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Radiological Hazards of Natural Radionuclides in Building Materials in Katsina State, Nigeria: A Systematic Review

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ABSTRACT

Trace amounts of radioactive elements are naturally present in building materials and may contribute to human exposure to ionizing radiation. This systematic review evaluates the concentrations of naturally occurring radionuclides including ^{226}Ra, ^{232}Th, ^{40}K in commonly used construction materials in Katsina State, Nigeria, and comparable geological environments. This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. A total of 345 records were initially identified from major scientific databases and institutional reports published between 2010 and 2025. After screening and eligibility assessment, 30 relevant studies were included for qualitative synthesis, while 20 studies containing detailed radiological parameters were selected for comparative analysis. Only peer-reviewed studies reporting activity concentrations of radionuclides and radiological hazard indices in building materials, particularly within Nigeria and similar geolo

gical environments, were included in the review. Reported activity concentration values ranged from 4.41–93.00 Bq/kg for ^{226}Ra, 16.71–320.00 Bq/kg for ^{232}Th, and 68.03–673.00 Bq/kg for ^{40}K across reviewed studies. Most evaluated radiological hazard indices, including radium equivalent activity and external hazard index, remained below internationally recommended safety limits. Gamma-ray spectroscopy and X-Ray Diffraction (XRD) were the major analytical methods employed. However, regional variations linked to geological formations, inadequate monitoring facilities, weak regulatory implementation, and limited integration of mineralogical analysis remain significant challenges in Nigeria. The review highlights the importance of continuous radiological monitoring, improved regulatory control, and standardized assessment procedures to ensure the safe and sustainable use of building materials.

Keywords: Building Materials, Gamma-Ray Spectroscopy, Natural Radioactivity Radiological Hazards, Katsina State

INTRODUCTION

The background radiation is the largest source of ionising radiation exposure for humans and it represents a major contribution to the radiation dose received world-wide. This exposure is terrestrial (from the earth) and cosmic (from the sun and other space sources), the terrestrial component of which comes mainly from naturally occurring radionuclides in the earth's crust of these, the radium-226 (^{226}Ra) , thorium-232 (^{232}Th) and potassium-40 (^{40}K) isotopes are significant because they have relatively long half-lives and are commonly found in geological materials. Radionuclides are ubiquitous in rocks, soils and minerals that are used as the raw materials for the manufacture of building and construction materials(Ogunobi et al., 2023).

The use of building materials is known to be a major source of indoor radiation exposure. They are primarily responsible for this because they are directly used in the building of residential and commercial buildings, which continuously emit radiation for long periods of time (Abbasi, 2013) . The radiological consequences of these materials can be realised in two ways: external via gamma radiation emitted by the radionuclides and internal via the inhalation of radon gas and its progeny (Popov, 2026). Among the decay products of ^{226}Ra the most important is ^{222}Rn because it can accumulate in the home environment and therefore be a potential health risk, especially after long exposure, where lung cancer can be a risk (Grzywa-Celinska et al., 2020).

With the awareness of the adverse health effects of the environment, and the development of more sophisticated radiation measurement methods, there has been an increased global concern with the radiological safety of building materials in recent decades. The guidelines and limits for the concentrations of the radionuclides and the radiological hazard indices in building materials have been set by international organizations like the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (Grzywa-Celinska et al., 2020). International Atomic Energy Agency (IAEA). These guidelines are important yardsticks for evaluating safety of construction materials, as well as ensuring the radiation exposure of the general public is kept within acceptable limits (Muhammad et al., 2024).

Radiological safety in building materials is a major concern in developing countries like Nigeria, where the population is growing rapidly, urbanization is accelerating and demand for construction materials is rising. In many instances, these locally-sourced materials including clay, sand, gravel and cement are used copiously without prior radiological evaluation. The underlying geology is the major controlling factor on the concentration found in these materials and can be very different in different areas. Therefore, the radiological properties of building materials may vary widely depending on their geographical source (United Nations et al., 2024).

In northern Nigeria, including Katsina state, there are various geological conditions which could affect the distribution and concentration of naturally occurring radionuclides. Soils and rocks in the region are frequently used as a source for building materials, and may contain variable amounts of ^{226}Ra, ^{232}Th and ^{40}K With population growth and infrastructural development, construction activities are on the rise, and there is a growing need to assess radiological risks these materials may pose. These evaluations are crucial for environmental safety, public health protection, and sustainable development (Grzywa-Celinska et al., 2020).

