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Evaluation of Excess Lifetime Cancer Risk for Environmental Exposures in Kaduna, Nigeria

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Abstract

This study assessed the excess lifetime cancer risk (ELCR) associated with natural radioactivity in marble samples from Gidan Waya and Ungwar Damishi, North Central Nigeria. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were determined using gamma ray spectrometer with a NaI (Tl) detector. From these data, radiological hazard indices, including ELCR, were calculated. Marble samples from Gidan Waya exhibited ELCR values ranging from 0.104×10^{-3} to 0.250×10^{-3}, with an average of 0.150×10^{-3}, which is below the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reference value of 0.29×10^{-3}. These results indicate that long-term use of Gidan Waya marble poses a low cancer risk to the population. In contrast, marble from Ungwar Damishi showed significantly higher ELCR values, ranging from 1.82×10^{-3} to 2.92×10^{-3}, with an average of 2.17×10^{-3}. Though other hazard indices, such as the radium equivalent activity (Raeq), absorbed dose rate, and annual effective dose, were within recommended safety thresholds, the elevated ELCR values suggest a potential health concern for long-term indoor exposure. The findings imply that marble from Gidan Waya is radiologically safe for construction and decorative purposes, while marble from Ungwar Damishi requires further investigation. In particular, long-term indoor exposure scenarios, radon exhalation rates, and refined dose modelling should be considered in future studies to provide a more comprehensive risk profile. This study not only advances understanding of natural radioactivity in building materials in Nigeria but also contributes to the achievement of Sustainable Development Goal 3 (SDG 3: Good Health and Well-being) by informing safe material use and promoting public health protection.

Keywords: Natural Radioactivity; Gamma ray spectrometer; Excess lifetime cancer risk; Marble mining.

I. INTRODUCTION

Estimating population exposure to ionizing radiation requires a clear understanding of the distribution and concentration of naturally occurring radionuclides in the environment. Of particular significance are radionuclides from the uranium-238 (^{238}U) and thorium- 232 (^{232}Th) decay series, together with potassium-40 (^{40}K). Due to their exceptionally long half-lives, these primordial radionuclides have persisted since the Earth's formation and continue to constitute a significant component of natural background radiation [1]. These radionuclides originate from various sources, including the Earth's crust, rocks, soils, sediments, minerals, water, plants, and even the atmosphere [2]. The geographical and geological settings of a region play a major role in determining the background radiation levels and, consequently, the exposure of local populations [1, 3].

In addition to natural factors, human activities such as mining, quarrying, and the use of fossil fuels can elevate natural background radiation levels [4, 5, 6]. This is particularly relevant in North Central, Nigeria, where artisanal and small-scale mining of marble and other minerals is common [7]. Such activities can enhance the dispersion of radionuclides into soils, water bodies, and the atmosphere.

Surveys of natural radioactivity and radionuclide distribution provide crucial data for calculating radiological hazard indices such as radium equivalent activity (Raeq), absorbed dose rate (D), external hazard index (Hex), internal hazard index (Hin), and most importantly, excess lifetime cancer risk (ELCR), which quantifies the potential long-term cancer risk to the population from prolonged exposure [8, 9]. Previous studies in North Central, Nigeria have reported elevated hazard indices in areas with intense mining and quarrying, highlighting the need for continuous monitoring and assessment to safeguard public health [7, 10].

The present study aims to assess natural radioactivity levels, compute radiological hazard indices, and estimate ELCR in selected marble mining sites in Kaduna State, North Central Nigeria. The findings will support efforts toward achieving Sustainable Development Goal 3, on Good Health and Well-being, by providing data for informed recommendations to minimize cancer risk and other radiological health effects in affected populations.

II. MATERIALS AND METHODS

A. Materials

Materials used for this study include Global Positioning System (GPS), hand-held geological auger, Chisels and hammers, Cylindrical Plastic containers and bags, Labels and markers, Mortar and pestle, Sieve set (2 mm mesh), Oven, Analytical balance, Gamma-ray spectrometer with a NaI (Tl) detector, Calibration gamma-ray sources, Marinelli beakers, Certified reference materials for calibration, Protective gloves and laboratory coats, Shielding materials (lead) and Waste disposal containers.

