

A Review Study of Natural Radioactivity and Radiological Hazards in Building Materials Used in Saudi Arabia

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Abstract: Population exposure to radiation may increase significantly when building materials with high concentrations of naturally occurring radionuclides are used, making the assessment of radioactivity levels and radiation hazard indicators for these materials crucial. This research provides a comprehensive review of naturally occurring radionuclide concentrations. ^{226}Ra , ^{232}Th , ^{232}Th , ^{40}K in six types of building materials: sand, gypsum, cement, marble, granite, and ceramic, as well as calculating the radiological risks associated with the use of these materials in dwellings in Saudi Arabia from 2007 to 2025. The calculated radium equivalent activity Ra_{eq} (Bq/kg), radiological hazard indices H_{ex} and H_{in} , absorbed dose rate D (nGy h^{-1}), and indoor/outdoor annual effective dose AED (mSvy^{-1}) exhibited considerable variation among the building materials. The highest recorded values were observed in granite ($\text{Ra}_{\text{eq}} = 8091.9$, $\text{H}_{\text{ex}} = 21.9$, $\text{H}_{\text{in}} = 22.34$, $\text{D} = 9706.3 \text{ nGy h}^{-1}$, $\text{AED}_{\text{in}} = 30.9 \text{ mSvy}^{-1}$, $\text{AED}_{\text{out}} = 4.2 \text{ mSvy}^{-1}$), whereas the lowest values were detected in gypsum ($\text{Ra}_{\text{eq}} = 1.7$, $\text{H}_{\text{ex}} = 0.00$, $\text{H}_{\text{in}} = 0.01$, $\text{D} = 0.8 \text{ nGy h}^{-1}$, $\text{AED}_{\text{in}} = 0.00561 \text{ mSvy}^{-1}$, $\text{AED}_{\text{out}} = 0.0014 \text{ mSvy}^{-1}$). Some extreme values (outliers) were observed, particularly in granite and cement, while most materials remained within safe radiological limits.

Keywords: Natural radionuclides, Risk assessment, Building materials, Uranium, Thorium, Potassium.

1 Introduction

Ionizing radiation can harm different organs in various ways, leading to both short-term and long-term effects.

These effects depend on how much radiation a person is exposed to, how long the exposure lasts, and how sensitive the tissue is. The blood-making system, known as the hematopoietic system, is particularly sensitive to radiation.

High levels of exposure can lower blood cell counts and, in serious cases, may cause multiple organs to fail. Research shows that the hematopoietic system, gastrointestinal system, nervous system, and skin often get damaged at the same time, with more severe injuries occurring as the radiation dose increases [1]. The kidneys and urinary system are also vulnerable to both immediate and lasting effects from radiation. Studies have found that if both kidneys receive doses over 4–5 Gy, it can result in sudden kidney failure or worsen other radiation-related injuries, potentially leading to chronic kidney disease [2]. The lungs are intricate organs with a delicate network of tiny blood vessels. Exposure to radiation can trigger acute pneumonitis

(lung inflammation), and a substance called transforming growth factor-beta ($\text{TGF-}\beta$) plays an important role in worsening lung scarring. Even low-dose radiation (LDR), which people might experience during medical scans or from environmental sources, can cause DNA damage over time and increase oxidative stress while affecting the immune response in various organs [3]. Building materials influence both structural performance and environmental safety, particularly due to naturally occurring radioactive isotopes such as ^{238}U , ^{232}Th , and ^{40}K . Assessing radiation levels and ensuring compliance with international safety standards is essential for occupant protection. Sand is a widespread geological material formed through the weathering and erosion of rocks. Its composition varies depending on the parent rock, but typically includes quartz, feldspar, and mica. Some heavy minerals may contain naturally occurring radioactive elements such as uranium, thorium, and potassium-40 [4]. Zircon, a common heavy mineral, contains trace amounts of uranium and thorium, contributing to natural radioactivity. Rutile and ilmenite, rich in titanium, may contain small amounts of radioactive elements. Monazite is one of the most radioactive minerals present in sand, containing high levels of thorium [5,6].

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Uranium, Thorium and potassium-40 are the primary naturally occurring radioactive elements found in sand. Uranium appears in zircon and monazite, thorium mainly in monazite, and potassium-40 in feldspar and mica. Radioactive series present in sand are Uranium-238(^{238}U), Thorium-232(^{232}Th), and Uranium-235(^{235}U) Series [7].

Gypsum is a non-metallic sedimentary mineral primarily composed of calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and is classified as an evaporite mineral formed through the evaporation of lakes or ancient inland seas. It is characterized by its lightness, softness, and workability, which makes it one of the most widely used minerals in construction materials and industry. This makes gypsum a naturally abundant sedimentary mineral [8,9]. Gypsum generally contains low levels of natural radiation, and its hazard depends on the concentration of radioactive isotopes present. Most gypsum samples are safe for use, but some samples with higher radioactivity may require caution when used in construction. Human exposure to radiation from building materials occurs in two ways: external exposure and internal exposure. Various studies conducted in different countries have shown that the levels of radioactivity in gypsum are generally within safe limits for construction use, making it reliable as a raw material for building and industry. For example, a study in Romania showed that most gypsum samples had radioactivity within the permissible limits, except for some samples that could be hazardous if used in large quantities. Another study in Pakistan indicated that gypsum and limestone contained very low levels of ^{40}K , ^{226}Ra , and ^{232}Th , and all radiological hazard indices were within the globally recommended values. Therefore, it can be concluded that gypsum is safe in terms of radiation when used in construction and industrial applications, as long as the permissible limits are respected [10-12]. Cement, in its general sense, is defined as a material with adhesive and cohesive properties that enable it to bind mineral particles into a solid, unified mass, encompassing a wide range of binding materials. However, in construction, the term “cement” refers specifically to materials used for binding bricks, building blocks, and similar substances. It is a powdery substance made with calcined lime and clay as the main ingredients. Cement is made primarily from calcareous materials such as limestone or chalk, which is the source of Calcium Carbonate (CaCO_3), and from alumina (Al_2O_3) and silica (SiO_2) found in clay or shale. Marl, a mixture of calcareous and argillaceous materials, is also used. Clay also provides silica and alumina as well as iron oxide (Fe_2O_3), while calcined lime provides calcium oxide (CaO). Natural clay also contains minor components such as sodium (Na) and potassium (K). In the chemical analysis of cement, the elemental composition is examined, including calcium (Ca), silicon (Si), aluminum (Al), magnesium (Mg), iron (Fe), sodium (Na), potassium (K), and sulfur (S) [13]. The materials that make up the basic composition of cement are not radioactive in themselves. Naturally, radioactive

materials are not added industrially. However, raw rocks (limestone and clay) may contain radioactive isotopes as part of their geological composition. Studies assessing radioactivity in cement show that the most common radioactive elements are uranium (^{238}U), thorium (^{232}Th), potassium (^{40}K) and its decay products, such as radium (^{226}Ra) - which serves as an indicator for the presence of uranium- and radon (^{222}Rn). Marble is a metamorphic rock consisting mainly of the mineral's calcite (calcium carbonate, CaCO_3) or dolomite (calcium magnesium carbonate, $\text{CaMg}(\text{CO}_3)_2$). Under high temperature and pressure, the original limestone or dolomite rocks recrystallize and become a denser and harder rock called marble. Humans are continuously exposed in homes and at workplaces to some ionizing radiation in the form of alpha- and beta-particles and gamma-photons emitted by radon, thoron, and their corresponding progenies coming from building materials and air pollution (cigarette smoke, fly ashes, and dusts). Hamdy and Aly recorded for the first time the mineralization of gold (0.98–2.76 ppm) and uranium (133–640 ppm) in marbles from the Arabian-Nubian Shield in the Eastern Desert of Egypt and stated that the encountered uranium minerals are of secondary origin, such as autunite, uranophane, and carnotite [14].

Granite is a coarse-grained intrusive igneous rock formed from the slow cooling of silica-rich magma within the continental crust. It is mainly composed of quartz, potassium feldspar, plagioclase feldspar, and smaller amounts of mica, such as biotite or muscovite. The presence of accessory minerals—including zircon, monazite-(Ce), xenotime-(Y), uraninite, and coffinite—plays a major role in its geochemical behavior and natural radioactivity. These minerals naturally host uranium and thorium, making granite one of the most significant crustal rocks containing radioactive elements [15].

Granite exhibits measurable natural radioactivity due to the presence of uranium (U), thorium (Th), and potassium-40 (K-40). These elements incorporate into accessory minerals during crystallization. As they undergo radioactive decay, they emit alpha particles, beta particles, and gamma rays. Gamma radiation is the most detectable outside the rock because of its high penetration capability. Radiation emitted from granite results from the decay of U-238, Th-232, and K-40. Alpha emissions mainly originate from uranium- and thorium-bearing accessory minerals, while beta and gamma emissions arise from intermediate decay steps. Radon and thoron gases—gaseous daughters of these decay series—may diffuse through microfractures within the rock and surrounding soil. Radioactive element concentrations vary widely among granite types. Highly evolved granites, such as topaz-albite granites, show significant enrichment in U, Th, rare-earth elements, and rare metals due to abundant accessory minerals.