A considerable number of studies have been conducted globally and within Nigeria to investigate the activity concentrations of natural radionuclides in building materials and to evaluate associated radiological hazard (Gambo & Baba- Kutigi, 2015).

Several radiological studies conducted in Nigeria and other countries have reported varying activity concentrations of naturally occurring radionuclides in building materials due to differences in geological formations, mineralogical composition, and analytical techniques employed. While many studies reported radionuclide concentrations and hazard indices within internationally recommended safety limits, some investigations from granitic and clay-rich regions of Northern Nigeria observed relatively elevated values of ^{226}Ra and ^{232}Th. Furthermore, differences in detector systems, sample preparation procedures, and hazard assessment models have contributed to inconsistencies in reported radiological parameters across studies. Despite the growing number of radiological assessments in Nigeria, there remains limited integration of mineralogical analysis with radiological evaluation, particularly in Katsina State and similar geological environments.

The procedures used in such studies generally involve the use of gamma-ray spectroscopy with the aim of quantifying the concentration of the radionuclides and determining some of the radiological indices like absorbed dose rate, radium equivalent activity, external hazard index, internal hazard index and annual effective dose. These studies help us gain insight, but they are difficult to synthesize and are sometimes geographically limited and use different methodologies (Abdel Gawad et al., 2024).

Although numerous studies have investigated natural radioactivity in building materials, considerable inconsistencies exist in reported activity concentrations and hazard indices. Some studies attributed elevated radionuclide concentrations to granitic geological formations and potassium-rich clay minerals, whereas others reported relatively lower values in sedimentary environments. Variations in analytical approaches, including the use of NaI(Tl) and HPGe detectors, sample preparation procedures, counting time, and calibration methods, may significantly influence measurement accuracy and comparability of results. In addition, several previous investigations focused mainly on radiological indices without adequately examining the associated mineralogical characteristics of the materials. These methodological differences have limited the development of a comprehensive understanding of radiological hazards associated with building materials in Northwestern Nigeria.

In light of this background, there is a need for a wide-ranging literature review to consolidate the existing data, highlight trends and assess the overall radiological safety of the building materials in Nigeria. This type of assessment can identify existing knowledge and knowledge gaps, as well as methodological inconsistencies, and suggest further research. Furthermore, it offers scientific support to the decision-making process of policy makers, regulatory bodies and building industry stakeholders for the use of building material (Garba et al., 2023).

Hence, this review seeks to critically review the available literature on the concentrations of naturally occurring radioactive materials and their radiological hazards in building materials in Nigeria and elsewhere with similar background radiation environments. The aim of the present study is to evaluate the concentrations of ^{226}Ra, ^{232}Th, ^{40}K in popular building materials, estimate the radiological risks and make a comparison with the international safety limits. In conclusion, the review helps to enhance awareness of the radiological aspects of building materials and fosters safe and sustainable building work practices (Estokova et al., 2022)

MATERIALS AND METHODS

Study Design

The current work used systematic review method to review published works on natural radionuclides and radiological hazards in building materials, highlighting those from Nigeria and the African continent as a whole, in a similar geological setting. This review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to improve the transparency, consistency and reproducibility of the selection and evaluation of related studies.

Search Period and Data Sources

A comprehensive search and collection of relevant literature was performed in databases for literature published in the years 2010 to 2025. Databases searched: Google Scholar, ScienceDirect, SpringerLink, JSTOR, ResearchGate, 1Scopus and Web of Science. Additional data were acquired from international organizations and regulatory entities, such as; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), International Atomic Energy Agency (IAEA) and World Health Organisation (WHO) documents.

Search Strategy

The literature search was conducted using combinations of relevant keywords and Boolean operators to identify studies associated with radiological assessment of building materials. The search terms included- Natural radionuclides in building materials, Radiological hazard indices in Nigeria, Gamma-ray spectroscopy of construction materials, Naturally Occurring Radioactive Materials (NORMs), Building materials in Katsina State, Activity concentration of and Radiological assessment of environmental materials.