B. Study Area

Gidan Waya and Ungwar Damishi are in the southern part of Kaduna State, North Central Nigeria, within the Nigerian Basement Complex geology. Gidan Waya is located at 9.46 °N, 8.45 °E in Jama'a Local Government Area, while Ungwar Damishi is situated within Chikun Local Government Area, both areas characterized by undulating terrain and a tropical savannah climate with distinct wet and dry seasons [11]. The geology is dominated by Precambrian migmatite-gneiss complexes, quartzite, and marble formations, which have supported local artisanal and small-scale mining activities [3]. Marble from these areas is widely used for building materials and road construction, making radiological assessment important for public safety. The communities depend on marble-related economic activities, though regulation and monitoring of quarrying practices remain limited [6]. These geological and socioeconomic factors make Gidan Waya and Ungwar Damishi relevant for evaluating natural radioactivity and potential radiological risks.

C. Sample Collection

Environmental surveys of the sampling site were conducted using a digital survey meter. Soil samples were taken at a depth of 10 cm and a distance of 50 m from each sampling point with the help of a hand-held geological auger [12]. At each sampling site, the longitude and latitude were determined using a Global Positioning System (GPS). The collected samples were labelled, packaged, and transported to the laboratory for processing.

D. Sample Preparation

Prior to processing, the collected samples was cleared of extraneous objects and oven dried for 24 hours at a temperature of 80 ℃ [13]. After being mashed with a mortar and pestle, the dried samples were filtered through a 2 mm mesh sieve. 200 g of each sample was weighed using an electronic balance. To achieve a secular equilibrium between ^{226}Ra and its transient progeny, the weighed samples were packaged into a cylindrical plastic container with a diameter matching the detector geometry and stored for a period of 28 days before counting.

E. Sample Measurement

The samples were examined in the environmental laboratory at the Centre for Energy and Technology (CERT), Ahmadu Bello University, Zaria, utilizing a gamma ray spectrometer with a NaI (Tl) detector. All sample's background radiation were counted for ten (10) hours. Each sample's net counts were calculated by subtracting background numbers from sample counts [14].

$$Ns = N_g - N_b \qquad (1)$$

Where Ns = net count or net count rate of the sample, N_b = Background counts, and N_g = Gross counts.

The activity concentration (Bq/kg) of each radionuclide was obtained using (2).

$$C = \frac{Ns}{System} \qquad (2)$$

C = Sample activity (e.g., in Bq/kg or Bq/L depending on the context), and System = System factor (which may include calibration factor, detection efficiency, counting time, and/or sample mass or volume).

F. Radiation Hazard Indices Calculation

The analysis of the radiation hazard indices must be conducted to reach a more accurate conclusion regarding the health state of the population in the environment. The following criteria have been established to evaluate the radiation risks associated with the samples that were obtained.

1) *Radium equivalent activity index (Raeq)*

The fundamental quantity to express the activity levels of ^{226}Ra, ^{40}K, and ^{232}Th in a material by a single amount that accounts for the radiation hazard they each pose [15].

$$Raeq = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (3)$$

Where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The maximum value of Raeq in soil must be less than 370 Bq/kg [1].

2) *Representative level index (Iγ):*

This is another radiation hazard index used for the estimation of gamma radiation associated with the natural radionuclide in the soil [16].

$$I\gamma = {C_{Ra}}/{150} + {C_{Th}}/{100} + {C_K}/{1500} \leq 1 \quad (4)$$

The safety value for this index is ≤ 1.

3) *Absorbed Dose rate (D)*

The basic quantity to express the exposure of material, such as the human body, is the absorbed dose, for which the unit is gray (Gy) [1].

$$D(nGyh^{-1}) = 0.042C_K + 0.429\, C_{Ra} + 0.666C_{Th} \quad (5)$$

Where C_{Ra}, C_{Th} and C_K are the activity concentration ^{226}Ra, ^{232}Th and ^{40}K respectively.