Other granites, such as the Narendle granodiorite, contain

moderate levels of radioactive elements but still display clear geochemical signatures linked to subduction-related magmatism. These variations reflect differences in source composition, magma evolution, and tectonic setting [16]. Granite is widely

used in construction for building blocks, floor tiles, wall cladding, and polished countertops due to its strength and durability. It is also employed in monuments, pavements, and bridges because of its resistance to weathering. Crushed granite serves as a key aggregate in concrete and roadbeds. Furthermore, zircon crystals within granite allow geologists to determine the age of continental crust through radiometric dating [17].

The majority of ceramics are compounds of metals or metalloids and nonmetals. Most frequently, they are oxides, nitrides, and carbides. The most widely accepted definition of a ceramic is given by Kingery et al. "A ceramic is a nonmetallic, inorganic solid" [18].

Thus, all inorganic semiconductors are ceramics, such as diamond and graphite. There are several broad categories of ceramics classifying the industrial products as follows: clay products, white ware, refractories, glasses, cements, abrasives [19,20].

In general, ceramics are divided according to their properties and application into traditional and advanced. Feldspar-forming minerals comprise about 60 % of the terrestrial rocks and form one of the main components in granites and related pegmatites. Feldspars represent an essential component of most known types of ceramics. Consequently, they may contain considerable concentrations of radionuclides, exhibiting some enhanced natural radioactivity levels; therefore, they must be taken into consideration from the environmental radiation point of view. Building materials influence both structural performance and environmental safety, particularly due to naturally occurring radioactive isotopes such as ^{238}U , ^{232}Th , and ^{40}K . Assessing radiation levels and ensuring compliance with international safety standards is essential for occupant protection. This work will shed light on the studies of activity concentrations in building materials in Saudi Arabia from 2007 to 2025. These studies measured the radioactivity of natural isotopes such as Ra^{226} , Th^{232} , and K^{40} , and some of them evaluated internal and external radiological hazard indices, providing a foundation for understanding the potential risks associated with the use of these materials in buildings and presenting detailed analyses of radiation levels in six widely used building materials, including sand, gypsum, cement, marble, granite, and ceramic.

2 Materials and methods

Gamma-ray spectrometry (HPGe), used to quantify natural radionuclides such as ^{238}U , ^{232}Th , ^{226}Ra , and ^{40}K , provides high resolution and non-destructive analysis, with

minimum detectable activities (MDA) typically in the range of a few Bq/kg, depending on counting time and detector efficiency. The CAN technique, Neutron Activation Analysis, ICP-MS and XRD analysis were also used for radionuclides, trace elements and minerals identification.

3 Radiological risks

Since building materials naturally contain radioactive constituents, a radiological assessment has been established to determine whether a material falls within the acceptable safety range. The European Commission (EC Report-112) and IAEA SSG-32 recommend using a special radioactive index to link the concentration of radioactive materials in building materials to the resulting annual effective dose:

$$I = \text{CRa}300 \text{ Bq/kg} + \text{CTh}200 \text{ Bq/kg} + \text{CK}3000 \text{ Bq/kg} \leq 1 \quad (1)$$

Where CRa, CTh, and CK represent the concentration of ^{226}Ra (^{238}U), ^{232}Th , and ^{40}K in Bq/kg, respectively.

If the index $I < 1$, the annual effective dose remains below 1 mSv, indicating that the building materials are considered safe and are not subject to any restrictions [21,22].

In order to assess the radiation hazard associated with the building materials used, the radium equivalent activity (Raeq) and the absorbed dose rate (D) have been evaluated, where it is assumed that all the decay products of ^{226}Ra and ^{232}Th are in radioactive equilibrium with their precursors. The Raeq is calculated according to the following formula:

$$\text{Raeq} = \text{ARa} + 1.43\text{ATh} + 0.077\text{AK} \quad (2)$$

Where, ARa, ATh and AK are the specific activities Bq/kg of ^{226}Ra , ^{232}Th and ^{40}K , respectively [23,24].

The outdoor absorbed dose rate nGy/h in air from terrestrial gamma radiation at 1 m above the ground is calculated according to the following formula:

$$\text{DnGyh} = 0.429\text{ARa} + 0.666\text{ATh} + 0.042\text{AK} \quad (3)$$

In addition, the annual effective dose rate (AED)(mSv/y) is of two types. The annual indoor effective dose (Ein) and annual outdoor effective dose (Eout) were calculated.

The annual indoor effective dose (Ein) is the dose that a person receives in the indoor environment. The formula used is:

$$\text{EinmSvy} = \text{DnGyh} \times 0.7\text{SvGy} \times 8760\text{hyear} \times 0.8 \times 10^{-6} \quad (4)$$

The annual outdoor effective dose (Eout) is estimated from the dose rate (D) and the time of stay in the outdoor environment:

$$\text{EoutmSvy} = \text{DnGyh} \times 0.7\text{SvGy} \times 8760\text{hyear} \times 0.2 \times 10^{-6} \quad (5)$$

The recommended upper limit for AED is 1 mSv/y [24-26].

The external hazard index (Hex) is an important parameter for evaluating the radiation dose expected to be delivered

externally when materials are used in building construction. While the internal hazard index (Hin) assesses internal exposure risks, including gamma radiation. In the present study, both were calculated to assess the radiological hazards of the studied samples using the following equation:

$$\text{Hex} = \text{ARa}370 + \text{ATh}259 + \text{Ak}4810 \leq 1 \quad (6)$$

$$\text{Hin} = \text{ARa}185 + \text{ATh}259 + \text{Ak}4810 \leq 1 \quad (7)$$

4 Results and Discussion

Review Studies of radioactivity of building materials in Saudi Arabia

Al- Saleh and Al-Berzan conducted a study on the Measurements of natural radioactivity in some kinds of marble and granite used in Riyadh Region; the radium equivalent activity (Raeq), radiation hazard indices (internal and external), and the absorbed dose rate in air were calculated for all the collected samples to evaluate the associated radiological risks [27].

Al-Mayahi et al. carried out a study on the radioactivity level measurement of some cement samples to measure the radioactivity levels in different cement samples. The research used gamma-ray spectrometry to determine the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K and to evaluate the radiation dose resulting from these materials [28].

Aydarous et al. stated that the measurements of natural radioactivity and the resulting radiation doses from commercial granites aimed at measuring the natural radioactivity levels in commercially available granite samples used in Saudi Arabia [29].

The researchers analyzed 24 granite samples using HPGe gamma-ray spectrometry to determine the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K , and then calculated the absorbed dose rate, annual effective dose, radium equivalent activity, and radiation hazard indices, in addition to assessing the radiological risks associated with these granites in dwellings, especially the internal exposure from radon gas (^{222}Rn) in poorly ventilated indoor environments. Alharbi and AlZahrani (2012) conducted a study titled Assessment of Natural Radioactivity Levels and Associated Radiation Hazards of Building Materials used in Saudi Arabia to measure the concentrations of natural radionuclides (^{226}Ra , ^{232}Th , and ^{40}K) in commonly used building materials in Saudi Arabia and evaluate the associated radiological hazards to determine their safety for construction use. El-Taher studied the Assessment of Natural Radioactivity Levels and Radiation Hazards for Building Materials Used in Qassim Area, Saudi Arabia, aiming to assess the natural radioactivity levels of ^{226}Ra , ^{232}Th , and ^{40}K in commonly used building materials in the Qassim region of Saudi Arabia using gamma-ray spectrometry [30].

The study also evaluated radiation hazards by calculating radium equivalent activity (Raeq), external hazard index (Hex), and the absorbed dose rate to determine whether these materials are safe for use in construction. Aydarous et al. conducted a study, Measurements of the natural radioactivity in building materials (raw and manufactured), other than granites in KSA, aimed at measuring the natural radioactivity levels in raw and manufactured building materials—excluding granites—in Saudi Arabia [24]. The objective was to determine the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K and to evaluate their associated radiological hazards using high-resolution HPGe gamma-ray spectrometry. AlZahrani conducted a study, Assessment of Radioactivity and the Exposure Doses from Local Cement Types in Saudi Arabia, to assess the radioactivity levels and exposure doses in local cement types used in Saudi Arabia [31].

The study measured ^{226}Ra , ^{232}Th , and ^{40}K in cement samples collected from six factories (Al Jouf, Yanbu, Al Qassim, Tabuk, Jeddah, and Al Rabia). The aim was to establish baseline data for natural radionuclides in Saudi cement and to evaluate potential radiological hazards. The results showed that all measured values were below international limits, indicating that local cement poses no radiological risk and is safe for construction use. Al-Dadi et al. conducted a study on the environmental impact of cement plants in western Saudi Arabia [32].

The aim was to assess natural radioactivity and trace elements in cement and the surrounding soil. Findings indicated minor increases in radionuclide levels near plants, but all radiation measurements remained below global safety limits. Cement products were found safe for use, with limited environmental impact detected. Hamidaldin conducted a study, Measurements of Natural Radioactivity of Industrial Raw Materials from the West of Saudi Arabia (Arabian Shield) [33].

The study aimed to measure concentrations of natural radionuclides (Ra-226, Th-232, K-40) in industrial raw materials used as building stones, and to evaluate radiological hazards. The results showed that all measured activity concentrations and hazard indices were within international safety limits, indicating the materials are safe for human use. Baz conducted a study on the Natural Radioactivity Levels in Local Gray and White Cement in Saudi Arabia to assess radiological safety by evaluating activity concentrations and hazard indices, including Raeq, Hex, Hin, I_γ, absorbed dose rate, and annual effective dose [34].