Transparency in Search Strategy

It is essential to provide detailed search strings and Boolean operators for each database. Transparency in the search process is critical for systematic reviews, as it allows other researchers to replicate the search, verify coverage, and assess whether relevant studies may have been missed. In this case an example, including exact syntax such as *"*radionuclides, building materials and Nigeria*"* ensures credibility and enhances the reliability of the review outcomes.

Inclusion and Exclusion Criteria

Inclusion Criteria

Studies were included in the review if they; Reported activity concentrations of in building materials, evaluated radiological hazard indices such as Ra_{eq}, H_{ex}, H_{in}, absorbed dose rate, and annual effective dose were conducted in Nigeria or regions with similar geological characteristics, published in peer-reviewed journals or conference proceedings, written in English language and were published within the selected review period (2010–2025).

Exclusion Criteria

Studies were excluded for lacked quantitative radiological data, unrelated to building materials or environmental radioactivity, duplicate publications, non-scientific reports or unpublished manuscripts, and insufficient methodological information

PRISMA Study Selection Process

The study selection procedure followed the PRISMA framework. A total of 345 records were initially identified through database searching and additional sources. After removal of duplicate articles, 290 studies remained for title and abstract screening. During screening, 210 articles were excluded due to irrelevance, language limitations, or lack of radiological information. Subsequently, 80 full-text articles were assessed for eligibility. Out of these, 50 studies were excluded because of incomplete data, inadequate methodological quality, or insufficient radiological analysis. Finally, 30 studies were included for qualitative review, while 20 studies containing detailed quantitative radiological parameters were selected for comparative analysis

Data Extraction Procedure

To ensure consistency and reproducibility, a structured data extraction procedure was employed using a standardized extraction template. Information extracted from eligible studies included study location, year of publication, type of building material, radionuclide activity concentrations (^{226}Ra, ^{232}Th, and ^{40}K), radiological hazard indices, analytical techniques, and major findings. Data extraction was independently conducted by two reviewers to minimize subjective bias and improve accuracy. Following extraction, collected data were cross-checked for consistency and completeness. Any disagreements between reviewers regarding extracted information or interpretation of study findings were resolved through discussion and consensus. Where disagreements persisted, consultation with an additional reviewer was undertaken.

Quality Assessment Criteria

To ensure reliability and scientific validity, the selected studies were evaluated based on the following quality assessment criteria:

i. Use of standard radiological measurement techniques such as Gamma-Ray Spectroscopy or X-Ray Diffraction (XRD)
ii. Clear description of sample collection and preparation procedures
iii. Proper reporting of radionuclide activity concentrations and hazard indices
iv. Comparison with international safety standards such as UNSCEAR and IAEA guidelines
v. Adequate statistical or analytical interpretation of results
vi. Publication in reputable peer-reviewed scientific journals

Only studies that satisfied this quality requirements were included in the final review and analysis.

Bias Assessment

To minimize potential sources of bias and improve methodological rigor, several measures were adopted during study selection and evaluation. Publication bias was minimized by searching multiple scientific databases and institutional reports to capture both highly cited and less prominent studies. Selection bias was reduced through predefined inclusion and exclusion criteria applied consistently throughout the screening process. In addition, independent review procedures were implemented to enhance objectivity. Reviewer agreement during study screening and selection was assessed through discussion and consensus procedures. Any disagreements regarding study eligibility were resolved collaboratively and, where necessary, through consultation with an additional reviewer. These procedures improved consistency and reduced subjective decision-making during study selection.

Data Analysis

The collected data were analysed using thematic and comparative approaches. The thematic analysis focused on identifying common trends in radionuclide concentrations, radiological hazard indices, and analytical techniques. Comparative analysis was further applied to evaluate similarities and differences among studies from different geographical regions and geological settings. This approach enabled the identification of research trends, methodological inconsistencies, and existing knowledge gaps related to radiological assessment of building materials.

