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NATURAL RADIOACTIVITY AND CANCER RISK ASSESSMENT OF BUILDING MATERIALS IN NORTHERN DELTA STATE, NIGERIA

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Abstract

Naturally occurring radionuclides in building materials represent potential long-term health hazards, although full excess lifetime cancer risk (ELCR) assessments remain restricted in Nigeria. This study examined the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th in 72 building material samples (cement, sand, granite, tiles, paint, wood, etc.) obtained from northern Delta State, Nigeria, using a NaI(Tl) gamma-ray spectrometer. Radiological hazard parameters such as radium equivalent activity (Raeq), external and internal hazard indices (Hex, Hin), gamma index (Iγ), alpha index (Iα), annual effective dose (AED), and ELCR were determined. The results showed that the mean activity concentrations were 94.00 ± 15.52 Bq/kg for ^{40}K, 11.57 ± 2.32 Bq/kg for ^{238}U, and 9.05 ± 1.43 Bq/kg for ^{232}Th which are all below global averages. All conventional hazard indices calculated were observed to be within global safety limits, with a mean AED of 0.0903 ± 0.0130 mSv/y which is 9% of the 1 mSv/y public limit. However, 94.4% of samples above the ELCR criterion of 0.29×10^{-3}, with a mean ELCR of 0.316×10^{-3}. The largest dangers were connected with POP paint and glossy tiles. Although all materials comply with annual dosage limitations, the high fraction surpassing the ELCR threshold implies significant potential lifelong cancer risk. Thus, regulatory frameworks should consequently incorporate ELCR alongside annual dose limitations for building material safety in Nigeria.

Keywords:

Natural Radioactivity, Building Materials, Excess Lifetime Cancer Risk, Radiological Hazards.

1. Introduction

Natural radioactivity is an inherent element of the Earth's environment, largely resulting from the decay chains of ^{238}U and ^{232}Th and the radionuclide ^{40}K [1]. These naturally occurring radioactive elements (NORMs) are present in different amounts in rocks, soils, and consequently in construction materials manufactured from them [2]. Because humans spend roughly 80% of their time indoors, the radiological quality of the built environment is a serious public health concern [3].

In Nigeria, the construction sector relies significantly on locally obtained materials such as sand, granite, cement, clay, and wood. The radioactive content of these minerals is largely dependent on the local geology and mineralogy of their source [4]. Several studies have analyzed natural radioactivity in Nigerian building materials [5.6, 7], mostly focused on conventional hazard indices such as radium equivalent activity (Ra_{eq}) and annual effective dose (AED) and most concluded that the materials are “safe” because these indices fell below international accepted limits.

However, the long-term health implication of low-dose radiation exposure is better analyzed using the excess lifetime cancer risk (ELCR) metric. ELCR predicts the likelihood of acquiring cancer throughout a lifetime (e.g., 70 years) of exposure to a certain annual effective dose [8, 9]. A substance that complies with the annual dosage limit may yet pose a considerable cumulative cancer risk over decades. In Nigeria, detailed ELCR assessments for building materials remain rare.

Therefore, this study attempted to: (i) quantify the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th in frequently used building materials from northern Delta State, Nigeria; (ii) analyze conventional radiological hazard indices; and (iii) estimate the AED and, more significantly, the ELCR to determine probable lifelong cancer risk.

2. Materials and Methods

2.1 Study Area and Sample Collection

The study was conducted in the northern part of Delta State, Nigeria (latitude 5°30′00″N to 6°30′00″N; longitude 5°00′00″E to 6°55′00″E). A total of 72 samples representing 13 material categories (sand, cement, granite, POP additives, POP mixture, PVC, paint, paint additives, roofing materials, stone, tiles, wood, ceiling materials) were collected from major building material markets, distributors, and construction sites across the nine Local Government Areas. Samples originated from local sources, Nigeria, India, Italy, China, South Africa, and other international origins. For solid products, approximately 2 kg was collected; for liquid materials (paints, sealants), approximately 1 L was collected, following [10] criteria.

