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Health Risk Assessment of Radiation Exposure to Radionuclides In Quarry Soil at Dawakin-Kudu Kano, Nigeria.

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Abstract
Advancements in global development heavily rely on innovation, with technology serving as a vital tool for achieving progress. However, sustainable development cannot be realized without prioritizing public health and environmental safety. This study investigates the potential health risks posed to the public by natural radionuclides present in quarry soil from Dawakin-Kudu, Kano, Nigeria. Using gamma-ray spectrometry and a Sodium Iodide (NaI (Tl)) detector, the activity concentrations of radionuclides, including ^{226}Ra, ^{232}Th, and ^{40}K, were measured. The findings revealed elevated levels of natural radioactivity in the soil, with activity concentrations ranging from ^{226}Ra: 42.41±1.73 Bqkg^{-1} – 65.24±1.92 Bqkg^{-1}, ^{232}Th: 114.61±1.25 Bqkg^{-1} – 182.71±1.44 Bqkg^{-1}, ^{40}K: 321.93±3.55 Bqkg^{-1} – 597.51±3.81 Bqkg$^{-1.}$ Radiological hazard assessments showed values below the safety limits recommended by UNSCEAR. Despite this, prolonged exposure may render the area unsafe for residents, underscoring the need for continuous monitoring of radioactivity levels to mitigate long-term environmental health risks.

Keywords: Health Risk, NaI (Tl) Detector, Radioactivity, Radiological Hazards, Soil

INTRODUCTION
Radiation originating from the Earth's subsurface poses potential threats to human health due to the presence of natural radionuclides. These radionuclides, classified as Naturally Occurring Radioactive Materials (NORMs), are influenced by environmental changes (Joel *et al*., 2020). Background radiation arises from two primary sources: natural sources, such as cosmic rays and environmental radioactivity from NORMs, and artificial sources, including medical X-rays, nuclear weapon testing, and accidents (Babatunde *et al*., 2023). Consequently, the environment inhabited by living organisms is inherently radioactive, exposing individuals

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to various sources of radiation, including natural radionuclides in water, air, and soil, as well as man-made sources (Mbonu & Ben, 2021).

The presence of radioactive nuclides such as Radium, Uranium, Thorium, Potassium, and Cesium can lead to adverse health effects, including cancer. While Cesium may result from nuclear fallout, accurately measuring radioactivity concentrations is essential to mitigate potential health risks (Ibrahim *et al.,* 2018). Soil, a dynamic natural entity formed through rock weathering, plays a critical role in maintaining ecological stability. However, contamination can compromise soil quality, leading to health and environmental challenges.

Human health risk assessment, as developed by the U.S. EPA, provides a systematic frame work for evaluating potential adverse effects of exposure to natural and artificial environmental hazards (USEPA 1991; USEPA 2004). This involves integrating scientific data to estimate risks through various exposure pathways, including inhalation, dermal contact, and ingestion. Advanced methodologies such as Human Health Risk Assessment (HHRA) (Egbueri *et al*., 2022), Monte Carlo Risk Simulation (Egbueri *et al*., 2022), and Quantitative Structure Activity Relationship (QSAR) (Ayejoto & Egbueri 2023) have been employed to assess cancer and non-cancer risks.

Study have been conducted on the quarry soil at Dawakin Kudu to examine the concentration and transfer mechanisms of Naturally Occurring Radioactive Materials (NORMs) to plants and humans (Kareemah *et al.,* 2024). A survey of earlier reported studies showed that there is no existing literature on health risk exposure to radionuclides at Dawakin Kudu in Nigeria. Therefore, this present study aims to assess the Health risk associated with natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in quarry soil at Dawakin-Kudu LGA. The objective of this research is to assess the health hazard associated with NORMs and also to evaluate the potential health risk assessment for adults and children for exposure medium (inhalation, inhalation and dermal contact). It will also act as additional information to concerned authorities on the assessment of health risks of natural radionuclides contributing valuable insights to authorities regarding the health risks posed by natural radionuclides in soil and inform strategies for mitigating environmental and public health risks.