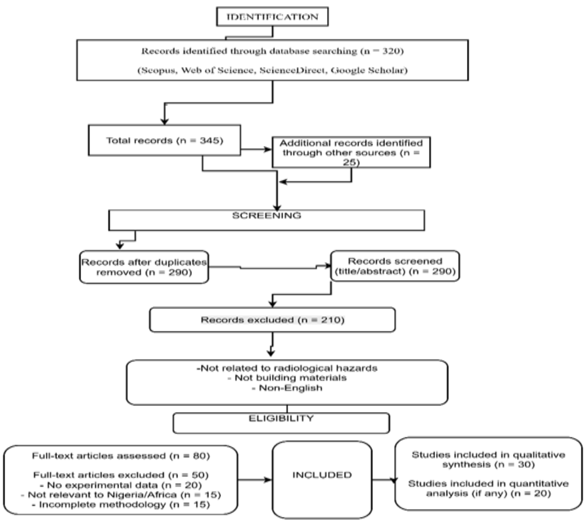

Figure 1: Shows the PRISMA Flowchart

RESULTS AND DISCUSSION

Sources of Natural Radioactivity in Building Materials

The main sources of building materials include naturally occurring geological resources like rocks and soils, as well as occasionally industrial byproducts like fly ash and slag. Naturally occurring radionuclides are present in trace concentrations in these products, which increases indoor background radiation exposure. The three most important radionuclides that are commonly found in building materials are potassium-40 (40_K) thorium-232 (232_{Th}) and radium-226 and 226_{Ra},. The uranium decay series is the source of radium-226, which is widely distributed in different concentrations based on the uranium content of the parent geological formations. Granitic and other igneous formations, where thorium-bearing minerals are widespread, are frequently linked to thorium-232. Conversely, feldspar-rich rocks and clay minerals are high in potassium-40, which frequently contributes to radioactivity in a variety of building materials.

The geological features of the source materials, the mineralogical composition, and the type of industrial processing methods used during material production all have an impact on the activity concentrations of these radionuclides. Changes in these variables may result in notable variations in the radiological characteristics of various building materials.

Measurement Techniques for Radionuclides

Gamma-Ray Spectroscopy

For the measurement of radionuclide activity concentrations in environmental and construction material samples, gamma-ray spectroscopy is generally accepted as a standard and very reliable method. Gamma-emitting radionuclides can be simultaneously identified and measured using this technique based on their distinctive energy peaks. Sodium Iodide (NaI (Tl)) Detector and High-Purity Germanium (HPGe) Detector are two widely utilized detection methods. Despite having a moderate energy resolution, NaI (Tl) detectors are reasonably priced and appropriate for everyday tests because of their excellent detection efficiency. HPGe detectors, on the other hand, offer better energy resolution and precision, which makes them better suited for accurate radionuclide identification and in-depth spectral analysis.

Sample Preparation Procedures

For gamma spectrometric analysis to be accurate and repeatable, sample preparation must be done correctly. To establish consistency, collected samples are usually crushed and completely homogenized. After that, the samples are dried at a regulated temperature until they reach a consistent weight, which removes any moisture content that might have an impact on measurement outcomes. In order to allow for the creation of secular equilibrium between parent radionuclides and their progeny, particularly within the uranium and thorium decay series, the samples are then sealed in airtight containers and kept for about 28 days.

Radiological Hazard Assessment Parameters

Several commonly used indices are used to assess the possible radiological dangers connected to construction materials; Radium Equivalent Activity (Ra_{eq}) is a measure that combines the activity concentrations of Potassium-40, Thorium-232, and Radium-226. The maximum allowable amount for safe use in building materials is typically regarded as 370 Bq/kg.

$$R_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (1)$$

Where:

C_{Ra}= activity concentration of ^{226}Ra (Bq/kg)

C_{Th}= activity concentration of ^{232}Th (Bq/kg)

C_K= activity concentration of ^{40}K (Bq/kg)

External Hazard Index (H_{ex}) External Hazard Index assesses the external gamma radiation risk posed by materials. For the material to be considered radiologically safe, this index should be less than unity ($H_{ex} < 1$).

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{359} + \frac{C_K}{4810} \quad (2)$$

Internal Hazard Index (H_{in}) Internal Hazard Index accounts for internal exposure risks, particularly due to radon and its progeny. A value below unity ($H_{in} < 1$) indicates acceptable safety levels.