4) *Annual Effective Dose rate*

The conversion coefficients from absorbed dose in air to effective dose (0.7 SvGy^{-1}) and the outdoor occupancy factor (0.2) are used to estimate the annual effective dose rate outdoors [1], while, (6) and (7), are used to calculate the annual effective dose.

$$DE = D \times 0.2 \times 0.7 \times 8760 \quad (6)$$

Where DE = total absorbed dose from all radionuclides (ηGyh^{-1}), 0.2 = Occupancy factor, 0.7 = Conversion factor (SvGy^{-1}), $8760 = 24\, hr \times 365\, days$.

$$DE = D \times 1.2264 \times 10^{-3} \quad (7)$$

The worldwide annual effective dose from the natural sources of radiation in areas of normal background is estimated to be 2.5 mSvy^{-1} [1].

5) *External hazard index (Hex)*

A widely used hazard index (reflecting the external exposure) called the external hazard index Hex is defined as follows [1].

$$Hex = {C_{Ra}}/{370} + {C_{Th}}/{259} + {C_K}/{4810} \quad (8)$$

6) *Internal hazard index (Hin)*

Radon and its short-lived byproducts are also harmful to the respiratory system, in addition to the external hazard index. The internal hazard index Hin, which is determined by the equation, measures the internal exposure to radon and its offspring:

$$Hin = {C_{Ra}}/{185} + {C_{Th}}/{259} + {C_K}/{4810} \quad (9)$$

The values of the indices (Hex, Hin) must be less than unity for the radiation hazard to be negligible [15].

7) *Excess Lifetime Cancer Risk (ELCR)*

The Excess Lifetime Cancer Risk can be computed using (10).

$$ELCR = AED \times DL \times R \quad (10)$$

Where, DL = duration of life (70 years), RF = risk factor (0.05 Sv^{-1})

III. RESULTS AND DISCUSSION

The results obtained from the analysis were used to determine the possible radiological health risk in the analysed samples and the dose rate associated with it. The National Nuclear Regulatory Authority (NNRA), as part of a national mission to establish data on environmental radioactivity in Nigeria, could use the study's findings as a baseline for its data bank.

Table I. Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Marble for Gidan Waya.

S/No	Sample Location Gidan Waya	Activity Concentration (BqKg^{-1})			
		^{40}K	^{226}Ra	^{232}Th	^{232}Th: ^{226}Ra
1	Tudun wada	35.32±6.43	25.65±2.14	20.23±3.92	0.79
2	Godogodo	33.93±5.30	21.69±2.77	33.57±2.69	1.55
3	Dankurciya	62.83±7.74	36.84±2.19	25.21±3.42	0.68
4	Baiya	56.48±2.05	18.86±1.83	21.73±2.33	1.15
5	Kanufi	83.43±7.06	54.11±3.62	49.24±4.06	0.91
Average		54.40	31.83	30.00	1.02
World Standard [1]		420.00	32.00	45.00	1.4

The activity concentrations of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in marble samples from Gidan Waya show notable spatial variations across the five sampled locations as indicated in Table I. The concentration of ^{40}K ranges from 33.93 ± 5.30 Bq/kg at Godogodo to 83.43 ± 7.06 Bq/kg at Kanufi, with an average of 54.40 Bq/kg. This average is significantly lower than the world average value of 420 Bq/kg reported by [1], indicating that the marble in this region generally contains low levels of potassium-40. For ^{226}Ra, the activity concentration spans from 18.86 ± 1.83 Bq/kg at Baiya to 54.11 ± 3.62 Bq/kg at Kanufi, averaging 31.83 Bq/kg. This mean value closely aligns with the UNSCEAR global reference of 32 Bq/kg, suggesting that the radium levels in these marble samples are typical of natural background levels, except in Kanufi where slightly elevated concentrations were observed. The activity concentration of ^{232}Th varies between