MATERIALS AND METHODS

Study Area

This research was conducted in Dawakin-Kudu, a densely populated community in Kano State, Nigeria, known for its active quarrying activities. The area is situated at a latitude of 11.841376°N and longitude of 8.591334°E. Soil samples were collected within specific coordinates, including 11.841343°N, 8.591276°E; 11.835379°N, 8.633655°E; and 11.844535°N, 8.601081°E. The region experiences a tropical wet and dry climate, and its rich mineral deposits have made it a hub for quarrying activities. The study site was chosen due to the ongoing quarrying operations and the potential radiological implications for the environment and public health.

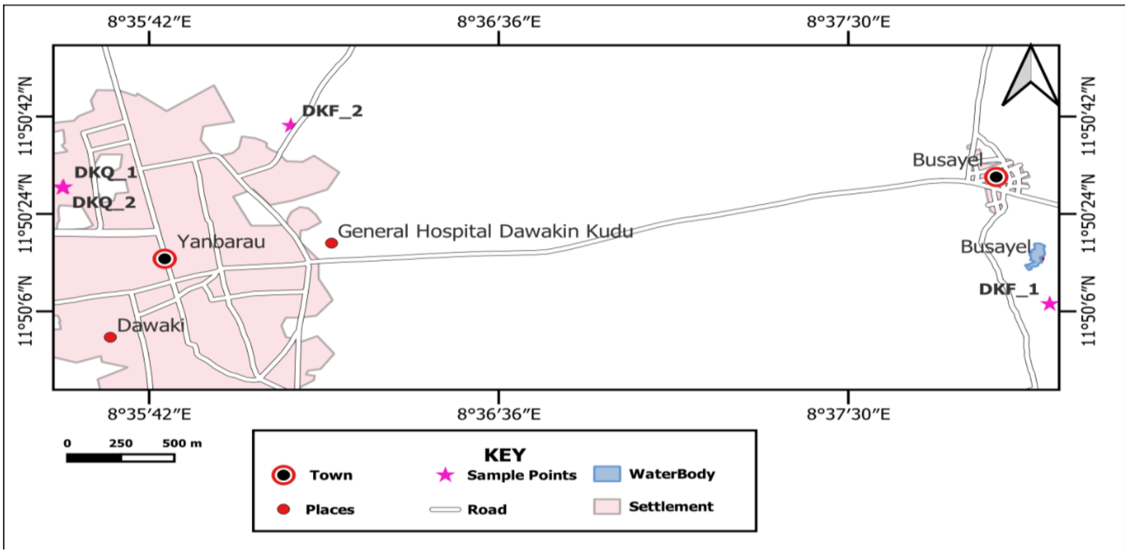

Figure 1- Map of Dawakin Kudu LGA Kano State showing locations of samples collection

Sample Collection

A Total of 11 soil samples were collected from the quarry site and surrounding farmlands. This included four samples from the quarry and seven from nearby farmlands. The samples were carefully placed in clean polythene bags and labeled to prevent cross-contamination. They were then transported to the Centre for Energy Research and Training (CERT) at Ahmadu Bello University, Zaria, for further analysis.

Sample Preparation and processing

The Soil samples were dried at ambient temperature to remove moisture until no further change in mass was detected. They were then crushed, ground, and sieved through a 2 mm mesh. Approximately 200–300 g of the sieved samples were weighed and transferred into radon-impermeable cylindrical plastic containers of uniform dimensions (60 mm height by 65 mm diameter) (Ibeanu, 1999 & Adamu *et al.*, 2013). The containers were sealed and stored for 30 days to allow for radon and its progenies to reach secular equilibrium before gamma spectroscopy analysis (Ramasamy *et al.*, 2004 & Veiga *et al.*, 2006).

Gamma-Ray Spectroscopy

The activity concentrations of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in the soil samples were measured using a gamma-ray spectrometer. The setup included a lead-shielded 76 × 76 mm Sodium Iodide (NaI (Tl)) detector (Model No. 727 series, Canberra Inc.) coupled with a Canberra Series 10 Multichannel Analyzer (Model No. 1104). The detector had a resolution of 8% at 662.0 keV (137Cs), which was sufficient to distinguish the gamma-ray energies of interest. Specific gamma-ray peaks were used to estimate radionuclide concentrations: 1760 keV for ^{226}Ra 2615 keV for ^{232}Th and 1460 keV for ^{40}K. Each sample was measured for 8 hours (29,000 seconds), and the net peak area was determined after subtracting background counts.