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{359} + \frac{C_K}{4810} \quad (3)$$

Absorbed Dose Rate (D)-Absorbed Dose Rate represents the rate at which radiation energy is absorbed in air, typically expressed in nGy/h. The global average outdoor value is approximately 59 nGy/h.

$$D = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \quad (4)$$

Annual Effective Dose (AED) Annual Effective Dose estimates the effective radiation dose received by individuals over a year. The recommended safety limit for the general public is 1 mSv/year.

$$AED = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (5)$$

D = absorbed dose rate (nGy/h)

8760 = hours in one year

0.2 = outdoor occupancy factor

0.7 Sv/Gy = conversion coefficient

10^{-6} = conversion from nGy to mSv

Review of Empirical Studies

Studies in Nigeria

Natural radionuclides are found in typical building materials in a variety of amounts, according to empirical research carried out throughout Nigeria. Due in great part to its abundance in materials rich in feldspar and clay, potassium-40 is often listed as the primary contributor to total activity concentration. Evaluated radiological hazard indices, such as the External Hazard Index and the Internal Hazard Index, are typically found to be below the suggested safety threshold of unity in the majority of investigations. This shows that, for the most part, the materials under analysis do not present serious radioactive concerns and are deemed appropriate for use in construction.

North-Western Nigeria

Research on Nigeria's northwest, especially in Katsina State, shows comparatively higher radioactive activity concentrations than in other parts of the country. The underlying geological formations, which are known to affect the concentration and distribution of naturally occurring radioactive elements, are primarily responsible for this tendency. Significant spatial diversity has been noted between sampling sites, which reflects variations in source materials and mineralogical composition. The corresponding radioactive hazard indices usually stay within globally recognized safety limits, indicating little radiological risk under ordinary usage conditions, even though certain samples show activity concentrations that are higher than global average values.

Comparative Global Studies

The comparative analyses of were done in various nations around the world are displayed in Table 1. Materials. These studies further highlight the significant impact of geological and mineralogical parameters on activity concentrations and reveal increased contributions from potassium-bearing radionuclides. The observed worldwide uniformity supports the idea that local geology, not human activity, is the primary determinant of variances in natural radioactivity.

Table 1: Global Comparative Analysis of Radiological Properties in Building Materials

Location	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	Reference
Ogun State	68.03	84.79	620.89	(Oladotun et al., 2021)
Egypt	230.44	-	28.79	(Ladan et al., 2022)
Ethiopia	115.65	26.59	26.59	(Legasu & Chaubey, 2022)
Saudi Arabia	16.71	4.41	55.51	Al-Ghamdi, 2019
Hungary	154.00	67.00	320.00	(Kocsis et al., 2021)
United Kingdom	79.37	42.51	41.00	(Ilemona, Thomas. Scott , Peter Martin & Olaluwoye, 2022)
Malaysia	673.00	93.00	68.00	(Abraham. A. et al., 2019)

Discussion

Quantitative Rigor and Statistical Synthesis

Since this is a review paper, refer to synthesized findings rather than experimental measurements. However, the current synthesis lacks statistical meta-analysis, pooled estimates, or confidence intervals that would provide stronger quantitative support. To improve rigor, future reviews should incorporate meta-analytic techniques such as pooled mean activity concentrations, trend analysis across regions, and calculation of confidence intervals. This would allow for more precise comparisons and strengthen the evidence base.

Additionally, the statement that “most materials are safe” requires quantitative backing. Rather than generalizing, the synthesis should present the proportion of studies reporting hazard indices below international limits, supported by numerical ranges and statistical summaries. This approach would reduce overgeneralization and provide a clearer, evidence-driven conclusion.

According to the reviewed studies, there are detectable levels of naturally occurring radionuclides including ^{226}Ra, ^{232}Th and ^{40}K in building materials that are often used in Nigeria. Rocks, soils, and mineral deposits that are used to make building materials naturally contain these radionuclides. The activity concentrations and radioactive hazard indices of these materials typically stay under the safety limits advised by international agencies like UNSCEAR and the IAEA, according to findings from the majority of the examined literature. The computed values of Radium Equivalent Activity (Raeq), External Hazard Index ($\mathrm{H_{ex}}$), and Internal Hazard Index (H_{in}) were frequently within the globally recognized limits, indicating that most of the materials under study are safe for household and construction use.

