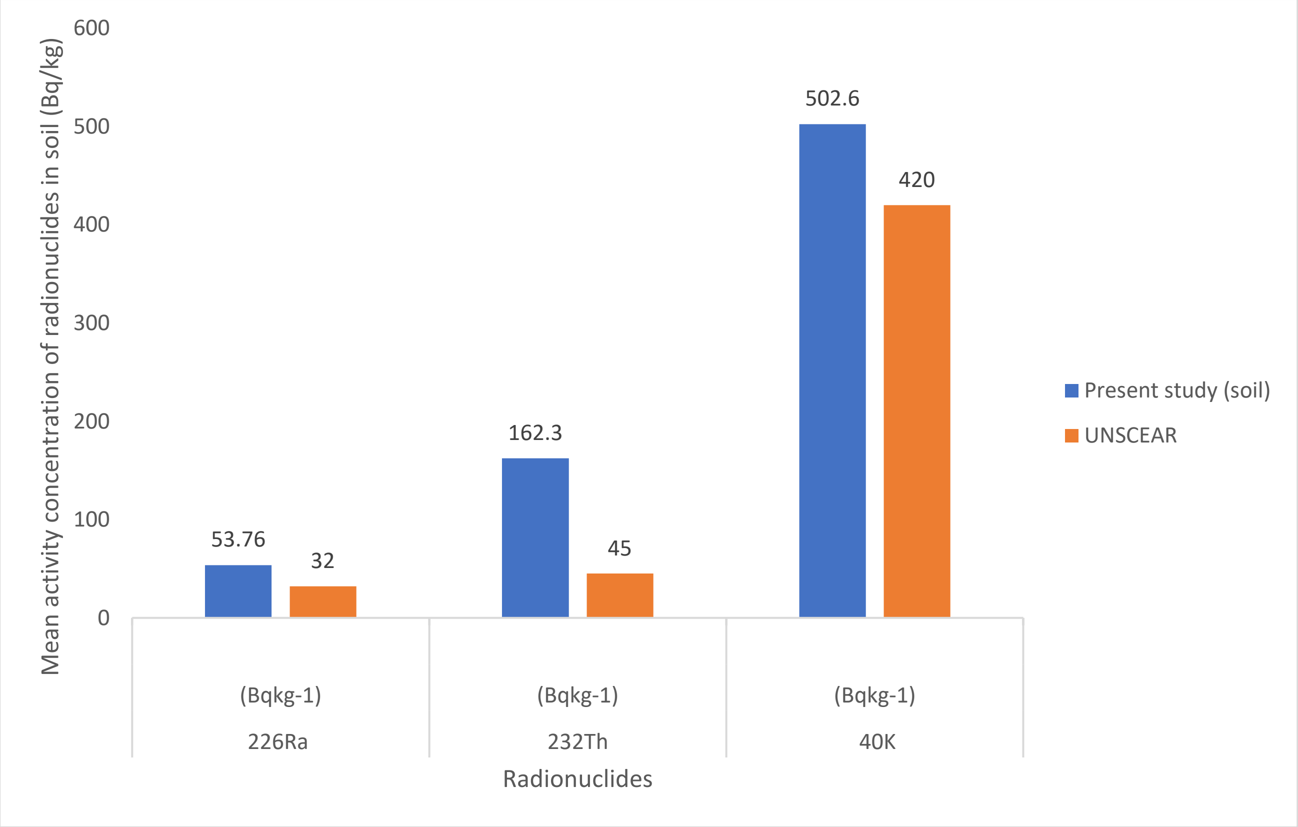

Figure 4: Comparison of mean activity concentration of radionuclides in soil sample with UNSCEAR, 2000

Assessment of Radiological Parameters

The potential health risks associated with exposure to radionuclides from quarry soil were evaluated by calculating the radiological hazard parameters. This was done to assess the risks for quarry personnel, consumers, and the general public. The results, as shown in Table 5, indicate that the average radium equivalent activity does not exceed the recommended safe limit of 370 Bqkg^{-1} (Ajayi, 2002). This indicates that using quarry products obtained from the selected area as building materials may not pose a radioactive hazard. The computed gamma dose rate (DR) was found to be higher than the average dose of 84 nGy h^{-1}. The result shows a significant correlation between the absorbed dose rate and the γ-radiation emitted by the naturally occurring radionuclides.