Health Risk Assessment

The health risk assessment evaluated potential adverse effects from exposure to radionuclides through soil. Both adults and children were considered, and exposure pathways included ingestion, inhalation, and dermal contact. The average daily intake (ADI) for each pathway was calculated using established equations, incorporating parameters such as radionuclide concentration, exposure frequency, and body weight. Hazard indices (HI) were also determined to assess the overall risk to human health as shown in Equations (1–3) (Onwukeme *et al.,* 2021, WHO 2011).

Ingestion of radionuclides through soil

$$ADI_{ing} = \frac{Cs \times IR \times EF \times ED \times CF}{BW \times AT} \quad (1)$$

Where ADIing is the average daily intake of radionuclides ingested from soil in mg/kg-day, Cs is the activity concentration of radionuclides in mg/kg for soil. IR is the ingestion rate (100mg/day-adults and 200mg/day-children), EF is the exposure frequency (350-day/year), ED is the exposure duration (30 years—adults and 6 years—children) (APHA 2000, Akpoveta *et al.,* 2011), BW is the body weight of the exposed individual (70 kg for adults and 15 kg for children), AT is the time period over which the dose is averaged (non-carcinogens=ED×365days; carcinogen=70×365 days), CF is the conversion factor (10–6 kg/mg for adults and children) (Charity *et al*., 2018, Ojaniyi *et al.,* 2021).

Inhalation of radionuclides through soil

$$ADI_{inh} = \frac{Cs \times IR \times EF \times ED}{BW \times AT \times PEF} \quad (2)$$

where ADIinh is the average daily intake of radionuclides inhaled from soil in mg/kg-day, IRair is the inhalation rate (20m^3/day-adults and 10m^3/day-children), PEF is the particulate emission factor (1.3 ×109 m^3/kg for adults and children) (APHA 2000, Charity *et al* 2018). Cs, EF, ED, BW and AT are as defined in Equation (1).

Dermal Absorption rate

$$ADI_{der} = \frac{Cs \times SA \times FE \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (3)$$

where ADI_{der} is the exposure dose via dermal contact in mg/kg/day. SA is exposed skin area (5800cm^2/day—adults and 2100 cm^2/day—children), FE is the fraction of the dermal exposure ratio to soil (unit-less) (0.61 for adults and children), AF is the soil adherence factor (0.07 mg/cm^2-adults and 0.2 mg/cm^2-children), ABS is the fraction of the applied dose absorbed across the skin (unit-less) (0.1 for adults and children) (Ojaniyi *et al*., 2021, Ibrahim *et al.,* 2018). EF, ED, BW, CF and AT are as defined in Equation (1).

RESULTS

In this section, we present a comprehensive analysis of the data obtained, followed by an in-depth discussion that elucidates the significance of these results in relation to the research objectives and the broader scientific context.

Activity Concentration of Radionuclides in Soil

The Gamma-ray spectrometry results revealed the activity concentrations of ^{40}K, ^{232}Th, and ^{226}Ra in the soil samples. The activity concentration of ^{40}K ranged from 321.93 ± 3.55 Bq/kg to 597.51 ± 3.81 Bq/kg, ^{232}Th ranged from 114.61 ± 1.25 Bq/kg to 182.71 ± 1.44 Bq/kg, and ^{226}Ra ranged from 42.41 ± 1.73 Bq/kg to 65.24 ± 1.92 Bq/kg. The mean activity concentrations were 502.60 ± 3.43 Bq/kg for ^{40}K, 162.30 ± 1.62 Bq/kg for ^{232}Th, and 53.76 ± 1.62 Bq/kg for ^{226}Ra. The activity concentrations followed the order ^{40}K >^{232}Th>^{226}Ra, with ^{40}K displaying the highest levels.