20.23 ± 3.92 Bq/kg at Tudun Wada and 49.24 ± 4.06 Bq/kg at Kanufi, with an average of 30.00 Bq/kg, which is below the global average of 45 Bq/kg. This indicates that thorium levels are generally moderate, with Kanufi being the only site where thorium approaches the UNSCEAR reference value. When examining the ^{232}Th to ^{226}Ra activity concentration ratio, values range from 0.68 at Dankurciya to 1.55 at Godogodo, with an average of 1.02. This average is lower than the UNSCEAR standard of 1.4, suggesting that, overall, the marble in Gidan Waya does not exhibit thorium enrichment relative to radium. The variation in this ratio across locations reflects differing geochemical characteristics of the marble in these areas. Kanufi stands out across all radionuclides as having relatively higher concentrations of both ^{226}Ra and ^{232}Th, which may warrant further localized investigation, particularly if marble from this site is intended for construction or decorative use due to potential indoor radiation exposure. The results indicate that the natural radioactivity levels in Gidan Waya are generally within safe limits, with no significant radiological risk implied except for localized elevations that merit caution.

The boxplots of activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in Gidan Waya marble samples shown in Fig. 1, reveal noticeable variability among the radionuclides. ^{40}K shows the widest spread, indicating greater variability in potassium content across the sites, with Kanufi having the highest concentration. ^{226}Ra and ^{232}Th display relatively narrower distributions, suggesting more consistent levels across the locations, though Kanufi again shows elevated values. The PCA biplot from Fig. I further highlights the relationships between the samples and radionuclide concentrations. The first principal component (PC1) explains the majority of variance in the dataset, largely driven by ^{40}K and ^{226}Ra loadings, while the second principal component (PC2) accounts for additional, smaller variations linked to ^{232}Th. Kanufi and Dankurciya appear distinct in the PCA space due to their higher radionuclide concentrations, while Tudun Wada, Godogodo, and Baiya cluster more closely, reflecting similar radiological profiles. The strong loadings of ^{40}K and ^{226}Ra suggest these radionuclides are key in differentiating the samples. Overall, the analyses confirm the variability of marble composition across Gidan Waya locations and support targeted monitoring of sites like Kanufi with elevated radionuclide content to ensure radiological safety.

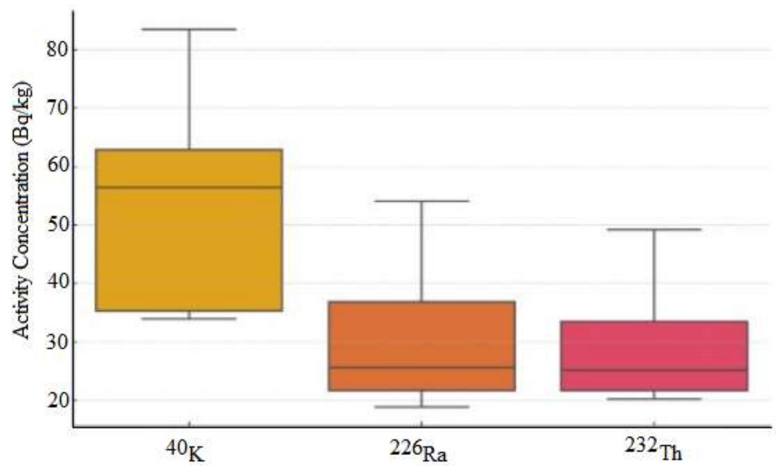

Fig. 1. Boxplots of activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in Gidan Waya.

