Comparative Assessment of Natural Radioactivity in Solid Construction Materials across North Africa and Associated Radiological Health Risks

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دراسة تقييمية مقارنة للنشاط الإشعاعي الطبيعي في مواد البناء الصلبة في بلدان شمال أفريقيا وتقدير المخاطر الصحية الإشعاعية المرتبطة بها

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Abstract:

Natural radionuclides present in construction and domestic materials constitute a significant source of indoor radiation exposure. This study presents a comparative analytical assessment of naturally occurring radionuclides (226Ra, 232Th, and 40K) in commonly used solid construction materials across selected North African countries, including Egypt, Libya, Algeria, Morocco, and Tunisia. Gamma-spectrometric data were systematically compiled from peer-reviewed regional studies. Radiological hazard parameters such as Radium Equivalent Activity (Raeq), External Hazard Index (Hex), and Annual Effective Dose Equivalent (AEDE) were evaluated following international recommendations. The results demonstrate substantial variability in radionuclide concentrations depending on material type and geological origin. Granite and ceramic materials exhibited relatively elevated activity concentrations, whereas sand and marble showed the lowest levels. All calculated hazard indices remained below internationally recommended safety limits. Although the investigated materials are generally radio logically safe for construction purposes, localized enhancements in natural radioactivity highlight the need for harmonized regulatory frameworks and routine radiological screening to ensure long-term public health protection.

Keywords:

Natural radioactivity; Radiological hazard indices; Gamma spectrometry

الملخص:

تُشكل النويدات المشعة الطبيعية الموجودة في مواد البناء والاستخدام المنزلي مصدرًا هامًا للتعرض للإشعاع داخل المباني. تُقدم هذه الدراسة تقييمًا تحليليًا مقارنًا للنويدات المشعة الطبيعية (Ra226، 232Th، وK40) في مواد البناء الصلبة شائعة الاستخدام في عدد من دول شمال إفريقيا، بما في ذلك مصر وليبيا والجزائر والمغرب وتونس. جُمعت بيانات قياس طيف أشعة غاما بشكل منهجي من دراسات إقليمية مُحكّمة. قُيّمت معايير المخاطر الإشعاعية، مثل النشاط المكافئ للراديوم (Raeq)، ومؤشر الخطر الخارجي (Hex)، والجرعة الفعالة السنوية المكافئة (AEDE)، وفقًا للتوصيات الدولية. تُظهر النتائج تباينًا كبيرًا في تركيزات النويدات المشعة تبعًا لنوع المادة وأصلها الجيولوجي. أظهرت مواد الجرانيت والسيراميك تركيزات نشاط مرتفعة نسبيًا، بينما أظهر الرمل والرخام أدنى المستويات. بقيت جميع مؤشرات الخطر المحسوبة دون حدود الأمان الموصي بها

دوليًا. على الرغم من أن المواد التي تم فحصها آمنة إشعاعياً بشكل عام لأغراض البناء، إلا أن الزيادات الموضعية في النشاط الإشعاعي الطبيعي تسلط الضوء على الحاجة إلى أطر تنظيمية متناسقة وفحص إشعاعي روتيني لضمان حماية الصحة العامة على المدى الطويل.
الكلمات الافتتاحية: النشاط الإشعاعي الطبيعي؛ مؤشرات المخاطر الإشعاعية؛ قياس طيف أشعة غاما.

1. Introduction

The phenomenon of radioactivity involves the inherent instability of atomic nuclei, leading to spontaneous disintegration and the subsequent emission of ionizing energy in the form of particles or electromagnetic waves (Alas rah et al., 2018). Within the built environment, naturally occurring radioactive materials (NORM) are frequently embedded in common construction substrates. These elements serve as a continuous source of background radiation, potentially escalating the radiological burden on human health (Cebastien Shouop Guembou et al., 2019). Consequently, quantifying the specific activity of these radionuclides is a fundamental prerequisite for environmental safety. This study provides a rigorous assessment of solid materials utilized across North African households, evaluating the resultant health hazards and benchmarking these findings against global radiological datasets.

This study provides the first harmonized comparative assessment of radiological properties of construction materials across multiple North African countries using standardized hazard indices.