Results showed all values were below world averages and international safety limits, indicating that Saudi cement is radiologically safe for construction. Mohamed et al. conducted a study on the Evaluation of radionuclide concentrations and associated radiological hazard indices in marble and granite used as building materials in Al-

Madinah Al-Munawara to evaluate safety levels of radionuclides (Ra-226, Th-232, K-40) [35].

Results showed marble had very low activity levels, while granite had higher but still safe levels. All hazard indices were within international safety limits, confirming the materials are safe for construction [35].

Issa and Alaseri conducted a study, Determination of Natural Radioactivity and Associated Radiological Risk in Building Materials Used in Tabuk Area, Saudi Arabia, to measure natural radionuclide concentrations (Ra-226, Th-232, K-40) in 35 building material samples and evaluate associated risks [26]. Results showed that average activity levels were lower than world-recommended limits. Hazard indices such as Raeq, Hex, Hin, and dose rates were mostly below safety thresholds, indicating no significant radiological risk [26].

Al-Zahrani conducted a study Estimation of Natural Radioactivity in Local and Imported Polished Granite Used as Building Materials in Saudi Arabia [25].

The study aimed to determine the levels of natural radionuclides (226Ra, 232Th, and 40K) in different granite materials used in Saudi Arabia and to evaluate the radiological risks associated with their use. The researcher analyzed 24 granite samples—both local and imported—using gamma-ray spectroscopy with a high-purity germanium detector to measure activity concentrations and calculate radiation hazard indices. The results showed that radionuclide concentrations varied by sample, with average values of 28.82 Bq/kg for 226Ra, 34.83 Bq/kg for 232Th, and 665.08 Bq/kg for 40K. Most samples were found to be within international safety limits, and the radiological hazard indices demonstrated that the majority of these granite types are safe for interior building use. Only a few samples exceeded certain limits and were recommended for exterior use [31].

Al-Zahrani and Al-Taher conducted a study titled Natural Radioactivity Levels and Elemental Analysis of Cement by Gamma-Ray Spectrometer to analyze the natural radioactivity and elemental composition of cement using gamma-ray spectroscopy and neutron activation analysis [36]. The results showed that radionuclide concentrations were low and safe, and the elemental composition met industrial quality standards for construction materials in Saudi Arabia. Al-Hamarneh conducted a study on the radioactivity of marble, granite, and ceramic tiles in Riyadh using HPGe detectors to assess radiological hazards. Results showed that Marble is the lowest; granite is the highest in Ra-226 and K-40; ceramic is the highest in Th-232 [23].

All hazard indices below international limits [23].

Alkhomashi et al. (2017) studied the Assessment of radioactivity and trace elements of cement produced in Saudi Arabia [37].

Analysis of cement from nine Saudi factories using gamma spectrometry and ICP-MS was used to measure the radionuclides and trace elements. Results indicated that Ra-226, Th-232, and K-40 levels were below global limits; trace elements were normal except slightly elevated chromium values. Challan and Labib investigated the Radiological Assessment of Exposure Doses and RadonExhalation Rates of Various Building Materials Available in Saudi Arabia [38].

The aim was to measure uranium, radium, and radon concentrations using the sealed-cup technique and CR-39 detectors, and to calculate radon exhalation rates and the annual effective dose (AED). The annual effective dose ranged from 1.07 to 8.07 mSv/y. Most samples met international safety limits and were deemed safe for use as building materials. Al-Sewaidan studied the Natural Radioactivity: Measurements and Dose Rate Assessment of Selected Ceramic and Cement Materials Used in Riyadh, Saudi Arabia [39].

The research aimed to analyze the activity concentrations of naturally occurring radionuclides such as (Ra-226, Th-232, and K-40), and to calculate radiological hazard indices, including.

radium equivalent, external hazard index, absorbed dose rate, and the annual effective dose. Results showed that most ceramic and cement samples were within internationally recommended limits. Some ceramic samples slightly exceeded the radium equivalent value of 370 Bq/kg and the external hazard index limit of 1, while all cement samples were considered safe for use. Alghamdi and Almugren conducted a study, Assessment of the Chemical Compositions and Natural Radioactivity in Ceramic Tiles Used in Some Saudi Arabian Buildings, to identify the heavy metals and natural radioactivity. Results: 21 detected elements) [40].

Ra-226, Th-232, and K-40 levels were within safety limits. No harmful organic or phosphate materials were found. Jemii conducted a study titled Screening Level of Gross Alpha and Beta Activities in Building Materials aimed to screen the gross alpha and gross beta activity of some building materials commercialized in Saudi Arabia by using a gas flow proportional counter [41].

They found that the gross alpha activity ranged between 0.21 and 8.27Bq/kg with an average activity of about 1.96Bq/kg, while the gross beta activity ranged between 6.47 and 276.47Bq/kg with an average activity of about 65.27Bq/kg. The obtained gross alpha and beta activity values were within the worldwide range, and no noteworthy activity was found to draw attention, which showed that these building materials and their origin regions do not pose radiation worries. Fallatah and Khattab conducted a study titled Evaluation of Environmental Radioactivity and Hazard Impacts of Saudi Arabia Granitic Rocks Used as Building Materials. They studied twenty-four granitic rock

samples collected from the Hai'l area in Saudi Arabia, where these samples were used as building material [42].

Gamma spectrometry was used to measure the amounts of ^{238}U , ^{232}Th , ^{226}Ra , and ^{40}K in the collected granitic rock samples and to calculate some environmental hazard parameters, such as radium equivalent (Raeq), external and internal hazard indexes (Hex and Hin). And found that the collected granitic samples are damaging and require additional attenuation if used as building materials. Alrowaili conducted a study titled Nature of radon, radium, exhalation and uranium concentration from construction materials used in Al Jouf city, Saudi Arabia aimed to study seven group samples used as building materials in the Saudi Arabian market in Al Jouf city in terms of their radon concentration, exhalation rate, radium activity, as well as the risk of death due to cancer (Excess Lifetime Cancer Risk). Radon levels were measured using Solid State Nuclear Track Detectors (SSNTDs) CR-39 and found that these values in Soil, Cement, Gypsum, and Ceramics were below the allowed limit of exposure to radon for humans, set at 200 Bq. M³, while in the cases of Marble, Bricks and Gravels, higher values than the allowed limit [43].

On the other hand, the results for Annual Effective Dose were higher than the global average. From a health hazard viewpoint, the results showed that the samples under review are safe and are not life-threatening. Shabaan et al. conducted a study titled Evaluation of the radiation emission of radon gas from various building materials, aimed at determining radon levels in different building materials sourced from the Jazan region of Saudi Arabia, using a CR-39 solid-state detector, and found that the average radon concentration for all building materials was 291 Bq/m³ [44].

Granite exhibited the highest radon concentration, with an average of 506 Bq/m³. Also, Granite recorded the highest radiation dose value, averaging 10.71 $\mu\text{Sv/yr}$. They also measured the uranium levels and found them to be within the safe limit. Omer et al conducted a study titled Measurements of Natural Radioactivity from Building Materials in the Rabigh Markets Area, Kingdom of Saudi Arabia. They studied a total of 15 samples of natural and manufactured materials used as building materials in the Rabigh Area by using gamma spectrometry equipment [45].

The activity concentrations have been determined for ^{232}Th , radium ^{226}Ra , ^{212}Pb , and ^{214}Pb , as well as ^{214}Bi , ^{228}Ac , and ^{208}Tl , and ^{40}K in each sample and found that most samples from each group had naturally occurring ^{40}K and radionuclides from the ^{238}U and ^{232}Th decay series. They found that most of the activity levels, including. ^{40}K , are safe for construction. However, samples with higher ^{226}Ra levels, such as the Cement Arab Cement Company sample, approach the exemption threshold of 1000 Bq/kg, while the Terlock Sand sample from Tipah Al-Khair Cement Products Factory had a particularly high ^{212}Pb concentration (378 ± 4.70

BBQ/kg). Heikal et al. conducted a study titled Radiation Assessment and Geochemical Characteristics of ^{238}U , ^{226}Ra , ^{232}Th , and ^{40}K of Selected Specialized Granitic Occurrences, Saudi Arabia, Arabian Shield [46].

They studied the radiological and geochemical characterization of naturally occurring radionuclides, specifically. ^{238}U , ^{226}Ra , ^{232}Th , and ^{40}K , within three strategically selected granitic prospects, namely, J. Tawlah albite granite (TW), J. Hamra (HM), and J. Abu Al Dod alkali feldspar syenite and granites (AD). And found that the radioactivity levels of the investigated granitic stocks measured average values demonstrate significant variability across the TW, HM, and AD stocks. ^{226}Ra levels are recorded at 172.4 (SD = 34.6), 75.62 (SD = 25.9), and 198.4 (SD = 139.5) Bq/kg. For ^{232}Th , the concentrations are markedly elevated in TW at 5453.8 (SD = 2182.9) Bq/kg, compared to 77.16 (SD = 27.02) and 160.2 (SD = 103.8) Bq/kg in HM and AD granitic stocks, respectively. Meanwhile, ^{40}K levels are reported at 1670 (SD = 535.9), 2846.2 (SD = 249.9), and 3225 (SD = 222.3) Bq/kg for TW, HM, and AD granitic plutons, respectively. These values exceed the average global background levels, indicating an anomalous enrichment of the studied granitic occurrences. Salama et al. conducted a study titled Marble and granite as natural radiation sources: Risk assessment and their impact on health and the environment [47].