The radiological hazard indices of marble from the Gidan Waya mining site reveal that the materials contain natural radionuclides at levels generally below international safety thresholds. The radium equivalent activity (Raeq) from Table II across all locations ranges from 54.28 Bq/kg (Baiya) to 130.95 Bq/kg (Kanufi), with an average of 78.51 Bq/kg. This is well below the world limit of 370 Bq/kg, indicating low combined radioactivity from ^{226}Ra, ^{232}Th, and ^{40}K. The absorbed dose rate (D) ranges from 24.19 nGy/h (Baiya) to 58.22 nGy/h (Kanufi), averaging 34.91 nGy/h, which is below the global reference of 60 nGy/h. The annual effective dose (AED) varies between 0.0297 mSv/y and 0.0714 mSv/y, with an average of 0.0428 mSv/y, well under the 1.0 mSv/y public exposure limit recommended by UNSCEAR [1]. Both external hazard index (Hex) and internal hazard index (Hin) have averages of 0.212 and 0.297, respectively, far below the safety limit of 1.0. The excess lifetime cancer risk (ELCR) values are also low, averaging 0.150 $\times 10^{-3}$, compared to a global reference of 0.29 $\times 10^{-3}$. Overall, the marble poses no significant radiological hazard for construction or decorative use, though Kanufi shows comparatively higher values that may warrant site-specific assessment.

Table II. Radiological Hazard Indices for Gidan Waya Marble Mining Site.

S/No	Sample Location	Raeq (Bq/kg)	Iγ	D (nGy/h)	AED (mSv/y)	Hex	Hin	ELCR ($\times 10^{-3}$)
1	Tudun Wada	57.30	0.964	25.54	0.0313	0.155	0.224	0.110
2	Godogodo	72.31	1.051	31.71	0.0389	0.195	0.254	0.136
3	Dankurciya	77.73	0.876	34.87	0.0428	0.210	0.310	0.150
4	Baiya	54.28	1.139	24.19	0.0297	0.147	0.198	0.104
5	Kanufi	130.95	0.910	58.22	0.0714	0.354	0.500	0.250
Average		78.51	1.008	34.91	0.0428	0.212	0.297	0.150
World Standard		370.00	1.000	60.00	1.00	1.00	1.00	0.29

The activity concentrations of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in samples from Ungwar Damishi from Table III show moderate variation across the five sampled locations. The concentration of ^{40}K ranges from 84.19 Bq/kg at UD1 to 149.32 Bq/kg at UD3, with an average of 106.97 Bq/kg. This is significantly below the UNSCEAR World Average of 420 Bq/kg [1], indicating low potassium-40 content. ^{226}Ra levels range from 18.74 Bq/kg (UD4) to 45.74 Bq/kg (UD2), averaging 28.54 Bq/kg, slightly below the global average of 32 Bq/kg. ^{232}Th activity varies between 26.72 Bq/kg (UD1) and 35.91 Bq/kg (UD2), with an average of 29.77 Bq/kg, also below the reference value of 45 Bq/kg. The $^{232}Th/^{226}Ra$ ratio averages 1.15, indicating no significant thorium enrichment relative to radium, as this is lower than the standard of 1.4. Among the locations, UD3 and UD4 exhibit higher $^{232}Th/^{226}Ra$ ratios, suggesting relatively higher thorium content at these sites. Overall, the results indicate that marble from Ungwar Damishi contains natural radionuclide concentrations within or below typical global levels, implying no substantial radiological risk for use in construction or related applications.

Table III. Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Ungwar Damishi.

S/No	Sample Location Ungwar Damishi	Activity Concentration (Bq/Kg) ^{40}K	^{226}Ra	^{232}Th	^{232}Th: ^{226}Ra
1	UD1	84.19±3.44	31.57±3.26	26.72±3.51	0.85
2	UD2	113.95±5.69	45.74±3.29	35.91±3.21	0.79
3	UD3	149.32±6.65	20.79±2.05	29.65±3.41	1.43
4	UD4	96.40±5.49	18.74±2.88	28.12±2.02	1.50
5	UD5	90.08±5.45	23.85±1.32	28.47±2.51	1.19
Average		106.97	28.54	29.77	1.15
World Standard [1]		420.00	32.00	45.00	1.4