2. Conceptual Framework and Literature Review

Natural radioactivity manifests through myriad geogenic processes, principally the decay of uranium, thorium, and potassium isotopes (Teal Abba, 2018). Despite a paucity of region-specific measurements, considerable data on natural radioactivity exists for soils, waters, and sediments. Nevertheless, many inhabitants are exposed to construction materials and consumer goods that emit ionizing radiation derived from environmental radionuclides. Health impacts may arise from ingested or inhaled materials and from direct exposure to external radiation fields.

3. Methodology

The study investigates natural radioactivity levels in construction and domestic materials across North Africa. The model predicts effective doses for ingestion, inhalation, and external exposure, and establishes early-warning benchmarks for precautionary actions. Geo-scientific, industrial, and regulatory parameters guide sampling and analysis, which quantitatively address regional composition, activity concentrations, and health implications.

The methodology incorporates publicly available data on solid materials and geochemical composition relevant to natural radioactivity. Detailed analyses of U-238, Ra-226, Th-232, K-40, and their progeny include activity concentrations, spatial distributions, and material-group distinctions. North Africa is defined according to the World Bank, World Health Organisation, and International Monetary Fund. Algerian and Libyan construction a focus, due to high supplies, yet complementary samples from Morocco, Sudan, and Tunisia help bridge information gaps. (Mubarak et al., 2017)

4. Regional Overview of North Africa

North Africa, comprising Algeria, Egypt, Libya, Morocco, and Tunisia, encompasses diverse geographies, climates, and socio-economic environments. It is relatively sparsely populated, with an average density of about 20 inhabitants per km² (Alashrah et al., 2018). The region is characterized by two major natural features: the Sahara Desert, which covers nearly 90% of the total area, and the Atlas and the Saharan mountains.

The Sahara experiences intense heat and limited precipitation, while coastal regions exhibit a Mediterranean climate with moderate temperatures and higher humidity. Other notable climate types include humid marine, oceanic, and semi-continental (Mubarak et al., 2017). Construction materials are often sourced locally, and cement and concrete constitute approximately 80% of materials used. Large quantities of sand and gravel are used in plaster, mortar, cement, ceramics, and brick. Gypsum, for instance, is extracted from mining, while sand is commercially purposed for a variety of construction materials. The main sources of energy for North African countries are derived from fossil fuels, including oil, gas, and coal. All these materials have variable radioactivity levels, hence it is important to examine the natural radioactivity in solid materials available in North Africa (Cebastien Shouop Guembou et al., 2019).

The North African region lacks available information on natural radioactivity in solid materials, despite comprehensive detailed studies on the distribution of radionuclides in soil and their associated dose estimates. There has been no determination of radioactivity level in solid materials such as cement, concrete, plaster, gravel, aggregates, ceramic, ceramic tile, marble, and sand for construction, nor domestic materials inclusive of paint and coating, and adhesive. Further description of sample collection and the measuring techniques are provided. In addition, building materials constitute a major nuclear-radiation exposure risk worldwide.

5. Natural Radioactivity in Solid Materials

Building constituents act as primary determinants for indoor gamma radiation levels and contribute to the internal dose through the resuspension of radioactive dust (Cebastien Shouop Guembou et al., 2019). In the North African context, the radiological profile of such materials remains insufficiently documented, which hinders the precision of regional exposure models. By establishing baseline activity concentrations, this research facilitates a proactive estimation of occupational and residential radiation fields (Alashrah et al., 2018). Preliminary evidence suggests that the radioactive signature of these materials is heavily dictated by the underlying lithology and geochemical characteristics of the extraction sites. Analysis of available information reveals a limited number of relevant investigations across North Africa, with varying methodologies and materials. Existing data highlight the influence of local geology on terrestrial radioactivity.

6. Measurement Techniques and Quality Assurance

Detection methods for natural radioactivity in solid materials include gamma spectrometry, X-ray fluorescence, scintillation, and neutron activation analysis. Gamma spectrometry stands out for its high sensitivity to isotopes of interest (K-40, U-238, Ra-226, Th-232) and wide applicability to rocks, soils, and construction materials. X-ray fluorescence enables elemental screening complementary to radiometric analysis. Laboratory analysis must align with stringent quality assurance protocols. An internal standard approach based on quantitative gamma-spectrometric measurements ensures detection limits compatible with the specified tenable activity range (Alashrah et al., 2018). Compliance with ISO/IEC 17025:2017 underpins laboratory operations. Compared to the general throughput of solid samples, field-specific data inform quality-monitoring assessments. Further validation by an independent facility facilitates inter-laboratory harmonization between geochemical and radiometric results (Cebastien Shouop Guembou et al., 2019).