2.2 Sample Preparation

Solid samples were washed, air-dried, crushed, and ground into fine powder using an agate mortar and pestle. Powdered samples (cement, sand, POP) were oven-dried at 110 °C for 24 h to eliminate moisture. All samples were sieved through a 2 mm mesh to achieve uniform particle size. Approximately 1 kg of each produced sample was put into 1-L cylindrical Marinelli beakers, hermetically sealed with PVC tape and paraffin wax, and stored for 28 days to reach secular equilibrium between ^{226}Ra and its short-lived descendants [11, 12].

2.3 Gamma-Ray Spectrometry

Activity concentrations of ^{40}K, ^{238}U (via ^{214}Bi at 1764 keV), and ^{232}Th (via ^{208}Tl at 2614 keV) were measured using a 3″ × 3″ thallium-activated sodium iodide [NaI(Tl)] gamma-ray spectrometer (Canberra Industries, USA) located at the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife. Each sample was counted for 36,000 s (10 h). The detector was energy-calibrated using ^{60}Co, ^{137}Cs, and ^{241}Am standard sources, and efficiency calibration was accomplished using IAEA-certified reference materials (RGU-1, RGTh-1, and RGK-1). Background spectra were removed from all sample observations. The minimal detectable activity was estimated using Currie's formula [13].

2.4 Radiological Hazard Parameters

The following parameters were calculated using standard equations [14, 1; 15]:

Radium Equivalent Activity

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2.1)$$

where Ra_{eq} is the radium equivalent activity in Bq/kg, A_{Ra} is the activity concentration of radium-226 in Bq/kg, A_{Th} is the activity concentration of thorium-232 in Bq/kg, and A_K is the activity concentration of potassium-40 in Bq/kg. The coefficients 1.43 and 0.077 account for the different dose contributions from thorium and potassium relative to radium [15]. The safe limit for Ra_{eq} is 370 Bq/kg, which corresponds to an annual effective dose of 1 mSv [1].

External Hazard Index (Hex)

$$Hex = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (2.2)$$

where H_{ex} represents the external hazard index, A_{Ra} is the activity concentration of radium-226, A_{Th} is the activity concentration of thorium-232, and A_K is the activity concentration of potassium-40. The denominators represent the maximum recommended activity concentrations for each radionuclide that would yield an external dose of 1.5 mSv per year [1]. For safe use, H_{ex} should be less than unity [14].

Internal Hazard Index (Hin)

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (2.3)$$

where H_{in} represents the internal hazard index, A_{Ra} is the activity concentration of radium-226, A_{Th} is the activity concentration of thorium-232, and A_K is the activity concentration of potassium-40. The lower denominator for radium (185 instead of 370) accounts for the additional internal exposure from radon and its progeny [14]. H_{in} should be less than unity for radiation safety.

Gamma Index

$$I\gamma=\frac{ARa}{300}+\frac{ATh}{200}+\frac{AK}{3000} \tag{2.4}$$

where Iγ represents the gamma index, A_{Ra} is the activity concentration of radium-226, A_{Th} is the activity concentration of thorium-232, and A_K is the activity concentration of potassium-40. Materials with Iγ less than or equal to 1 are considered safe for construction, corresponding to an annual effective dose of less than 1 mSv [15].

Alpha Index

$$I\alpha=\frac{ARa}{200} \tag{2.5}$$

where Iαrepresents the alpha index and A_{Ra} is the activity concentration of radium-226 in Becquerels per kilogram. Materials with Iα less than or equal to 1 are considered safe regarding radon exposure, corresponding to a radon exhalation rate of less than 200 Bq/m³ [16].

Absorbed Gamma Dose Rate

$$D\ (nGy/h)=0.462A_{Ra}+0.604A_{Th}+0.0417A_K \tag{2.6}$$

where D represents the absorbed gamma dose rate in nGy/h, A_{Ra} is the activity concentration of radium-226, A_{Th} is the activity concentration of thorium-232, and A_K is the activity concentration of potassium-40. The coefficients are dose conversion factors derived from Monte Carlo simulations [1].