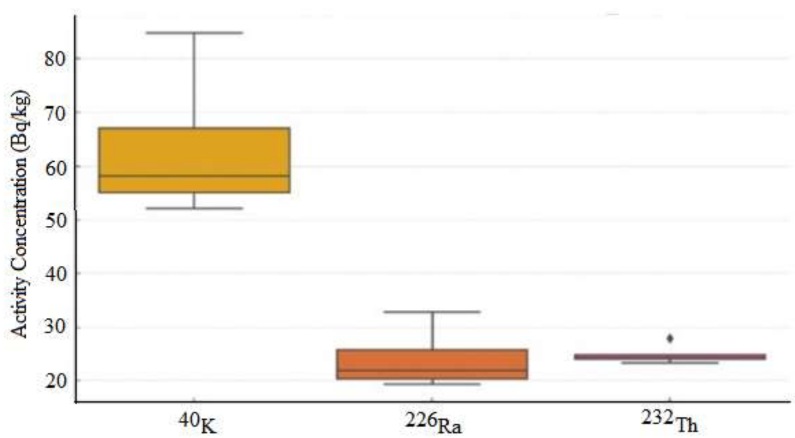

Fig. 2. Boxplots of activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in Ungwar Damishi.

The boxplots for Ungwar Damishi marble activity concentrations illustrate variability in ^{40}K, ^{226}Ra, and ^{232}Th levels across the samples as shown in Fig. 2. ^{40}K shows the widest spread, ranging from about 84 Bq/kg to 149 Bq/kg, reflecting considerable variation in potassium content. ^{226}Ra displays more moderate variability, with values between 18.74 Bq/kg and 45.74 Bq/kg. ^{232}Th shows the most consistent distribution, with concentrations clustered closely between 26.72 Bq/kg and 35.91 Bq/kg. No extreme outliers are evident, indicating that while natural variability exists, all measured values fall within an expected range for such geological materials. The boxplots confirm that ^{40}K is the most variable radionuclide in Ungwar Damishi marble, likely reflecting differences in mineral composition or geochemical processes across sample sites.

The radiological hazard indices for marble samples from Ungwar Damishi indicate that the materials contain natural radionuclides at levels generally within safe limits for use in construction and related applications. From Table IV, the radium equivalent activity (Raeq) ranges from 66.37 Bq/kg (UD4) to 105.87 Bq/kg (UD2), with an average of 78.94 Bq/kg, far below the recommended maximum of 370 Bq/kg. The absorbed dose rate (D) varies between 29.66 nGy/h (UD4) and 47.57 nGy/h (UD2), averaging 35.43 nGy/h, which is well below the global safety limit of 60 nGy/h. Similarly, the annual effective dose (AED) values range from 36.38 µSv/y at UD4 to 58.34 µSv/y at UD2, with an average of 43.46 µSv/y, considerably lower than the 1 mSv/y public exposure limit. The external hazard index (Hex) and internal hazard index (Hin) averages are 0.213 and 0.289, respectively, both significantly below the safety threshold of 1.0, indicating minimal hazard from external and internal radiation exposure. The excess lifetime cancer risk (ELCR) values average 2.173 $\times10^{-3}$, which appears elevated compared to the global reference of 0.29 $\times10^{-3}$. This suggests a need to review the ELCR calculation, as it is disproportionately high relative to the other indices and dose levels. Overall, the marble from Ungwar Damishi is radiologically safe based on Raeq, dose rate, and hazard indices.