They studied the natural radioactivity and associated radiological hazards in marble and granite widely used in Al-Jouf, Saudi Arabia. Where twenty-eight marble and thirty granite samples were systematically collected and analyzed by gamma-ray spectrometry using a high-purity germanium (HPGe) detector. The mean annual indoor effective dose equivalent (AEDE) was below the public exposure limit of 1 mSv/y for both. Most marble samples were deemed radiologically safe for construction, while certain granite varieties may require additional attenuation. All the previous results were tabulated and drawn in Tables 1, 2, 3, 4, 5 & 6 and Figs 1a & b, 2a & b, 3a & b, 4a & b, 5a & b and 6a & b. a CR-39 solid-state detector, and found that the average radon concentration for all building materials was 291 Bq/m³ [44].

Granite exhibited the highest radon concentration, with an average of 506 Bq/m³. Also, Granite recorded the highest radiation dose value, averaging 10.71 $\mu\text{Sv/yr}$. They also measured the uranium levels and found them to be within the safe limit. Omer et al conducted a study titled Measurements of Natural Radioactivity from Building Materials in the Rabigh Markets Area, Kingdom of Saudi Arabia. They studied a total of 15 samples of natural and manufactured materials used as building materials in the Rabigh Area by using gamma spectrometry equipment [45]. The activity concentrations have been determined for ^{232}Th , radium ^{226}Ra , ^{212}Pb , and ^{214}Pb , as well as ^{214}Bi , ^{228}Ac , and ^{208}Tl , and ^{40}K in each sample and found that most samples from each group had naturally occurring ^{40}K and radionuclides from the ^{238}U and

^{232}Th decay series. They found that most of the activity levels, including, ^{40}K , are safe for construction. However, samples with higher ^{226}Ra levels, such as the Cement Arab Cement Company sample, approach the exemption threshold of 1000 Bq/kg, while the Terlock Sand sample from Tipah Al-Khair Cement Products Factory had a particularly high ^{212}Pb concentration (378 ± 4.70 BBQ/kg). Heikal et al. conducted a study titled Radiation Assessment and Geochemical Characteristics of ^{238}U , ^{226}Ra , ^{232}Th , and ^{40}K of Selected Specialized Granitic Occurrences, Saudi Arabia, Arabian Shield [46].

They studied the radiological and geochemical characterization of naturally occurring radionuclides, specifically, ^{238}U , ^{226}Ra , ^{232}Th , and ^{40}K , within three strategically selected granitic prospects, namely, J. Tawlah albite granite (TW), J. Hamra (HM), and J. Abu Al Dod alkali feldspar syenite and granites (AD). And found that the radioactivity levels of the investigated granitic stocks measured average values demonstrate significant variability across the TW, HM, and AD stocks. ^{226}Ra levels are recorded at 172.4 (SD = 34.6), 75.62 (SD = 25.9), and 198.4 (SD = 139.5) Bq/kg. For ^{232}Th , the concentrations are markedly elevated in TW at 5453.8 (SD = 2182.9) Bq/kg, compared to 77.16 (SD = 27.02) and 160.2 (SD = 103.8) Bq/kg in HM and AD granitic stocks, respectively. Meanwhile, ^{40}K levels are reported at 1670 (SD = 535.9), 2846.2 (SD = 249.9), and 3225 (SD = 222.3) Bq/kg for TW, HM, and AD granitic plutons, respectively. These values exceed the average global background levels, indicating an anomalous enrichment of the studied granitic occurrences. Salama et al. conducted a study titled Marble and granite as natural radiation sources: Risk assessment and their impact on health and the environment [47].

They studied the natural radioactivity and associated radiological hazards in marble and granite widely used in Al-Jouf, Saudi Arabia. Where twenty-eight marble and thirty granite samples were systematically collected and analyzed by gamma-ray spectrometry using a high-purity germanium (HPGe) detector. The mean annual indoor effective dose equivalent (AEDE) was below the public exposure limit of 1 mSv/y for both. Most marble samples were deemed radiologically safe for construction, while certain granite varieties may require additional attenuation. All the previous results were tabulated and drawn in Tables 1, 2, 3, 4, 5 & 6 and Figs 1a & b, 2a & b, 3a & b, 4a & b, 5a & b and 6a & b.

Table (1) summarizes the natural activity concentrations values for the isotopes. ^{226}Ra , ^{232}Th , and ^{40}K , in Sand samples as reported in previous studies conducted in various regions of Saudi Arabia. The table also lists the internal and external radiological hazard indices (Hin and Hex) associated with these isotopes (Fig. 1a & b). Some values were taken directly from the original studies, while others were calculated in the present review based on the published radioactivity values for each study. The highest recorded Hin value for Sand was 1.83, while the lowest

value was 0.002. Similarly, the Hex values ranged from a maximum of 1.83 to a minimum of 0.002.

Table (2) summarizes the natural activity concentration values for the isotopes. ^{226}Ra , ^{232}Th , and ^{40}K , in gypsum samples as reported in previous studies conducted in various regions of Saudi Arabia. The table also includes the values of the internal and external radiological hazard index (Hin and Hex) associated with these isotopes (Fig. 2a & b). The highest recorded Hin value for gypsum was 0.42244, while the lowest value was 0.01. Similarly, the Hex values ranged from a maximum of 0.32258 to a minimum of 0.00.

Table (3) summarizes the natural activity concentration values for the isotopes. ^{226}Ra , ^{232}Th , ^{234}Th and ^{40}K , in cement samples as reported in previous studies conducted in various regions of Saudi Arabia. The table also includes the values of the internal and external radiological hazard index (Hin and Hex) associated with these isotopes (Fig. 3a & b). The highest recorded Hin value for cement was 21.206, while the lowest value was 0.013. Similarly, the Hex values ranged from a maximum of 11.137 to a minimum of 0.01.

Table (4) summarizes the natural activity concentration values for the isotopes. ^{226}Ra , ^{232}Th and ^{40}K , in marble samples as reported in previous studies conducted in various regions of Saudi Arabia. The table also includes the values of the internal and external radiological hazard indices (Hin and Hex) associated with these isotopes (Fig. 4a & b). The highest recorded Hin value for marble was 1.0931, while the lowest value was 0.007. Similarly, the Hex values ranged from 0.483 to 0.012.

Table (5) summarizes the natural activity concentration values of radionuclides in granite samples, as reported in previous studies conducted in various regions of Saudi Arabia. The table also presents the corresponding internal and external radiological hazard indices (Hin and Hex) associated with these radionuclides (Fig. 5a & b). The highest recorded internal hazard index (Hin) for granite was 22.34, whereas the lowest value was 0.35. Similarly, the external hazard index (Hex) values ranged from a maximum of 21.9 to a minimum of 0.17.

Table (6) summarizes the natural activity concentration values for the isotopes. ^{226}Ra , ^{232}Th and ^{40}K , in ceramic samples as reported in previous studies conducted in various regions of Saudi Arabia. The table also includes the values of the internal and external radiological hazard indices (Hin and Hex) associated with these isotopes (Fig. 6a & b). The highest recorded Hin value for ceramic was 1.049, while the lowest value was 0.41. Similarly, the Hex values ranged from a maximum of 0.8 to a minimum of 0.34.

Table 1. ^{226}Ra , ^{232}Th , ^{234}Th , ^{40}K and Ra_{eq} activity concentration (Bq/kg), and the calculated H_{ex} and H_{in} . The absorbed dose rate (nGy h^{-1}) and the indoor/outdoor annual effective dose (AED) (mSv/y) for sand samples in Saudi Arabia measured over yea.

Year	Title of research	Sample	Activity concentration (Bq/kg)					H_{ex} Index	H_{in} index	Absorbed dose rate (nGy h^{-1})	Annual effective dose AED (mSv/y)	
			^{226}Ra	^{232}Th	^{234}Th	^{40}K	Ra_{eq}				in	out
2012	Assessment of Natural Radioactivity Levels and Associated Radiation Hazards of Building Materials Used in Saudi Arabia [48]	Saudi-Jeddah	22.6 ± 0.5	20.7 ± 0.6	--	171.9 ± 2.8	65.4	0.17674	0.25	30.2	0.148	0.037
2012	Assessment of Natural Radioactivity Levels and Radiation Hazards for Building Materials Used in Qassim Area, Saudi Arabia [30]	Saudi- Al-Qassim	12.3 ± 2.3	24.2 ± 1.3	--	195 ± 4	59.88	0.16722	0.20046	28.4	0.139	0.035
2012	Measurements of the natural radioactivity in building materials (raw and manufactured), other than granites in KSA [24]	Teyma sand	5.6 ± 0.6	7.6 ± 0.0	--	1.9 ± 0.0	16.6	0.04	0.06	7.3	0.036	0.009
		Bahra sand	4.9 ± 0.6	5.4 ± 0.4	--	638.2 ± 0.32	61.8	0.17	0.18	32.1	0.157	0.039
		Kumreyyeh sand	3.1 ± 0.3	2.6 ± 0.0	--	8.9 ± 0.0	7.5	0.02	0.03	3.4	0.017	0.004
2015	Determination of Natural Radioactivity and Associated Radiological Risk in Building Materials Used in Tabuk Area, Saudi Arabia [26]	Saudi-Tabuk	17.51	24.78	--	289.77	75.2	0.20324	0.25056	35.1	0.172	0.043
2025	Measurements of Natural Radioactivity from Building Materials in the Rabigh Markets Area, Kingdom of Saudi Arabia. [45]	Sand- Salman Al-Khabout	--	--	--	8.61 ± 0.34	-	0.002^1	0.002^1	-	-	-
		Sand- Tipah Al-Khair	--	--	471.16 ± 6.09	73.12 ± 1.14	-	1.83^1	1.83^1	-	-	-
		Interlock Sand- Tipah Al-Khair	--	--	435.46 ± 5.54	53.93 ± 0.93	-	1.69^1	1.69^1	-	-	-
		White sand- Tipah Al-Khair	--	--	394.12 ± 4.92	24.50 ± 0.45	-	1.53^1	1.53^1	-	-	-
		White sand- Marice Salman	--	--	373.67 ± 4.86	271.02 ± 4.42	-	1.5^1	1.5^1	-	-	-