Annual Effective Dose Equivalent

$$AEDE_{indoor}(mSv/y)=D\times8760\times0.7\times0.8\times10^{-6} \tag{2.7}$$

The outdoor annual effective dose was calculated using the formula:

$$AEDE_{outdoor}\ (mSv/y)=D\times8760\times0.7\times0.2\times10^{-6} \tag{2.8}$$

The total annual effective dose was calculated as the sum of the indoor and outdoor components:

AEDEtotal (mSv/y)=AEDEindoor+AEDEoutdoor (2.9)

In these equations, D is the absorbed dose rate in nanograys per hour, 8760 represents the number of hours in a year, 0.7 is the conversion factor from Gy to Sv for environmental exposure, 0.8 represents the indoor occupancy factor indicating 80 % of time spent indoors, 0.2 represents the outdoor occupancy factor indicating 20 % of time spent outdoors, and 10^{-6} is the conversion factor from nGy to mGy [1]. The International Commission on Radiological Protection recommends a limit of 1 mSv/yr for public exposure [17].

Excess Lifetime Cancer Risk

ELCR=AEDEtotal×DL×RF (2.10)

where ELCR represents the excess lifetime cancer risk, $AEDE_{total}$ is the total annual effective dose in Sv/yr, DL is the average life expectancy of 70 years [1], and RF is the risk factor of 0.05 /Sv as recommended by ICRP Publication 60 [17]. The acceptable ELCR threshold is 0.29 $\times 10^{-3}$ as established by [18].

2.5 Statistical Analysis

Descriptive statistics (mean, standard deviation, minimum, maximum, coefficient of variation) were calculated for all radioactive concentrations and hazard parameters. Pearson correlation analysis was done to assess correlations between radionuclides and hazard indices. One-way ANOVA was performed to assess for significant differences between material categories and sources at the 95% confidence level. All statistical analyses were performed using Python 3.9.

3. Results

3.1 Activity Concentrations of Radionuclides

Table 1 gives the descriptive data for the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th in the 72 construction material samples. The mean readings were all below the world average values given by [1]: 94.00 ± 15.52 Bq/kg (^{40}K) vs. 420 Bq/kg; 11.57 ± 2.32 Bq/kg (^{238}U) vs. 33 Bq/kg; and 9.05 ± 1.43 Bq/kg (^{232}Th) vs. 45 Bq/kg.

Table 1. Descriptive Statistics of Activity Concentrations and Radiological Parameters (N = 72)

Parameter	Mean ± SD	Minimum	Maximum
^{40}K (Bq/kg)	94.00 ± 15.52	64.27	130.65
^{238}U (Bq/kg)	11.57 ± 2.32	7.39	20.31
^{232}Th (Bq/kg)	9.05 ± 1.43	6.15	11.86

Ra_{eq} (Bq/kg)	31.74 ± 4.61	23.25	44.80
Hex	0.086 ± 0.012	0.063	0.121
Hin	0.117 ± 0.018	0.084	0.176
Iγ	0.115 ± 0.016	0.084	0.160
Iα	0.058 ± 0.012	0.037	0.102
AED_{total} (mSv/y)	0.0903 ± 0.0130	0.0657	0.1270
ELCR (×10^{-3})	0.316 ± 0.046	0.230	0.445

3.2 Radiological Hazard Indices and ELCR

All traditional hazard indicators (Raeq, Hex, Hin, Iγ, Iα) were significantly below their respective safety limits as shown in Table 1. The mean AED_total was barely 9% of the 1 mSv/y public dose limit. Critically, 68 out of 72 samples (94.4%) exhibited an ELCR value exceeding the threshold of 0.29×10^{-3} (Figure 1). The greatest ELCR values were obtained in POP paint (0.445×10^{-3}), Best Will Polish tiles (0.429×10^{-3}), and Burnt Brick Stone tiles (0.404×10^{-3}) as shown in Table 2.