Table V presents the average activity concentrations of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) from soils and related studies across various regions. Gidan Waya and Ungwar Damishi show relatively low levels of ^{226}Ra (31.83 and 28.54 Bq/kg, respectively) and ^{232}Th (30.00 and 29.77 Bq/kg), with ^{40}K concentrations at 54.40 Bq/kg and 106.97 Bq/kg, significantly lower than global averages. Comparatively, Tilapia sediment in Tanzania reports higher ^{226}Ra (avg 88.05 Bq/kg) and ^{40}K (505.63 Bq/kg) [17]. Irele soil in South West, Nigeria [18], reported activity concentration of ^{226}Ra ranging from 21.81–31.26 Bq/kg and ^{40}K up to 504 Bq/kg, indicating higher potassium content than Gidan Waya and Ungwar Damishi. In South Korea (DIRAMS), activity concentrations of ^{226}Ra and ^{232}Th are lower (21.9 and 11.1 Bq/kg), but ^{40}K is high (661.1 Bq/kg) [19]. Turkey (Konya) reports elevated activity concentration of ^{226}Ra (125 Bq/kg) and ^{232}Th (157 Bq/kg), with ^{40}K at 671 Bq/kg, reflecting geogenic enrichment [20]. Similarly, Denmark soils present activity concentration of ^{226}Ra (9–29 Bq/kg) and ^{232}Th (8–30 Bq/kg) with ^{40}K up to 610 Bq/kg [1]. Overall, Gidan Waya and Ungwar Damishi soils exhibit low natural radioactivity, posing minimal radiological risk when compared to regions with elevated levels like Turkey or Tanzania.

Table IV. Radiological Hazard Indices for Ungwar Damishi.

S/No	Location	Raeq (Bq/kg)	Iγ	D (nGy/h)	AED (mSv/y)	Hex	Hin	ELCR ($\times10^{-3}$)
1	UD1	76.26	0.534	34.23	41.9857	0.206	0.291	2.0993
2	UD2	105.87	0.740	47.57	58.3438	0.286	0.41	2.9172
3	UD3	74.69	0.535	33.74	41.379	0.202	0.258	2.069
4	UD4	66.37	0.470	29.66	36.3778	0.179	0.23	1.8189
5	UD5	71.5	0.504	31.97	39.2091	0.193	0.258	1.9605
Average		78.94	0.557	35.43	43.4591	0.213	0.289	2.173
World Standard		370.00	1	60.00	1	1	1	0.29

Table V. Average Activity Concentrations of Soils and Other Related Studies.

S/No	Location	Region	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	References
1	Gidan Waya	Nigeria (NC)	31.83	30.00	54.40	Present Study
2	Ungwar Damishi	Nigeria (NC)	28.54	29.77	106.97	Present Study
3	Tilapia sediment	Tanzania (lakes)	79.95 – 113.42	—	505.63	[17]
4	(Lake/movie ponds)		(avg 88.05)			
5	Irele soil	Nigeria (Ondo)	21.81–31.26	12.10–21.54	357–504	[18]
6	DIRAMS	South Korea	21.9	11.1	661.1	[19]
7	Turkey (Konya)	Europe	125	157	671	[20]
8	Denmark	Europe	9–29	8–30	240–610	[1]

IV. CONCLUSION

The evaluation of excess lifetime cancer risk (ELCR) exhibited in marbles from Gidan Waya and Ungwar Damishi highlights differences in potential radiological health impact. Marbles from Gidan Waya present ELCR values that are within international safety limits (average 0.150 $\times10^{-3}$, below the 0.29 $\times10^{-3}$ benchmark recommended by UNSCEAR. This aligns with the low radium equivalent activity and hazard indices recorded for the site. However, marbles from Ungwar Damishi show notably higher ELCR values, averaging 2.17 $\times10^{-3}$, significantly exceeding the global reference. Other indices, such as Raeq, absorbed dose rate, and annual effective dose remain within acceptable limits. The elevated ELCR figures suggest that either the dose-risk conversion factor applied was conservative or that the marble contains radionuclide distributions contributing disproportionately to long-term risk, despite low external dose rates. Therefore, while immediate use of marble from both sites does not pose a substantial hazard, the long-term cancer risk associated with Ungwar Damishi marble, particularly in indoor environments, requires further investigation. Continuous monitoring, precise dose modelling, and inclusion of radon exhalation studies, necessary to provide a more comprehensive risk profile, are recommended.

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DISCLOSURE STATEMENT

The authors declare that they have no conflict of interest to disclose.

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