¹ H_{ex} and H_{in} were calculated without ^{226}Ra measurements, and ^{232}Th is represented by ^{208}Tl in the research

Table 2. ^{226}Ra , ^{232}Th , ^{40}K and Ra_{eq} activity concentration (Bq/kg), and the calculated H_{ex} and H_{in} , the absorbed dose rate (nGy h^{-1}), and the indoor/outdoor annual effective dose (AED) (mSv/y) for gypsum samples in Saudi Arabia measured over years

Year	Title of research	Sample	Activity concentration (Bq/kg)				H_{ex} Index	H_{in} Index	Absorbed dose rate (nGy h^{-1})	Annual effective dose AED (mSv/y)	
			^{226}Ra	^{232}Th	^{40}K	Ra_{eq}				in	out
2012	Assessment of Natural Radioactivity Levels and Associated Radiation Hazards for Building Materials used in Qassim Area, Saudi Arabia [48]	Saudi-Qassim	33.28 $\pm$ 4.7	47.2 $\pm$ 2.8	88 $\pm$ 4.4	122.7 ₁	0.24	0.38	54.27	0.38	0.10
2012	Assessment of Natural Radioactivity Levels and Associated Radiation Hazards of Building Materials used in Saudi Arabia [50]	Saudi-Jeddah	22.34 $\pm$ 0.7	8.6 $\pm$ 0.3	224.9 $\pm$ 3.2	51.9	0.14 ₃	0.20	48.01	0.34	0.08
2012	Measurements of the Natural Radioactivity in Building Materials (Raw and Manufactured) Other Than Granites in KSA [24]	Saudi-Yanbu	0.7 $\pm$ 0.1	0.4 $\pm$ 0.1	6.3 $\pm$ 0.5	1.7	0.00	0.01	0.8	0.00561	0.0014
		Saudi-Kumryy	7.2 $\pm$ 1.8	0.2 $\pm$ 0.1	47.3 $\pm$ 0.0	11.1	0.03	0.05	5.2	0.04	0.009
2015	Determination of Natural Radioactivity and Associated Radiological Risk in Building Materials Used in Tabuk Area, Saudi Arabia [26]	Saudi-Tabuk	36.95	52.23	101.29	119.4 ₄	0.32	0.42	99.5502	0.69812	0.17
2018	Radiological assessment of exposure doses and radon exhalation rates of building materials in Saudi Arabia [49]	Saudi-Soft Gypsum (SG)	2.02	--	--	--	--	--	--	--	--
		Saudi-Gypsum (GM)	0.61	--	--	--	--	--	--	--	--
2023	Nature of radon, radium, exhalation and uranium concentration from construction materials used in Al-Jouf city, Saudi Arabia [41]	Saudi-Aljouf	73.9 $\pm$ 6.9 ₉	--	--	--	--	--	--	--	--
2025	Evaluation of the radiation emission of radon gas from various building materials [44]	Saudi-Jazan	9.14	--	--	--	--	--	--	--	--

Table 3. ^{226}Ra , ^{232}Th , ^{234}Th , ^{40}K and Ra_{eq} activity concentrations (Bq /kg), and the calculated H_{ex} and H_{in} , the absorbed dose rate (nGyh^{-1}), and the indoor/outdoor annual effective dose (AED) (mSv/y) for cement samples in Saudi Arabia measured over years.

Year	Title of research	Sample	Activity concentration (Bq /kg)					H_{ex} Index	H_{in} Index	Absorbed dose rate (nGyh^{-1})	Annual effective dose (AED) (mSv/y)	
			^{226}Ra	^{232}Th	^{234}Th	^{40}K	Ra_{eq}				in	out
2009	Radioactivity level measurement of some cement samples [28]	Gasseem-Saudi Arabia (Al-Qassim)	3593 $\pm$ 20.56	47.81 $\pm$ 22.56	--	2621 $\pm$ 7.40	3785.38	10.440	20.151	1798.15	8.82	2.21
		Medinaa-Saudi Arabia (Al-Madinah)	3725.45 $\pm$ 14.93	124.31 $\pm$ 14.93	--	2831.07 $\pm$ 9.27	4121.29	11.137	21.206	1769.91	8.68	2.18
		Mogaum Yamamh-Saudi Arabia	626.85 $\pm$ 20.77	31.87 $\pm$ 20.69	--	3145.6 $\pm$ 16.92	864.42	2.471	4.166	329.80	1.62	0.40
2012	Assessment of Natural Radioactivity Levels and Radiation Hazards for Building Materials Used in Qassim Area, Saudi Arabia [30]	Qassim area-Saudi Arabia	38.4 $\pm$ 3.8	45.3 $\pm$ 1.2	--	86 $\pm$ 4	108.23	0.19	0.401	48.94	0.24	0.06
2012	Assessment of Radioactivity and the Exposure Doses from Local Cement Types in Saudi Arabia [31]	Al Jouf	35 $\pm$ 1.2	31 $\pm$ 1.4	--	505 $\pm$ 1.7	117 $\pm$ 3.3	0.157	0.409	57 $\pm$ 1.5	0.279	0.07
		Yanbo	30 $\pm$ 1.3	28 $\pm$ 1.1	--	120 $\pm$ 2.1	83 $\pm$ 2.9	0.163	0.297	39 $\pm$ 1.4	0.189	0.05
		Al Qassim	33 $\pm$ 1.1	34 $\pm$ 1.6	--	170 $\pm$ 1.3	94 $\pm$ 3.5	0.127	0.342	45 $\pm$ 1.7	0.219	0.06
		Tabuk	29 $\pm$ 1.2	26 $\pm$ 1.1	--	434 $\pm$ 2.1	100 $\pm$ 3.0	0.134	0.347	48 $\pm$ 1.4	0.237	0.06
		Jeddah	37 $\pm$ 1.5	29 $\pm$ 1.3	--	168 $\pm$ 2.1	92 $\pm$ 3.6	0.122	0.347	42 $\pm$ 1.7	0.208	0.05
		Alarabia	38 $\pm$ 1.4	30 $\pm$ 1.2	--	313 $\pm$ 2.2	104 $\pm$ 3.3	0.139	0.383	49 $\pm$ 1.5	0.192	0.06
2012	Measurements of the natural radioactivity in building materials (raw and manufactured), other than granites in KSA [24]	white cement Egypt	11.2 $\pm$ 1.0	6.0 $\pm$ 0.0	--	2.2 $\pm$ 0.0	19.9	0.05	0.08	8.9	0.04	0.01
		Yanbu cement	17.8 $\pm$ 2.1	4.9 $\pm$ 0.0	--	165.2 $\pm$ 0.06	37.5	0.10	0.15	17.8	0.09	0.02
2014	Environmental impact of some cement manufacturing plants in Saudi Arabia [32]	Cement Plant A (Makkah Region)	65.7 $\pm$ 0.5	8.7 $\pm$ 0.2	23.0 $\pm$ 1.1	53.1 $\pm$ 1.6	88.96	0.222	0.340	39.1	0.19	0.05
		Cement Plant B (Makkah Region)	5.0 $\pm$ 0.4	6.1 $\pm$ 0.5	0.31 $\pm$ 0.04	135 $\pm$ 2.0	16.36	0.065	0.079	7.81	0.04	0.01
		Cement depository C (Makkah city): D sample	11.4 $\pm$ 0.2	11.2 $\pm$ 0.2	6.6 $\pm$ 0.6	231 $\pm$ 3.6	38.11	0.122	0.153	20.62	0.10	0.03
		Cement depository C (Makkah city): E	26.5 $\pm$ 0.3	7.7 $\pm$ 0.2	9.0 $\pm$ 0.5	123 $\pm$ 2.3	40.92	0.127	0.199	18.96	0.09	0.02