Table 1 Activity Concentrations of Radionuclides in Sampled Quarry and Farmland Soil from Dawakin Kudu

S/N	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

DKQ= Dawakin Kudu Quarry, DKF= Dawakin Kudu Farmland

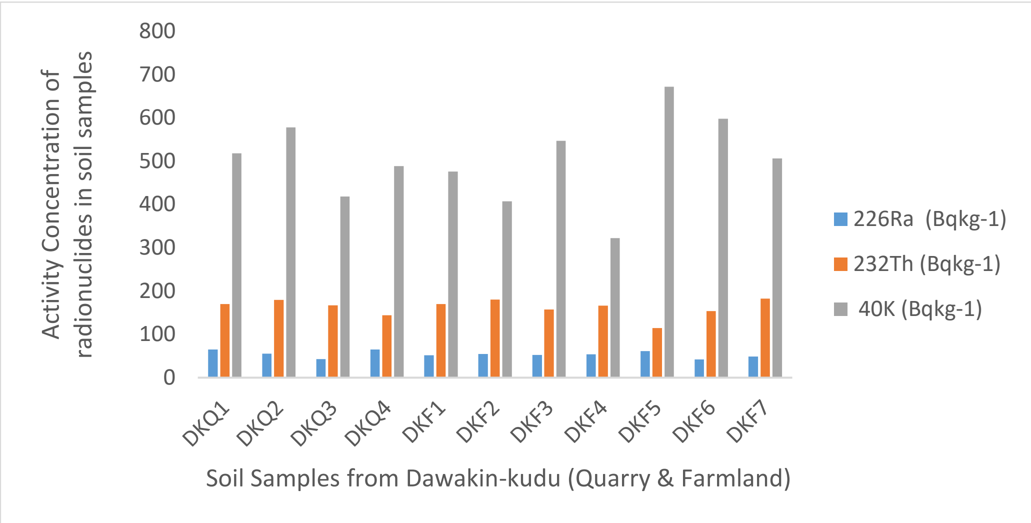

Figure 1- Activity Concentration of Radionuclides in soil samples

Comparison with Other Studies

The average activity concentrations of the radionuclides in this study were compared with values reported in previous studies and international safety limits. The mean concentration of ^{226}Ra exceeded the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) recommended value of 32 Bq/kg, while ^{232}Th and ^{40}K also surpassed their respective limits of 45 Bq/kg and 420 Bq/kg. These findings indicate elevated levels of natural radioactivity in the soil, which may pose radiological risks.

Table 2 Comparison of mean activity concentration (Bqkg^{-1}) with other studies

S/N	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

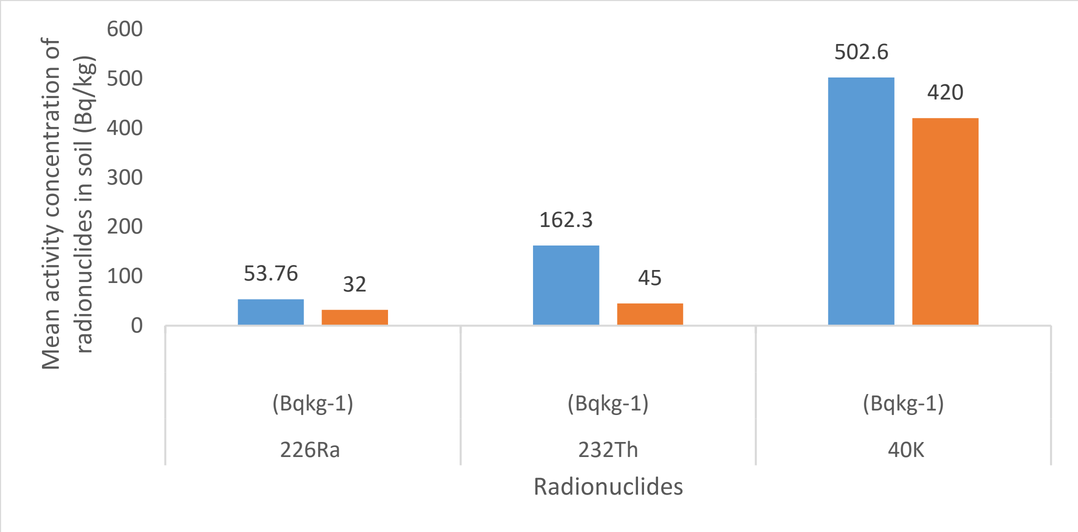

Figure 2- Comparison of mean activity concentration of radionuclides in soil sample with UNSCEAR, 2000.