The total annual effective dose for indoor (AEDin) ranged from 0.622 to 0.792 mSvy^{-1} and for outdoor (AEDout) ranged from 0.198 to 0.155 mSvy^{-1}. The calculated mean values of all the samples from the quarry site are lower than 2.4 mSvy^{-1}, the acceptable worldwide annual effective dose rate. The internal hazard index varied from 0.915 to 1.117 with an average internal hazard index of 1.023 and the external hazard index ranged from 0.749 to 0.965 with an average of 0.877. This value is below the recommended limit set by (UNSCEAR, 2000). This shows that the soil in the studied location is safe to use in the construction of buildings or roads.

The average values of the activity level indices for the selected site are given in Table 5. All the values recorded were above the recommended limit of (Iγ ≤ 1) (UNSCEAR, 2008). This shows that soil from the selected site exhibits high γ-radiation levels. While the Alpha index (Iα) exhibits low-level radiation. The excess lifetime cancer risk (ECLR) ranged from 2.719 to 3.465 quarry samples at Dawakin Kudu with a mean value of 3.114. The mean value is higher than the unity limit as recommended by (UNSCEAR, 2000), i.e. there is a tendency for the general public to develop cancer because of the radiation exposure caused by radionuclides in quarry soil. Thus, the radiation from radionuclides (Radium-226, Thorium-232, and Potassium-40) in the quarry at Dawakin Kudu that was chosen poses a significant health risk to quarry personnel, quarry users, and members of the general public in the area.

Table 5: Radiological parameters in quarry soil from Dawakin Kudu

S/N	Sample Code	DR (nGy h^{-1})	Raeq (Bqkg^{-1})	Hex	Hin	AEDEout (mSvy^{-1})	AEDEin (mSv y^{-1})	Iγ	Iα	ELCR x 10^{-3}
1	DKQ1	157.157	347.880	0.940	1.117	0.193	0.771	2.478	0.326	3.374
2	DKQ2	161.445	357.201	0.965	1.115	0.198	0.792	2.554	0.279	3.465
3	DKQ3	126.717	319.420	0.848	0.963	0.155	0.622	2.236	0.213	2.719
4	DKQ4	140.015	308.970	0.834	1.010	0.172	0.687	2.201	0.326	3.007
5	DKF1	149.459	331.780	0.896	1.036	0.183	0.733	2.364	0.260	3.206
6	DKF2	154.056	343.510	0.928	1.076	0.189	0.756	2.437	0.273	3.308
7	DKF3	144.698	319.440	0.863	1.005	0.177	0.709	2.286	0.262	3.031
8	DKF4	141.415	316.080	0.854	0.999	0.173	0.694	2.234	0.269	3.035
9	DKF5	127.651	227.230	0.749	0.915	0.157	0.626	2.005	0.308	2.741
10	DKF6	139.963	308.230	0.832	0.946	0.172	0.687	2.218	0.212	3.007
11	DKF7	156.952	348.710	0.941	1.072	0.192	0.769	2.487	0.242	3.364
	Mean	145.412	320.771	0.877	1.023	0.178	0.713	2.318	0.270	3.114

N=11, DKQ= Dawakin Kudu Quarry, DKF= Dawakin Kudu Farmland, DR= Dose Rate.