2015	Determination of Natural Radioactivity and Associated Radiological Risk in Building Materials Used in Tabuk Area, Saudi Arabia [26]	Tabuk Area	42.6	52.9	--	97.7	125.83 ¹	0.340 ¹	0.455 ¹	60.77	0.518 ¹	0.074 ¹
2015	Evaluation of natural radioactivity and the associated radiation hazards in local cement used in Saudi Arabia [34]	Local Gray Cement	32.21	23.30	--	177.32	79.12 ¹	0.214 ¹	0.301 ¹	39.51	0.341 ¹	0.05
		Local White Cement	23.90	25.60	--	125.64	76.72 ¹	0.210 ¹	0.302 ¹	30.21	0.293 ¹	0.03
2017	Assessment of radioactivity and trace elements of cement produced in Saudi Arabia [37]	Al-Jawf	25.11± 1.33	25.37± 1.75	--	152.10± 8.79	73.10	0.20	0.265	33.70	0.17	0.04
		Al-Madinah	15.83± 0.28	27.52± 0.68	--	103.08± 2.96	63.12	0.17	0.213	28.70	0.14	0.03
		Al-Qassim	18.14± 0.95	15.41± 0.81	--	175.80± 9.46	53.71	0.15	0.194	25.28	0.12	0.03
		Ash-Sharqiyah	1.52± 0.45	1.00± 1.49	--	3.11± 2.10	3.19	0.01	0.013	1.45	0.006	0.001
		Ha'il	27.63± 1.24	15.68± 0.85	--	116.53± 6.38	59.03	0.16	0.234	27.36	0.13	0.03
		Riyadh	15.29± 0.79	14.77± 0.79	--	45.06± 2.53	39.88	0.11	0.149	18.12	0.09	0.02
		Saudi-Bahrain	28.69± 1.52	25.83± 1.40	--	132.74± 7.67	75.85	0.20	0.282	34.83	0.16	0.04
		Tabuk	16.56± 0.88	7.95± 0.04	--	183.97± 10.58	42.09	0.11	0.159	20.26	0.10	0.02
		Yanbu	21.58± 1.13	8.31± 0.46	--	120.80± 6.50	42.76	0.12	0.174	20.17	0.10	0.02
2017	Natural Radioactivity Levels and Elemental Analysis of Cement by Gamma-Ray Spectrometer and Neutron Activation Analysis [36]	Local Portland cement	35.60± 4.41	43.17± 2.18	--	82.08± 4.10	103.09	0.22	0.377	51.94	0.25	0.06
		Local White cement	28.53± 3.75	43.46± 2.18	--	67.38± 3.36	95.40	0.18	0.336	42.24	0.21	0.05
2018	Radiological assessment of exposure doses and radon exhalation rates of building materials in Saudi Arabia [49]	Local Gray Cement	2.93	--	--	--	--	--	--	--	--	--
		Local White Cement	1.63	--	--	--	--	--	--	--	--	--
2019	Natural radioactivity measurements and dose rate assessment of selected ceramic and cement types used in Riyadh, Saudi Arabia [39]	Riyadh - Saudi Arabia	21.7	9.8	--	101.6	36.80	0.12	1.176	20.35	0.10	0.02

2023	Nature of radon, radium, exhalation and uranium concentration from construction materials used in Al Jouf city, Saudi Arabia [43]	Al Jouf- Saudi Arabia	67.6 ± 5.6	--	--	--	--	--	--	--	--	--
2025	Measurements of Natural Radioactivity from Building Materials in the Rabigh Markets Area, Kingdom of Saudi Arabia [45]	Rabigh - Arab Cement Company	366.14 ± 3.32	--	423.65 ± 3.63	120.00 ± 1.57	980.56^2	5.97^2	3.64^2	--	--	--

¹ This value represents the calculated average

² ^{232}Th is represented by ^{208}Tl in the research

Table 4. ^{226}Ra , ^{232}Th , ^{234}Th , ^{40}K and Ra_{eq} activity concentrations (Bq/kg), and the calculated H_{ex} and H_{in} , the absorbed dose rate (nGy^{-1}), and the indoor/outdoor annual effective dose (AED) (mSv/y) for marble samples in Saudi Arabia measured over years.

Year	Title of research	sample	Activity concentration (Bq/Kg)					H_{ex} Index	H_{in} Index	Absorbed dose rate (nGy/h)	Annual effective dose AED (mSv/y)	
			Ra_{eq}	^{40}K	^{234}Th	H_{ex} Index	^{226}Ra				in	out
2007	Measurements of natural radioactivity in some kinds of marble and granite used in Riyadh Region [50]	Saudi	$0-32^1$	$0-32^1$	--	$0-897^1$	146.89^1	0.397^1	0.483^1	70.889^1	0.497^1	0.124^1
2012	Assessment of natural radioactivity level and radiation hazards for building materials used in Qassim area, Saudi Arabia [30]	Saudi- Al- Qassim	12.7 ± 3.4	13.2 ± 1.4	--	64 ± 3	39.64	0.0986	0.114	18.17	0.127	0.031
2015	Determination of Natural Radioactivity and Associated Radiological Risk in Building Materials Used in Tabuk Area, Saudi Arabia [26]	Saudi- Tabuk	18.46	17.36	--	77.03	49.21	0.133	0.215	22.226	0.155	0.038
2015	Evaluation of radionuclide concentrations and associated radiological hazard in marble indices and granite used as building materials in Al- Madinah Al- Munawarah [35]	Turkish	5.70 ± 0.30	0.10 ± 0.07	--	0.90 ± 0.20	5.91	0.016	0.031	5.426	0.038	0.0095
		Egyptian	7.30 ± 0.40	0.90 ± 0.09	--	0.96 ± 0.10	8.66	0.023	0.043	7.783	0.055	0.014
		Omani	2.00 ± 0.10	0.31 ± 0.06	--	0.80 ± 0.09	2.504	0.006	0.012	2.245	0.016	0.0039

2017	Radiological hazards for marble, granite and ceramic tiles used in buildings in Riyadh, Saudi Arabia [23]	Saudi-Riyadh	5.8	2.3	--	33.7	11.6	0.031	0.047	10.50	0.073	0.018
2023	Nature of radon, radium, exhalation and uranium concentration from construction materials used in Al Jouf city, Saudi Arabia [43]	Saudi-Al-Jouf	--	--	74.0 ± 4.57	--	--	--	--	--	--	--
2025	Marble and granite as natural radiation sources: Risk assessment and their impact on health and the environment [47]	Saudi-Al-Jouf	14.82 ± 10.63	16.54 ± 8.53	--	78.61 ± 41.64	38	1.0931	0.221	17.57	0.087	0.022
2025	Evaluation of the radiation emission of radon gas from various building materials [44]	Saudi	8.7	--	--	08.0 to 0.39	--	--	--	--	--	--

¹ The radiological hazard indices were calculated using the mean activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K as reported in the abstract only, due to the unavailability of the full text of the study.

Table 5. ^{226}Ra , ^{232}Th , ^{40}K , and Ra_{eq} activity concentration (Bq/kg), and the calculated H_{ex} and H_{in} , the absorbed dose rate (nGyh⁻¹), and the indoor/outdoor annual effective dose (AED) (mSv/y) for granite samples in Saudi Arabia measured over the years.

Year	Title of research	Sample		Activity concentration (Bq/kg),				H _{ex} Index	H _{in} Index	Absorbed dose rate (nGyh ⁻¹)	Annual effective dose AED (mSv/y)	
				²²⁶ Ra	²³² Th	⁴⁰ K	Ra _{eq}				in	out
2007	Measurements of natural radioactivity in some kinds of marble and granite used in Riyadh Region [51]	Saudi-Riyadh		0–147 ²	0–186 ²	0–1532 ²	160.15 ²	0.41 ²	0.48 ²	82.09 ²	0.407 ²	0.1007 ²
2010	Measurements of Natural Radioactivity and The Resulting Radiation Doses from Commercial Granites [29]	Saudi-Jeddah	Spring Green	43.6±0.9	24.9±3.0	1416±9	188.6	0.51	0.63	94.8	0.47	0.1162
			Royal Gold	30.9±2.1	21.6±3.2	1368±9	167.1	0.45	0.54	85.1	0.42	0.1044
			Sweet Gold	55.8±0.7	45.6±2.0	1223±10	215.3	0.58	0.73	105.7	0.56	0.1296
			Saudi Brown	10.2±1.9	4.9±1.3	1806±9	156.3	0.42	0.45	83.5	0.41	0.1024
			Saudi Bianco	11.6±0.6	19.7±0.7	1027±5	119.0	0.32	0.35	61.3	0.30	0.0752
			Saudi Green	19.1±0.4	16.6±1.0	1188±6	134.3	0.36	0.41	69.1	0.34	0.0847
			Najran Brown	17.6±0.4	22.8±0.1	1463±7	162.9	0.44	0.49	84.2	0.41	0.1032
			Saudi Pink	19.7±0.8	14.8±0.9	1378±7	147.0	0.40	0.45	76.2	0.37	0.0935
			Salmon	11.1±0.1	19.1±0.6	1483±7	152.6	0.41	0.44	79.8	0.39	0.0979
			Golden Leaf	24.7±0.7	21.0±0.1	1347±7	158.4	0.43	0.49	81.2	0.40	0.0996