Health Risk Assessment

The health risk assessment considered exposure pathways such as ingestion, inhalation, and dermal contact. For ingestion, the Average Daily Intake (ADI) values for ^{40}K, ^{232}Th, and ^{226}Ra were calculated for both adults and children. The ADI values for children were higher than those for adults, reflecting their increased susceptibility to radiological hazards. Inhalation and dermal absorption rates were also evaluated, with results indicating that the dose rates for these pathways were below the recommended safety thresholds established by the United States Environmental Protection Agency (USEPA).

Table 3: Exposure parameters for children and adult population used in this present study (Bakshi *et al.*, 2018)

Parameter	Unit	Adult	Child
Ingestion rate (IR_{ing})	mg/day	100	200
Exposure duration (ED)	Years	30	6
Body weight (BW)	kg	70	15
Inhalation rate (IR_{inh})	m^3/day	20	10
Exposure frequency (EF)	Days/year	350	350
Dermal exposure ratio (FES)	–	0.61	0.61
Conversion factor (CF)	kg/mg	10^{-6}	10^{-6}
Dermal absorption factor (ABS)	–	0.1	0.1
Skin surface area (ESA)	cm^2	5800	2100
Soil adherence factor (SAF)	mg/cm^2	0.07	0.2
Average time (AT) For carcinogenic	Days	365 × 70	365 × 70
Average time (AT) For non-carcinogenic	Days	365 × ED	365 × ED

Table 4: Average Daily Intake (ADI) for ingestion of radionuclides through soil.

S/N	SAMPLES	RECIPIENTS	^{226}Ra	^{232}Th	^{40}K
1	DKQ1	ADULTS	0.00009	0.00023	0.00071
		CHILDREN	0.00083	0.00217	0.00662
2	DKQ2	ADULTS	0.00008	0.00025	0.00079
		CHILDREN	0.00071	0.00229	0.00739
3	DKQ3	ADULTS	0.00006	0.00023	0.00057
		CHILDREN	0.00055	0.00214	0.00535
4	DKQ4	ADULTS	0.00009	0.00019	0.00067
		CHILDREN	0.00083	0.00184	0.00624
5	DKF1	ADULTS	0.00007	0.00023	0.00065

		CHILDREN	0.00067	0.00217	0.00608
6	DKF2	ADULTS	0.00007	0.00025	0.00056
		CHILDREN	0.00069	0.00230	0.00521
7	DKF3	ADULTS	0.00007	0.00022	0.00075
		CHILDREN	0.00067	0.00201	0.00699
8	DKF4	ADULTS	0.00007	0.00023	0.00044
		CHILDREN	0.00069	0.00212	0.00412
9	DKF5	ADULTS	0.00008	0.00016	0.00092
		CHILDREN	0.00079	0.00147	0.00858
10	DKF6	ADULTS	0.00006	0.00021	0.00082
		CHILDREN	0.00054	0.00197	0.00764
11	DKF7	ADULTS	0.00007	0.00025	0.00069
		CHILDREN	0.00062	0.00234	0.00647
	MEAN	ADULTS	0.00007	0.00022	0.00069
		CHILDREN	0.00069	0.00207	0.00643