Annual Effective ingestion dose of plants (AEDing) and Excess lifetime cancer risk (ELCR)

The mean cancer risk assessed in the study location is 3.114×10^{-3} as shown in Table 5 for quarry soil which is above the World average value of 0.29×10^{-3} (UNSCEAR, 2000). Therefore, it implies that there is a high probability of occupational exposure to workers and individuals living around the study area to cancer risk due to the high level of ionizing radiation of radionuclides. However, long-term accumulation of radiation doses can cause a radiological health burden to the exposed populace. The mean ELCR value of all the plants from Dawakin-Kudu soil is 5.471×10^{-3} (Table 6) which is higher than the recommended value of 0.29×10^{-3} and continuous consumption of these plants and food crops can lead to cancerous diseases. Okro plant (7.445× 10^{-3}), Pepper plant (6.919×10^{-3}), and Onion plant (6.213×10^{-3}) showed high ELCR at Dawakin Kudu farmland located around the quarry site. This is a result of the high ingestion dose rate of the noted radionuclides in the plants. Therefore, there is a tendency of higher potential health risk due to plant ingestion exposure to radiation from Th-232 and Ra-226. Also, other life-threatening diseases from health risk exposure include kidney disease, liver disease, cardiovascular disorder, chromosomal aberrations, leukemia, benign tumors, bone and pancreas cancers, and can even lead to death if not treated. There should be regular and strict monitoring of radioactive elements in the studied area to check the impact of anthropogenic activities in the locations so as not to increase the observed high concentrations. This scenario can control environmental health problems through the impact of long-term accumulations of radiation dose associated with radionuclides concentrations.

Table 6: Evaluated AEDing and ELCR in plants from Dawakin Kudu

S/N	Plants	AEDing ($mSvy^{-1}$)			Total	
		^{226}Ra ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	^{40}K ($Bqkg^{-1}$)	AEDing ($mSvy^{-1}$)	ELCR X 10^{-3}
1	**Maize**	0.602	0.766	0.042	1.410	4.935
2	**Tomato**	0.793	0.492	0.020	1.305	4.568
3	**Onion**	1.129	0.625	0.021	1.775	6.213
4	**Green beans**	0.647	0.386	0.032	1.065	3.728
5	**Pepper**	0.478	1.404	0.095	1.977	6.919
6	**Okro**	0.869	1.196	0.062	2.127	7.445
7	**Spinach**	0.597	0.615	0.070	1.282	4.487
	Mean	0.731	0.783	0.049	1.563	5.471

CONCLUSION

This study delved into the environmental risks associated with natural radioactivity and toxic elements in quarry sites, with a focus on the transfer mechanism from soil to plant to human pathways. The activity concentrations of Ra-226, Th-232, and K-40 in soil and plant samples obtained from Dawakin Kudu LGA in Kano State, Nigeria, were measured using a Gamma-ray spectrometry method coupled with thallium thallium-activated sodium iodide (NaI) detector. The activity concentrations, radium equivalents, gamma dose rates, annual effective dose, excess lifetime cancer risk, gamma index, and hazard indices were obtained for the soil samples. The annual effective dose for ingestion of radionuclides in plant samples was obtained to calculate the ELCR. The mean values obtained for the activity concentration of Ra-266, Th-232, and K-40 in soil and plant samples exceeded the average value recommended by the international community. The estimated radiological parameters for a significant approach to health hazards in the soil were above the recommended global limit. The estimated transfer factor of the radionuclides was more than unity signifying high absorption and translocation of gamma radiation from soil to leafy parts of the plants. The results showed that the activity concentration of natural radionuclides is higher in both soil and plant samples at Dawakin Kudu. The Concentration of Ra-266 in a tomato plant, onion plant, okro plant, and Th-232 in a pepper plant was found to be higher than the value recommended by International Commission on Radiation Protection "unity" (TF > 1), while the concentration of K-40 in all plants was found to be less than the value recommended by International Commission on Radiation Protection "unity" (TF < 1). The mean value Concentration of Ra-266, Th-232, and K-40 in Soil was found to be higher than the value recommended by UNSCEAR. The calculated AEDR mean values of all the samples from the quarry site are lower than 2.4 $mSvy^{-1}$, the acceptable worldwide annual effective dose rate. The excess lifetime cancer risk (ECLR) ranged from 2.719 to 3.465 quarry samples at Dawakin Kudu with a mean value of 3.114. The mean value is higher than the unity limit as recommended by (UNSCEAR, 2000), i.e. there is a tendency for the general public to develop cancer because of the radiation exposure caused by radionuclides in quarry soil.

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