Table 2: Annual Effective Dose (AED) and Excess Lifetime Cancer Risk (ELCR) by Material Category

Material Category	N	AED (mSv/y) Mean ± SD	ELCR (×10^{-3}) Mean ± SD	Samples Exceeding ELCR Threshold (%)
Sand	4	0.0901 ± 0.0131	0.315 ± 0.046	4 (100%)
Cement	7	0.0851 ± 0.0101	0.298 ± 0.035	5 (71.4%)
Granite	17	0.0908 ± 0.0110	0.318 ± 0.039	17 (100%)
POP Additive	2	0.1033 ± 0.0107	0.361 ± 0.037	2 (100%)
POP Mixture	1	0.0856	0.299	1 (100%)
PVC	1	0.1028	0.360	1 (100%)
Paint	8	0.0907 ± 0.0167	0.318 ± 0.058	8 (100%)
Paint Additive	1	0.1049	0.367	1 (100%)
Roofing	1	0.1080	0.378	1 (100%)
Stone	4	0.0912 ± 0.0176	0.319 ± 0.062	4 (100%)
Tiles	8	0.0948 ± 0.0185	0.332 ± 0.065	8 (100%)
Wood	13	0.0864 ± 0.0098	0.302 ± 0.034	12 (92.3%)
Ceiling	4	0.0901 ± 0.0131	0.315 ± 0.046	4 (100%)
Overall	**72**	**0.0903 ± 0.0130**	**0.316 ± 0.046**	**68 (94.4%)**

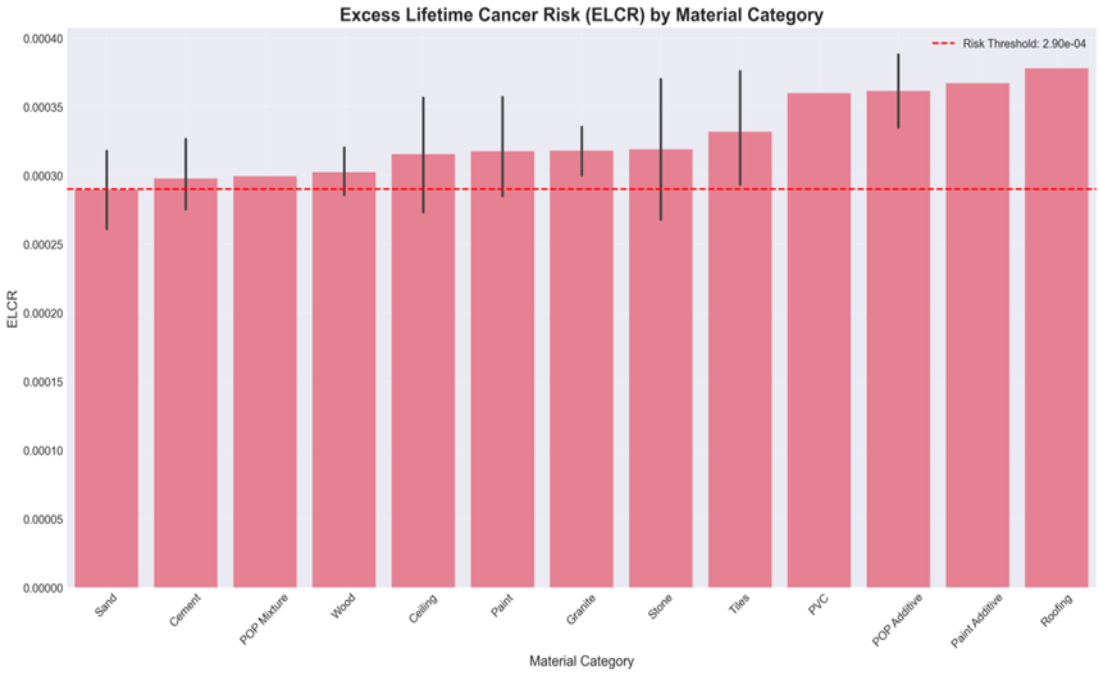

Figure 1. Distribution of ELCR by Material Category.