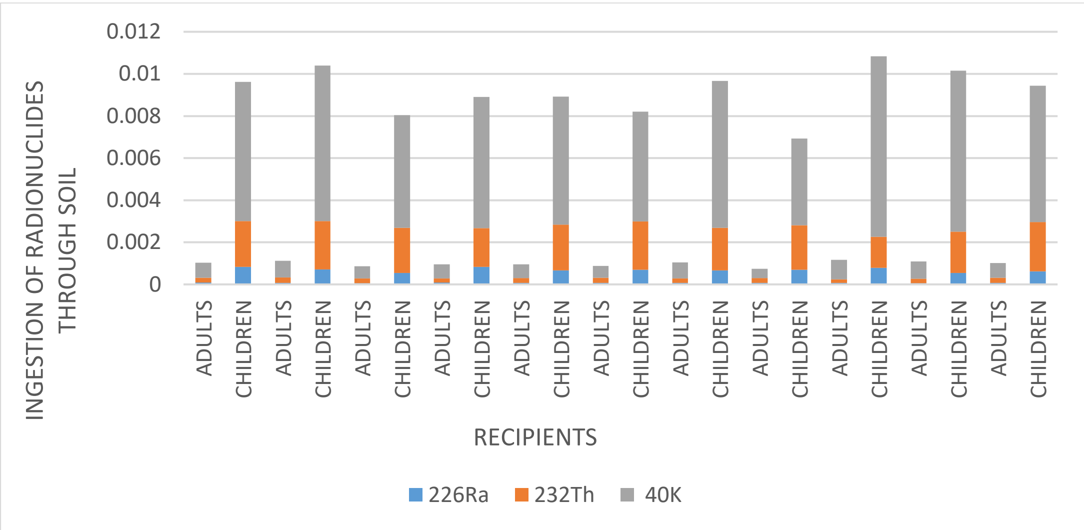

Figure 3- Average Daily Intake (ADI) for ingestion of radionuclides through soil

Table 5: Average Daily Intake (ADI) for Inhalation of radionuclides through soil

S/ N	SAMPLES	RECIPIENTS	^{226}Ra	^{232}Th	^{40}K
1	DKQ1	ADULTS	0.00002	0.00004	0.00014
		CHILDREN	0.00021	0.00054	0.00165
2	DKQ2	ADULTS	0.00002	0.00005	0.00016
		CHILDREN	0.00018	0.00057	0.00185
3	DKQ3	ADULTS	0.00001	0.00005	0.00011
		CHILDREN	0.00014	0.00053	0.00134
4	DKQ4	ADULTS	0.00002	0.00004	0.00013
		CHILDREN	0.00021	0.00046	0.00156
5	DKF1	ADULTS	0.00001	0.00005	0.00013
		CHILDREN	0.00017	0.00054	0.00152
6	DKF2	ADULTS	0.00001	0.00005	0.00011
		CHILDREN	0.00017	0.00058	0.00130
7	DKF3	ADULTS	0.00001	0.00004	0.00015
		CHILDREN	0.00017	0.00050	0.00175
8	DKF4	ADULTS	0.00001	0.00005	0.00009
		CHILDREN	0.00017	0.00053	0.00103
9	DKF5	ADULTS	0.00002	0.00003	0.00018
		CHILDREN	0.00019	0.00037	0.00215
10	DKF6	ADULTS	0.00001	0.00004	0.00016
		CHILDREN	0.00014	0.00049	0.00191

11	DKF7	ADULTS	0.00001	0.00005	0.00014
		CHILDREN	0.00015	0.00058	0.00162
	MEAN	ADULTS	0.00001	0.00004	0.00014
		CHILDREN	0.00017	0.00052	0.00161