2012	Assessment of Natural Radioactivity Levels and Radiation Hazards for Building Materials Used in Qassim Area, Saudi Arabia [30]	Saudi-Qassim	23±1.6	30.0±0.4	340±6.7	61.89	0.17	0.311	25.08	0.0240	0.0308
2012	Assessment of Natural Radioactivity Levels and Associated Radiation Hazards of Building Materials used in Saudi Arabia [48]	Saudi-Jeddah	31.5±0.8	27.2±0.7	534.7±3.6	111.6	0.306	0.39	12.40	0.06	0.0152
2015	Evaluation of radionuclide concentrations and associated radiological hazard in marble indices and granite used as building materials in Al-Madinah Al-Munawarah [35]	Saudi- Al-Madinah Al-Munawarah	56.4 ± 3.0	48.6 ± 2.5	1492.8 ± 79.7	244.19	0.659	0.791	226.176	1.109	0.2774
2015	Measurements of Natural Radioactivity of Industrial Raw Materials from the West of Saudi Arabia (Arabian Shield) [31]	Saudi-Alquryyah	80.85 ± 0.01	68.50 ± 0.03	1376.69 ± 0.1	284.8142	0.769217	0.987738	135.173	0.165898	0.1658
2017	Estimation of natural radioactivity in local and imported polished granite used as building materials in Saudi Arabia [25]	Saudi-Jeddah	28.82	34.83	665.08	129.84	0.351	0.914	62.60	0.307	0.0768
2017	Radiological hazards for marble, granite and ceramic tiles used in buildings in Riyadh, Saudi Arabia [23]	Riyadh-SA	54.5	43.4	677.7	168.7	0.458	0.605	152.98	0.75	0.1876
2018	Radiological assessment of exposure doses and radon exhalation rates of building materials in Saudi Arabia [49]	Saudi	4.64	----	----	----	----	----	----	8.07	3.03
2023	Evaluation of Environmental Radioactivity and Hazard Impacts Saudi Arabia Granitic Rocks Used as Building Materials [42]	Saudi-Hai'l	102.5	486.8	726	844.46	2.31	2.58	651.03	0.8	0.7984

2024	Evaluation of the radiation emission of radon gas from various building materials [44]	Saudi-Jazan	21.19 ¹	----	----	----	----	----	----	10.7	----
2025	Radiation Assessment and Geochemical Characteristics of ²³⁸ U, ²²⁶ Ra, ²³² Th, and ⁴⁰ K of Selected Specialized Granitic Occurrences, Saudi Arabia, Arabian Shield [46]	Saudi Tawlah	172.4	5453.8	1670	8091.9	21.9	22.34	9706.3	30.9	4.2
		Saudi Hamra alkali	75.62	77.16	2846.2	404.8	1.1	1.3	585.7	1.9	0.24
		Saudi Abu al Dod	198.4	160.2	3225	675.3	1.8	2.4	940.1	3.1	0.4
2025	Marble and granite as natural radiation sources: Risk assessment and their impact on health and the environment [47]	Saudi Arabia-(Aljouf)	28.58	37.04	960.48	151.14	0.41	0.48	74	0.363	0.091

¹ The values represent the average

²The radiological hazard indices were calculated using the mean activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K as reported in the abstract only, due to the unavailability of the full text of the study.

Table 6. ²²⁶Ra, ²³²Th, ⁴⁰K and Ra_{eq} activity concentration (Bq/kg), and the calculated H_{ex} and H_{in}, the absorbed dose rate (nGy h⁻¹), and the indoor/outdoor annual effective dose (AED) (mSv/y) for ceramic samples in Saudi Arabia measured over years.

Year	Title of research	Sample	Activity concentration (Bq/kg)				H _{ex} Index	H _{in} Index	Absorbed dose rate (nGy h ⁻¹)	Annual effective dose AED (mSv/y)	
			²²⁶ Ra	²³² Th	⁴⁰ K	Ra _{eq}				in	out
2012	Measurements of the natural radioactivity in building materials (raw and manufactured), other than granites in KSA [24]	China	26.0 ± 2.7	34.9 ± 0.2	660.2 ± 0.02	126.8	0.34	0.41	62.1	0.30	0.0762
		Saudi	36.8 ± 4.1	30.9 ± 0.4	734.1 ± 0.0	137.5	0.37	0.47	67.2	0.33	0.0824
2017	Radiological hazards for marble, granite and ceramic tiles used in buildings in Riyadh, Saudi Arabia [23]	Saudi-Riyadh	47.18	80.7	590.2	207.9	0.562	0.689	179.40	0.88	0.2201

2018	Radiological assessment of exposure doses and radon exhalation rates of building materials in Saudi Arabia [49]	Saudi	2.79	---	---	---	---	---	---	---	---
2019	Natural radioactivity measurements and dose rate assessment of selected ceramic and cement types used in Riyadh, Saudi Arabia [39]	Saudi-Riyadh	89.0	105.5	772.9	299.4	0.8	1.049	138.8	0.68	0.1703
2019	Assessment of the chemical compositions and natural radioactivity in ceramic tiles used in some Saudi Arabian buildings [40]	Saudi-Riyadh	85±6	64±5	466±36	212	0.57	0.80	186	0.91	0.2282
2023	Nature of radon, radium, exhalation and uranium concentration from construction materials used in Al Jouf city, Saudi Arabia [43]	Saudi- Al-Jouf	47.8 ± 4.20	---	---	---	---	---	---	---	---
2025	Evaluation of the radiation emission of radon gas from various building materials [44]	Saudi-Jazan	8.9	---	---	---	---	---	---	---	---

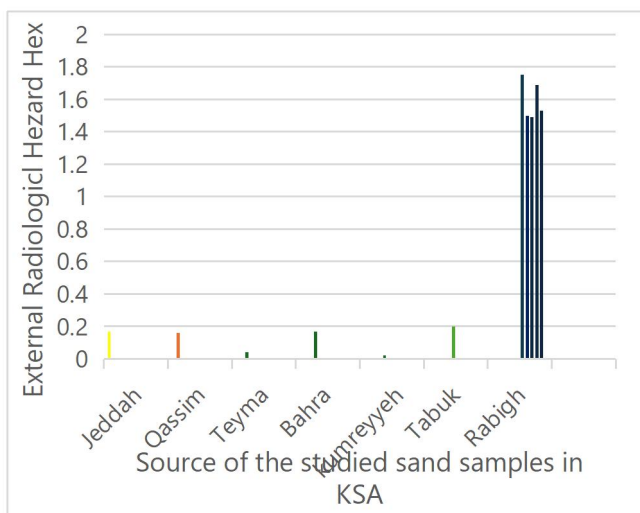


Fig.1. (a): External Hazard Index (Hex) values for sand samples collected from different cities in Saudi Arabia [24,26, 30,45,48] .

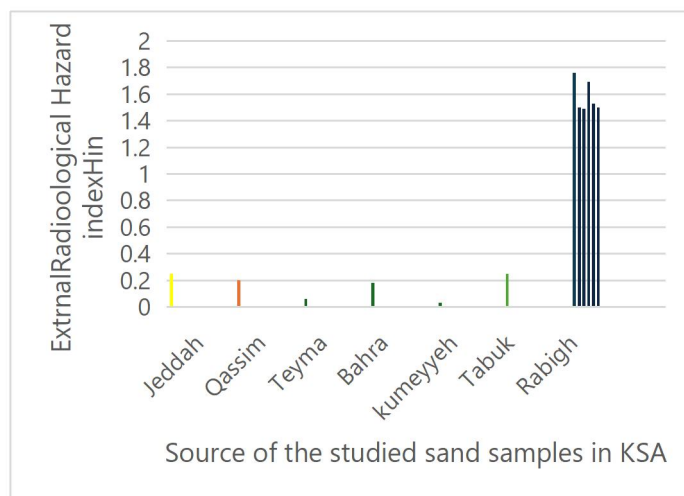


Fig. 1. (b): Internal Hazard Index (Hin) values for sand samples collected from different cities in Saudi Arabia [24,26, 30,45,48]

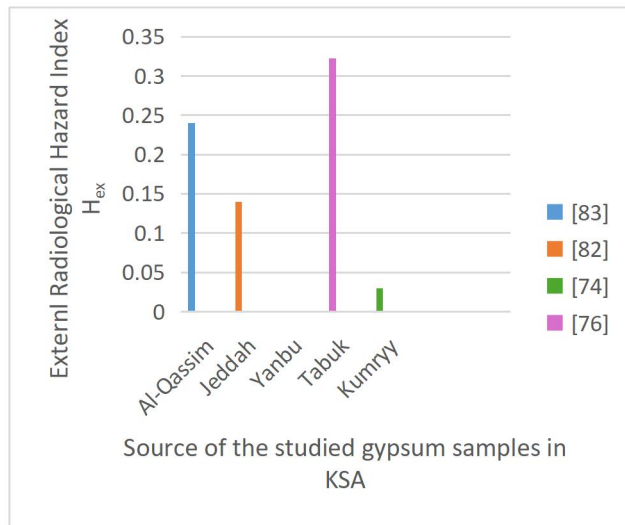


Fig.2. (a): External Hazard Index (H_{ex}) values for gypsum samples collected from different cities in Saudi Arabia. [24,26, 30,45,48].