3.3 Correlation Analysis

Pearson correlation analysis as shown in Figure 2 revealed strong positive associations between ^{238}U and Ra_{eq} ($r = 0.93$, $p < 0.01$), ^{232}Th and Ra_{eq} ($r = 0.85$, $p < 0.01$), and between Ra_{eq} and AED ($r = 0.99$, $p < 0.01$). A perfect positive correlation ($r = 1.00$) was established between AED and ELCR, as ELCR is directly derived from AED. These data confirm that ^{238}U and ^{232}Th are the key sources of the total radiation dose from building materials.

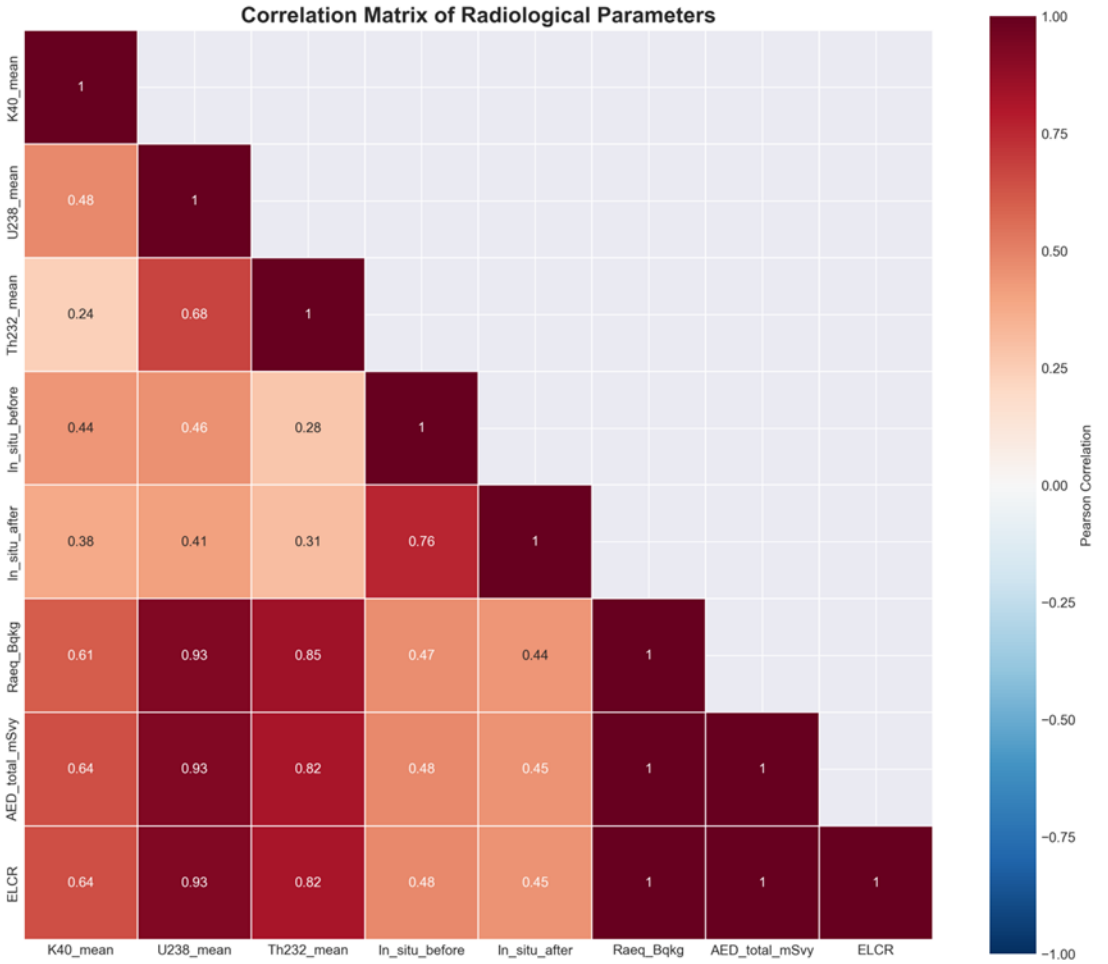

Figure 2. Correlation Heatmap of Radiological Parameters

4. Discussion

This study presents a critical paradox: all building materials from northern Delta State, Nigeria, are radiologically “safe” according to conventional annual dose limits (mean AED = 0.09 mSv/y, well below the 1 mSv/y public limit), yet a vast majority (94.4%) pose a potential excess lifetime cancer risk that exceeds the internationally recognized threshold of 0.29×10^{-3}. This conclusion challenges the validity of relying exclusively on annual dose limits for public health protection and highlights the significance of adding ELCR into regulatory systems.