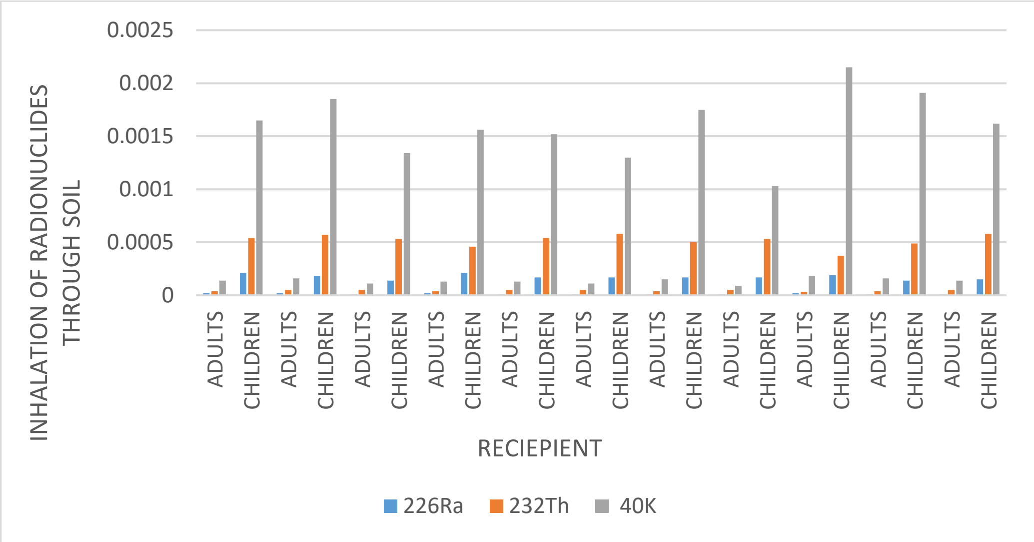

Figure 4- Average Daily Intake (ADI) for inhalation of radionuclides through soil

Table 6: Average Daily Intake (ADI) for Dermal Absorption rate through soil

S/ N	SAMPLES		^{226}Ra	^{232}Th	^{40}K
1	DKQ1	ADULTS	0.00002	0.00006	0.00018
		CHILDREN	0.00011	0.00028	0.00085
2	DKQ2	ADULTS	0.00002	0.00006	0.00019
		CHILDREN	0.00009	0.00029	0.00095
3	DKQ3	ADULTS	0.00001	0.00006	0.00014
		CHILDREN	0.00007	0.00027	0.00069
4	DKQ4	ADULTS	0.00002	0.00004	0.00017
		CHILDREN	0.00011	0.00024	0.00079
5	DKF1	ADULTS	0.00002	0.00006	0.00016
		CHILDREN	0.00009	0.00028	0.00078
6	DKF2	ADULTS	0.00002	0.00006	0.00014
		CHILDREN	0.00009	0.00029	0.00067
7	DKF3	ADULTS	0.00002	0.00005	0.00019
		CHILDREN	0.00009	0.00026	0.00089
8	DKF4	ADULTS	0.00002	0.00006	0.00011
		CHILDREN	0.00009	0.00027	0.00053
9	DKF5	ADULTS	0.00002	0.00004	0.00023
		CHILDREN	0.00010	0.00019	0.00109
10	DKF6	ADULTS	0.00001	0.00005	0.00020
		CHILDREN	0.00007	0.00025	0.00098
11	DKF7	ADULTS	0.00002	0.00006	0.00017
		CHILDREN	0.00008	0.00029	0.00083
	MEAN	ADULTS	0.00002	0.00005	0.00017
		CHILDREN	0.00009	0.00026	0.00082