The observed variations in radionuclide activity concentrations across reviewed studies may not only be attributed to geological differences but also to methodological variations employed during radiological assessment. Differences in sample preparation techniques, detector sensitivity, calibration procedures, counting geometry, and measurement duration can significantly affect radionuclide quantification. For instance, studies utilizing High-Purity Germanium (HPGe) detectors generally provide improved spectral resolution and radionuclide discrimination compared with Sodium Iodide NaI(Tl) detectors. Consequently, discrepancies among reported values may partly arise from methodological limitations rather than actual environmental differences. This emphasizes the need for standardized measurement protocols to improve comparability and reliability across studies.

Comparative evaluation of studies conducted across Nigeria and other countries reveals notable regional differences in radionuclide concentrations and hazard indices. Studies from Northwestern Nigeria, particularly areas characterized by granitic and clay-rich formations, generally reported relatively elevated activity concentrations of ^{226}Ra and ^{232}Th compared with sedimentary regions. Similar trends have been reported in countries such as Hungary and Malaysia, where geological composition significantly influenced radiological properties of building materials. Furthermore, detector methodologies may contribute to reported differences. HPGe detector systems typically provide superior energy resolution and lower uncertainty levels than NaI(Tl) systems, thereby affecting radionuclide identification and quantification accuracy. Such comparisons suggest that both geological characteristics and analytical methodology influence variability among studies.

Certain regions of northwest Nigeria, particularly parts of Katsina State, have been found to have comparatively greater radioactive concentrations, despite the overall radiation danger appearing low. These variations are mostly related to the region's geological features. Because these rocks naturally include uranium, thorium, and potassium-related minerals, building materials derived from granitic formations, clay-rich deposits, and potassium-bearing minerals frequently exhibit higher amounts of natural radioactivity. This explains the discernible differences in radioactive amounts between various material kinds and sample locations. The predominance of potassium-40 in many reviewed materials reflects its association with feldspar-rich and silicate minerals commonly present in clay and granitic formations. However, the relative contribution of individual radionuclides varied considerably depending on geological origin and mineral composition. This variability demonstrates the importance of integrating mineralogical characterization with radiological assessment, since geological composition strongly influences radionuclide behavior and associated hazard levels

The presence of radionuclides in construction materials is significant because these materials are commonly used in houses, offices, and other indoor locations where people spend a significant amount of their daily lives. Long-term radiation dose buildup may come from continuing exposure to gamma radiation from construction materials. Radon exposure resulting from the decay of ^{226}Ra remains an important public health concern because radon and its progeny can accumulate in enclosed indoor environments, particularly under poor ventilation conditions. According to epidemiological studies and international health organizations, prolonged exposure to elevated radon concentrations is recognized as a significant risk factor for lung cancer, second only to smoking among environmental causes. Therefore, routine monitoring of building materials and indoor environments remains important for minimizing potential long-term health risks.

Effective environmental radiation monitoring in Nigeria is still hampered by a number of issues, despite advancements in radiological assessment research. These include poor laboratory facilities, restricted access to contemporary radiation detection technology, a lack of technical know-how, and lax adherence to regulations. Furthermore, comparison and long-term monitoring are made more challenging by the lack of a thorough national database on radioactive contents in construction materials. Resolving these issues would enhance environmental safety evaluations and fortify radiological safety procedures in the building industry.

In totality, the reviewed literature suggests that most building materials used in Katsina State and other parts of Nigeria are radiologically safe for construction purposes when compared with international safety standards. However, in order to guarantee environmental safety and long-term public health protection, there is an ongoing need for periodic radiological assessment, more stringent regulatory monitoring, and more public awareness due to geological fluctuations and growing building activity.

Despite the generally acceptable radiological safety levels reported in reviewed studies, interpretation of findings should be approached cautiously because of heterogeneity among methodologies, sample sizes, and geographical coverage. Future investigations should adopt harmonized analytical procedures and incorporate statistical synthesis approaches such as meta-analysis to improve quantitative comparison and strengthen evidence-based conclusions.