The mean activity concentrations recorded in this study (^{40}K: 94 Bq/kg; ^{238}U: 11.6 Bq/kg; ^{232}Th: 9.1 Bq/kg) are lower than or comparable to those reported in other Nigerian studies. For instance, [4,18] recorded mean values of 286 Bq/kg (^{40}K), 29 Bq/kg (^{226}Ra), and 26 Bq/kg (^{232}Th) for building materials in southwestern Nigeria, whereas [7] discovered ^{226}Ra concentrations (47-63 Bq/kg) surpassing the world norm in northwestern Nigeria. The relatively low values in the present study presumably reflect the sedimentary geology of the

Niger Delta basin, which normally has lower radioactive concentrations than the basement complex rocks found in other parts of Nigeria [19, 20].

All conventional hazard indices (Raeq, Hex, Hin, Iγ, Iα) were far below their respective safety limits, comparable with prior findings for Nigerian construction materials [5,6,21,22). The mean Raeq of 31.7 Bq/kg is an order of magnitude lower than the 370 Bq/kg safety level, while the mean Hex of 0.086 is substantially below unity. These data would normally lead to a conclusion of "no major radiological hazard." However, such a finding would be incomplete since it ignores the cumulative effect of low-dose radiation throughout a lifetime.

The ELCR calculation indicates the hidden danger. Using the linear no-threshold (LNT) model, which is the current worldwide standard for radiological protection [17,23], an annual dose of 0.09 mSv/y over 70 years provides an ELCR of roughly 0.000315. This surpasses the 0.00029 threshold, implying that even if each year's exposure is substantially below the 1 mSv/y limit, the total lifetime risk is not negligible. The threshold of 0.29×10^{-3} translates to an annual dose of around 0.083 mSv/y over 70 years. Therefore, any material producing an AED > 0.083 mSv/y would surpass the ELCR criterion. In this investigation, 68 out of 72 samples exceeded this amount, with the highest reaching 0.127 mSv/y.

The high connections between ^{238}U, Raeq, and AED show that uranium decay series radionuclides are the principal contributors to the overall radiation dose. This conclusion accords with the scientific understanding that the ^{238}U decay chain produces numerous gamma-emitting progeny that significantly contribute to external exposure [1].

5. Conclusion

This study investigated natural radioactivity and associated cancer risk in 72 construction material samples from northern Delta State, Nigeria. Activity concentrations of ^{40}K, ^{238}U, and ^{232}Th were below global averages, corresponding with the sedimentary geology of the Niger Delta region. All conventional hazard indices (Raeq, Hex, Hin, Iγ, Iα, and AED) were within international safety standards, with a mean yearly effective dose of 0.090 mSv/y, reflecting only 9% of the 1 mSv/y public limit.

Despite compliance with annual dosage restrictions, 94.4% of samples surpassed the excess lifetime cancer risk (ELCR) threshold of 0.29×10^{-3}, with a mean ELCR of 0.316×10^{-3}. The largest hazards were connected with POP paint, shiny tiles, and granite. This contradiction illustrates that annual dose limitations alone are insufficient for full public health protection.

Accordingly, regulatory agencies should adopt the ELCR metric alongside yearly dose limits, establish a nationwide database of ELCR values for construction materials, and require special inspection for materials with AED < 1 mSv/y but ELCR > 0.29×10^{-3}. Construction professionals should prefer materials with lower ELCR values for residential constructions.

Further research should include direct radon and thoron exhalation measurements, longitudinal health studies, and assessment of seasonal fluctuations.

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