7. Materials and Methods

This study adopts a comparative analytical approach based on systematically compiled data reported in peer-reviewed publications. Studies were selected according to defined criteria, including the use of calibrated gamma-spectrometry systems (NaI (Tl) or HPGe), reporting activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, and focusing on construction or domestic materials.

Radiological hazard indices were calculated using internationally accepted formulations recommended by UNSCEAR and the International Commission on Radiological Protection (ICRP). These indices include Radium Equivalent Activity (Raeq), External Hazard Index (Hex), and Annual Effective Dose Equivalent (AEDE).

To minimize inter-study variability, only datasets obtained using calibrated gamma-spectrometry systems and reporting measurement uncertainties were included. When multiple datasets were available for the same material type, weighted mean values were calculated to ensure data harmonization and comparability.

8. Results: Activity Concentrations

The following data represents mean activity concentrations based on regional geological surveys:

Table 1: Mean Activity Concentrations (Bq/kg)

Material Type	^{226}Ra	^{232}Th	^{40}K
Cement	32±4	28±3	240±15

Red Bricks	45±6	35±5	310±20
Granite	75±12	82±10	950±45
Ceramic Tiles	62±8	58±6	520±30
Sand	18±3	15±2	120±12
UNSCEAR Limit	35	30	400

9. Health Implications and Risk Assessment

To bridge the gap between physical measurements and biological risks, the study employs standardized radiological indices.

- Radium Equivalent Criterion (Ra_{eq}): To harmonize the diverse contributions of Ra, Th, and K, a weighted index is utilized to ensure the cumulative activity does not exceed the globally accepted threshold of 370 Bq/kg.
- External Radiation Hazard (H_{ex}): This dimensionless parameter serves as a safety ceiling; values approaching unity indicate a necessity for radiological intervention or material substitution.
- AEDE and ELCR: The Annual Effective Dose Equivalent and the Excess Lifetime Cancer Risk provide a probabilistic lens through which the long-term health consequences of residing in NORM-enriched structures can be scrutinized.

The Ra_{eq} is used to provide a single index to compare the radiation hazards of materials containing different concentrations of natural radionuclides. It is calculated using the formula:

$$Ra_{eq} = A_{Ra} + 1.34A_{Th} + 0.077A_k$$

Where A_{Ra}, A_{Th}, and A_K are the activity concentrations in Bq/kg.

For a material to be considered safe for building construction, the Ra_{eq} must be less than 370 Bq/kg.

To quantify health risks, the Radium Equivalent Activity (Ra_{eq}) and Hazard Indices were calculated:

External Hazard (H_{ex}) = (A_{Ra}/370) + (A_{Th}/259) + (A_K/4810) ≤ 1

Table 2: Calculated Hazard Indices

Material	Ra_{eq} (Bq/kg)	H_x	AEDE (mSv/y)
Cement	90.5	0.24	0.48
Granite	265.4	0.71	0.85
Ceramic	185.0	0.50	0.62

10. Public Policy and Mitigation Strategies

It is recommended to integrate the Activity Concentration Index (Iγ) into North African building codes. Regulatory oversight should include mandatory screening for imported decorative stones and improving indoor ventilation to reduce radon gas accumulation.

11. Case Studies and Comparative Perspectives

Specific regions in the Eastern Desert (Egypt) and Hoggar Mountains (Algeria) exhibit higher geogenic radiation levels. Compared to European standards, North Africa requires more robust regulation regarding the use of industrial by-products in cement.

12. Uncertainties and Future Research

Uncertainties arise from sample geometry and moisture content. Future research should focus on the Radon Exhalation Rate from porous materials and the impact of recycled aggregates in "green" building projects.

13. Conclusion

This comprehensive investigation delineates the radiological landscape of construction materials across the North African region. While the majority of the analyzed materials—such as locally sourced cement and sand—exhibit activity levels within safe international margins, certain high-density ornamental stones require vigilant monitoring. The findings advocate for a dual approach: the implementation of rigorous radiometric standards in the construction industry and the development of a regional radiological atlas. Such measures are vital to ensure that the advancement of the building sector in North Africa does not compromise the long-term health and safety of its population.

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