Research Gaps

Additionally, sophisticated analytical techniques like statistical modelling and machine learning are not used sufficiently for forecasting Even though a number of studies have looked into natural radioactivity in Nigerian building materials, there are still significant gaps, particularly in Katsina State. The majority of studies don't offer complete data for the entire state and are restricted to a small number of places. It is challenging to completely comprehend the connection between radioactive concentration and mineral composition since radiological evaluations are frequently carried out without thorough mineralogical examination, such as XRD. Additionally, there is insufficient application of sophisticated analytical techniques, such as statistical modelling and machine learning, to forecast radiological risks in construction materials. Inadequate regulatory oversight and inadequate application of uniform safety regulations continue to be significant obstacles. Furthermore, not much research has evaluated the radiological characteristics of Katsina State's domestically and internationally supplied building materials. There is also a dearth of research on radiological safety policy formulation and public awareness. Closing these gaps will enhance environmental monitoring, radiological assessment, and sustainable building methods in the area.

CONCLUSION

This systematic review evaluated the occurrence of naturally occurring radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) and associated radiological hazard indices in building materials commonly used in Katsina State and other regions with similar geological characteristics. The reviewed studies revealed activity concentration ranges of 4.41–93.00 Bq/kg for ^{226}Ra, 16.71–320.00 Bq/kg for ^{232}Th, and 68.03–673.00 Bq/kg for ^{40}K. Most calculated radiological parameters, including radium equivalent activity, external hazard index, internal hazard index, absorbed dose rate, and annual effective dose, were generally below internationally recommended safety limits established by UNSCEAR and the IAEA, indicating that most investigated building materials are radiologically safe for construction purposes.

Nevertheless, noticeable regional variations were observed, particularly in parts of Northwestern Nigeria characterized by granitic and clay-rich geological formations, where relatively elevated radionuclide concentrations were reported. These findings demonstrate that geological composition remains a major controlling factor influencing the radiological characteristics of building materials. In addition, variations in analytical techniques, detector systems, and methodological procedures among reviewed studies contributed to inconsistencies in reported radiological parameters.

The findings of this review have important policy and environmental safety implications. There is a need for Nigerian regulatory agencies and environmental monitoring authorities to establish and enforce standardized national guidelines for radiological assessment of building materials. Routine radiological monitoring using reliable analytical techniques such as gamma-ray spectroscopy and complementary mineralogical analyses should be integrated into construction material quality-control processes to ensure long-term public safety.

Future research should focus on comprehensive radiological mapping of building materials across different geological zones of Nigeria, integration of mineralogical and radiological analyses, and application of advanced statistical and predictive modelling approaches, including machine learning techniques, for radiological risk assessment. Furthermore, harmonization of analytical methodologies and development of national radiological databases would improve data comparability, support evidence-based policy formulation, and strengthen environmental radiation protection strategies in Nigeria.

National standards defining permissible radionuclide concentration limits in building materials must be developed and effectively implemented in order to enhance radiological safety in building materials. To guarantee ongoing assessment of radiation levels in frequently used materials, regular monitoring and evaluation using trustworthy methods like gamma-ray spectroscopy should be promoted. Furthermore, encouraging multidisciplinary cooperation between specialists in materials science, geology, physics, and environmental science would improve the precision and Caliber of radiological studies.

To enhance community knowledge and safety procedures, public awareness campaigns on radiation safety and the possible health risks connected to radioactive building materials should be reinforced. Additionally, creating thorough national and local databases for radiological mapping would offer useful data for future research projects in Nigeria, policy development, and environmental monitoring.

REFERENCES

Abbasi, A. (2013). *Environmental Radiation in High Exposure Building Materials*. (July).

Abdel Gawad, A. E., Hanfi, M. Y., Tawfik, M. N., Alqahtani, M. S., & Mira, H. I. (2024). Assessment of radioactivity levels and radiation hazards in building materials in Egypt. *Nuclear Engineering and Technology*, *56*(2), 707–714. https://doi.org/10.1016/j.net.2023.11.006

Abraham. A., N., Fazli Ismail, A., & Samat, S. (2019). ASSESSMENT OF NATURALLY OCCURRING RADIONUCLIDES IN MALAYSIA'S BUILDING

MATERIALS. *Radiation Protection Dosimetry*, *186*(4), 520–523. https://doi.org/10.1093/rpd/ncz125

Chougule, A., & Kumar Jain, G. (2024). Radiation Hazards, Protection, and Cultivating a Radiologically Safe Environment for Nurses. *Journal of Medical and Clinical Nursing Studies*, *2*(4), 1–5. https://doi.org/10.61440/jmcns.2024.v2.58

Estokova, A., Singovszka, E., & Vertal, M. (2022). *Investigation of Building Materials' Radioactivity in a Historical Building — A Case Study*. 1–18.