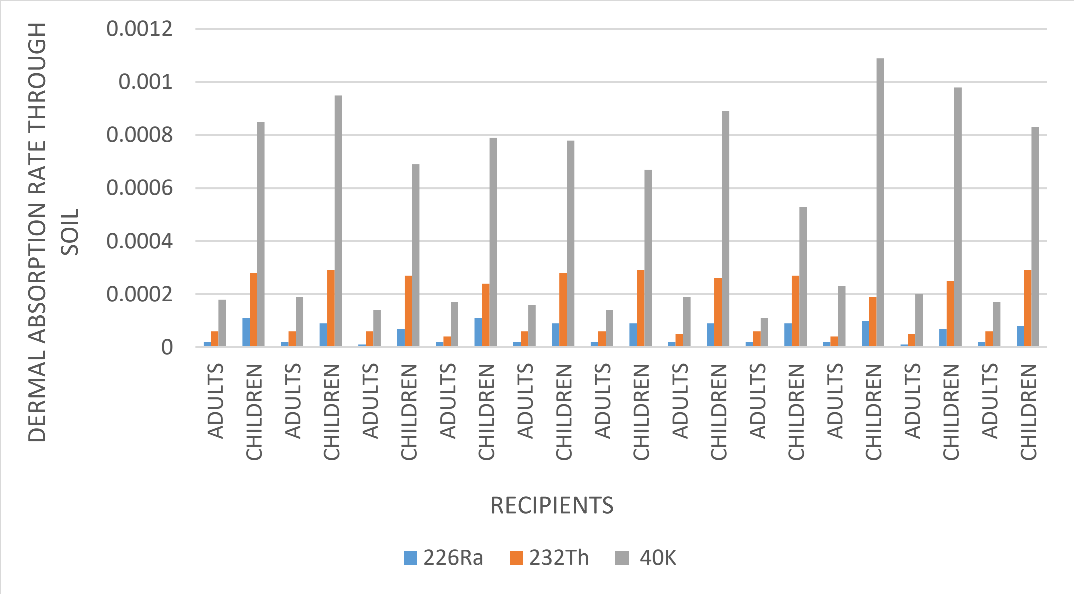

Figure 5- Average Daily Intake (ADI) for Dermal Absorption rate through soil

DISCUSSION

A descriptive analysis was carried out on the activity concentration of radionuclides and the data obtained using NaI detector. The mean activity concentration values of ^{40}K, ^{232}Th, and ^{226}Ra in Dawakin-Kudu soil were 502.60 ± 3.43, 162.30 ± 1.62, and 53.76 ± 1.62 Bq/kg. These activity concentration values obtained from these locations and their environs were above the world permissible value of 32.0Bq/kg for Ra-226, 45.0Bq/kg for Th-232 and 420.0Bq/kg for K-40. Generally, potassium displayed the highest activity concentration among the radionuclides in the soil at Dawakin kudu in this order $^{40}K > ^{232}Th > ^{226}Ra$. The mean activity concentration of ^{40}K, ^{232}Th, and ^{226}Ra of soil samples in this study is lower than the values reported by (Yadav *et al.,* 2015) India. The comparison of average activity concentrations of radionuclides with other locations and United Nations Scientific Committee on the Effects on Atomic Radiation standards (UNSCEAR 2000) shows that the current amount of the estimated elements in the quarry soil from Dawakin kudu are not within the safe limit and can pose any radiological health defect to public humans.

Table 3 gives the Exposure parameters for children and adult population used in the present study (Bakshi *et al.,* 2018). The results, as shown in Table 4 indicates that the Average Daily Intake (ADI) for ingestion of radionuclides through soil for both adults and children does not exceed the recommended limit set by (UNSCEAR 2000). The average daily intake (ADI) values in soil for non-carcinogenic effects Table 4 indicated more effects on children than adults. The result shows a significant correlation between the ingestion rate and the γ-radiation emitted by the naturally occurring radionuclides. The Average Daily Intake (ADI) for Inhalation of radionuclides through soil are provided in Table 5. The value recorded for inhalation for both adults and children were lower than the committed effective doses. This value is below the recommended limit set by (UNSCEAR, 2000).

The result shows low ingestion and inhalation dose rate of the noted radionuclides in the soil. Therefore, there is no tendency of higher potential health risk due to soil ingestion and inhalation exposure to radiation from ^{226}Ra, ^{232}Th, and ^{40}K. 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 in cases of long term inhalation and ingestion of this radionuclides. There should be regular and strict monitoring of radioactive elements in the studied area to check the impact of anthropogenic activities in the locations as not to increase the observed concentrations. This scenario can control environmental health problems through the impact of long-term accumulations of radiation dose associated with radionuclides concentrations.

CONCLUSION

This study assessed the health risks associated with natural radionuclides ^{40}K, ^{232}Th, and ^{226}Ra in quarry soil from Dawakin-Kudu, Kano, Nigeria. The results revealed elevated activity concentrations of these radionuclides, with values exceeding the global permissible limits recommended by UNSCEAR (2000). Potassium-40 exhibited the highest activity concentration, followed by Thorium-232 and Radium-226.

The radiological hazard indices calculated for both adults and children were within acceptable safety limits. However, the health risk assessment indicated that children are more vulnerable to radiological hazards, particularly through the ingestion pathway. While the inhalation and dermal absorption pathways contributed less significantly, their potential long-term effects cannot be overlooked.

These findings highlight the need for regular monitoring of radionuclide concentrations in quarry soil to prevent potential radiological health risks. Public health authorities and environmental agencies should implement strategies to mitigate these risks, such as raising awareness among local communities and enforcing regulations on quarrying activities. Further research is recommended to evaluate the long-term environmental and health impacts of radionuclide exposure in the study area and similar region.

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