Gambo, N., & N, Baba- Kutigi A.N, H. A. & M. M. (2015). INVESTIGATING THE CONCENTRATION OF 226 Ra IN CONCRETE BLOCK AS RAW MATERIALS FOR BUILDING IN KATSINA STATE. *International Journal of Latest Research in Engineering and Technology (IJLRET) ISSN: 2454-5031(Online) Www.Ijlret.Com‖ Volume 1 Issue 6‖November 2015 ‖ PP 36-42*, *1*(6), 36–42.

Garba, N. N., Rabi'u, N., Aliyu, A. S. ad, Kankara, U. M., Vatsa, A. M., Isma'ila, A., & Bello, S. (2023). Evaluation of radiological risk associated with local building materials commonly used in Northwestern Nigeria. *Heliyon*, *9*(5), e15791. https://doi.org/10.1016/j.heliyon.2023.e15791

Grzywa-Celinska, A., Krusinski, A., Mazur, J., Szewczyk, K., & Kozak, K. (2020). Radon — The Element of Risk. The Impact of Radon. *Toxics*, *8*(120), 1–20.

Ilemona C. Okeme , Thomas B. Scott , Peter G. Martin, Y. S., & Olaluwoye, T. I. O. and M. O. (2022). *Assessment of the Mode of Occurrence and Radiological Impact of Radionuclides in Nigerian Gamma-Ray Spectroscopy*.

Kocsis, E., Tóth-Bodrogi, E., Peka, A., Adelikhah, M., & Kovács, T. (2021). Radiological impact assessment of different building material additives. *Journal of Radioanalytical and Nuclear Chemistry*, *330*(3), 1517–1526. https://doi.org/10.1007/s10967-021-07897-4

Ladan, S. C., Mustapha, I. M., Hassan, A., Aliyu, M. S., & Rahmat, S. (2022). Assessment of Radioactivity Concentration Level in Soil Samples of some Gold Mining Areas of Shiroro, Niger State, Nigeria. *Journal of Radiation and Nuclear Applications*, *7*(2), 1–6. https://doi.org/10.18576/jrna/070201

Legasu, M. L., & Chaubey, A. K. (2022). Determination of dose derived from building materials and radiological health related effects from the indoor environment of Dessie city, Wollo, Ethiopia. *Heliyon*, *8*(3), e09066. https://doi.org/10.1016/j.heliyon.2022.e09066

Muhammad, A. N., Ismail, A. F., & Garba, N. N. (2024). Natural radioactivity in food crops and soil and estimation of the concomitant dose from tin mining areas in Nigeria. *Journal of Taibah University for Science*, *18*(1). https://doi.org/10.1080/16583655.2024.2366507

Nation, U., Committee, S., & Radiation, A. (2024). *UNSCEAR 2024 Report: I*.

Ogunobi, S., Abdulkareem, A., & Ayodele, A. (2023). Radiological Impact Assessment of Natural Radioactivity of Ceramic Wares and Decorations in Abeokuta, Nigeria. *The Journals of the Nigerian Association of Mathematical Physics*, *65*(October 2022), 1–10.

Oladotun, A. O., McKay, R. R., Sunday, J. E., Usikalu, M. R., Embong, Z., & Saeed, A. (2021). Evaluation of Radiological Health Risk Associated with Indian Tiles Available in Nigerian Markets. *Advances in Science, Technology and Engineering Systems Journal*, *6*(3), 271–276. https://doi.org/10.25046/aj060330

Popov, D. (2026). *Inhalation and Ingestion of Radioactive Nuclides : Mechanisms of Internal Contamination, Radio toxicity, and Medical Management. Biokinetics and Organ-Specific Targeting of Radionuclides after Respiratory and Gastrointestinal Entry.* (Vol. 137). https://doi.org/10.13140/RG.2.2.36756.56963