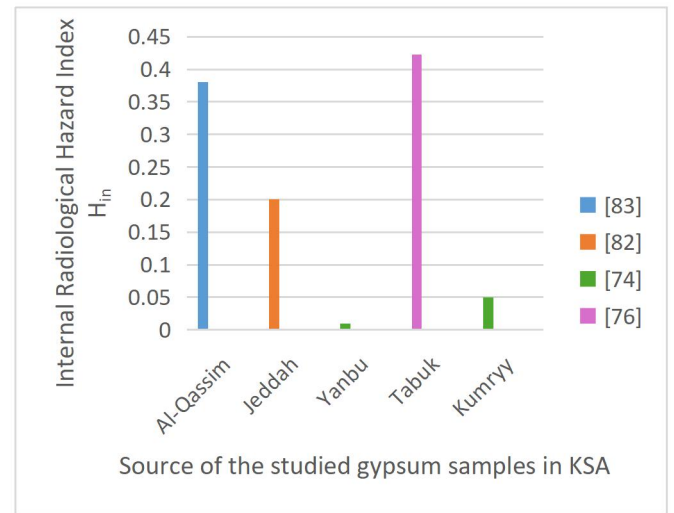


Fig.2. (b): Internal Hazard Index (H_{in}) values for gypsum samples collected from different cities in Saudi Arabia. [24,26, 30,45,48]

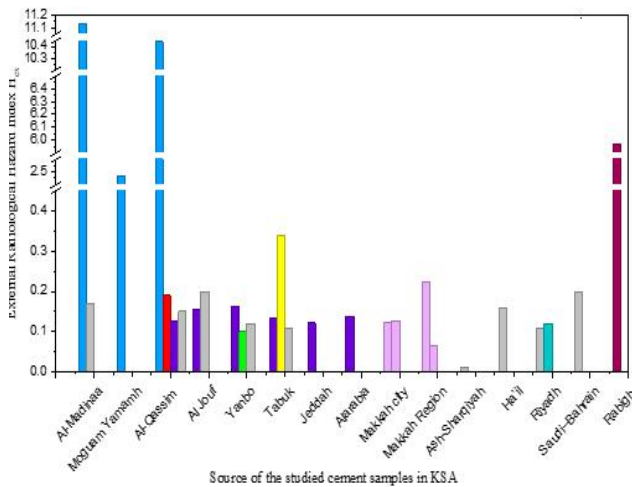


Fig. 3. (a): External Hazard Index (H_{ex}) values for cement samples collected from different cities in Saudi Arabia. Some high values were truncated on the y-axis to improve the visibility of lower values.

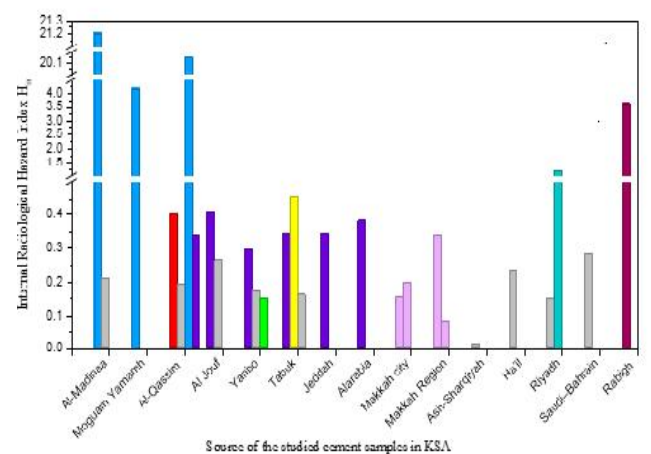


Fig.3 (b): Internal Hazard Index (H_{in}) values for cement samples collected from different cities in Saudi Arabia. Some high values were truncated on the y-axis to improve the visibility of lower values [24,26,28, 30, 31, 32, 37, 39,45].

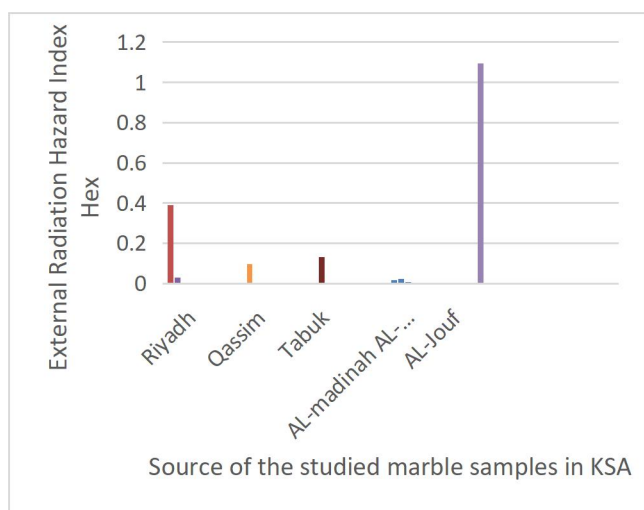


Fig.4. (a): External Hazard Index (Hex) values for marble samples collected from different cities in Saudi Arabia.

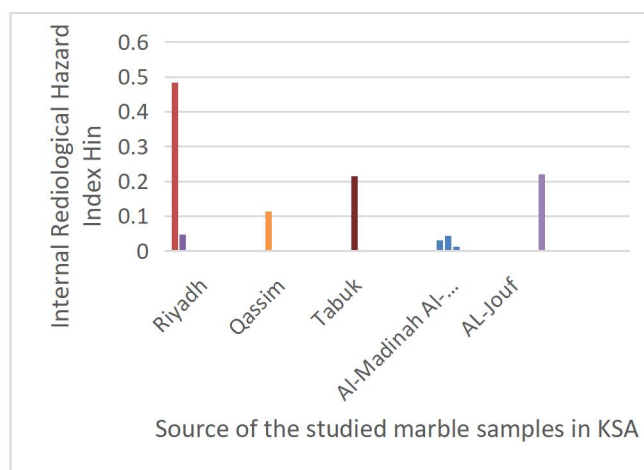


Fig. 4. (b): Internal Hazard Index (Hin) values for marble samples collected from different cities in Saudi Arabia [23,26,30,35,47,50]

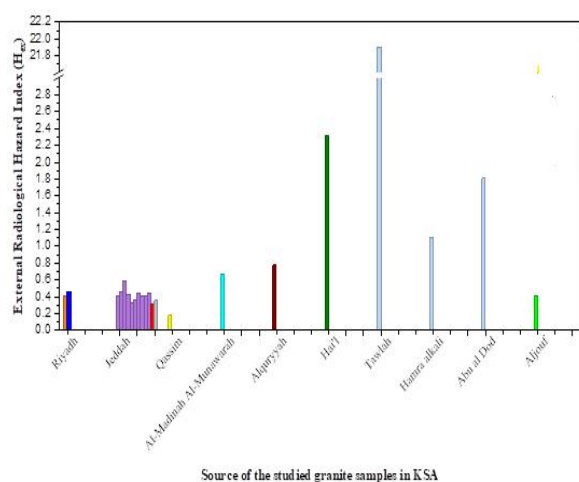


Fig. 5. (a): External Hazard Index (Hex) values for granite samples collected from different cities in Saudi Arabia. Some high values were truncated on the y-axis to improve the visibility of lower values.

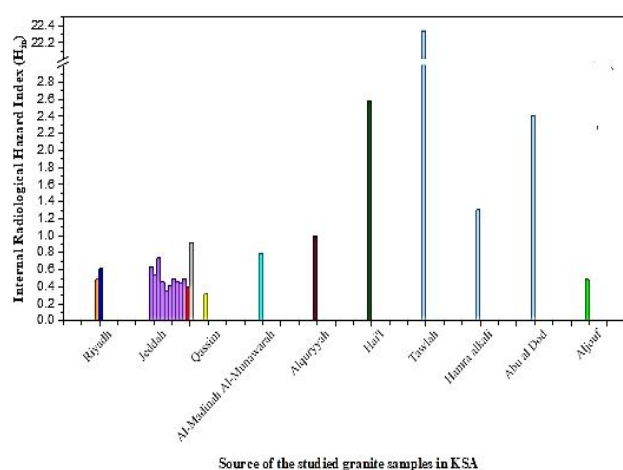


Fig. 5. (b): Internal Hazard Index (Hin) values for granite samples collected from different cities in Saudi Arabia. Some high values were truncated on the y-axis to improve the visibility of lower values [23,25,29,30,33,35,42,46,47,48,51]

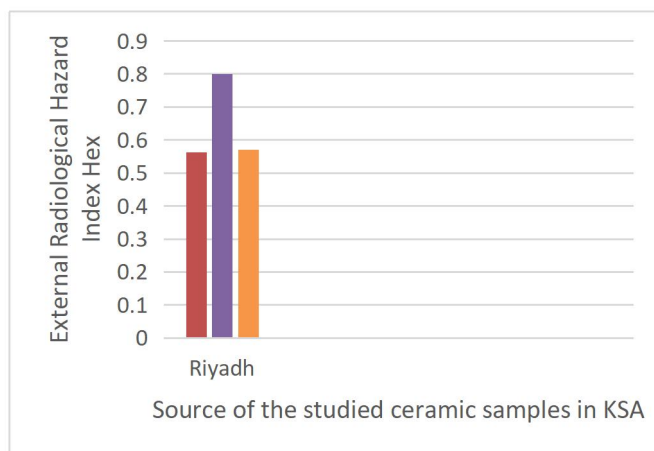


Fig.6. (a): External Hazard Index (Hex) values for ceramic samples collected from different cities in Saudi Arabia [23, 39,40]

hazard indices for granite fall within acceptable safety limits, as these indices should not exceed unity.

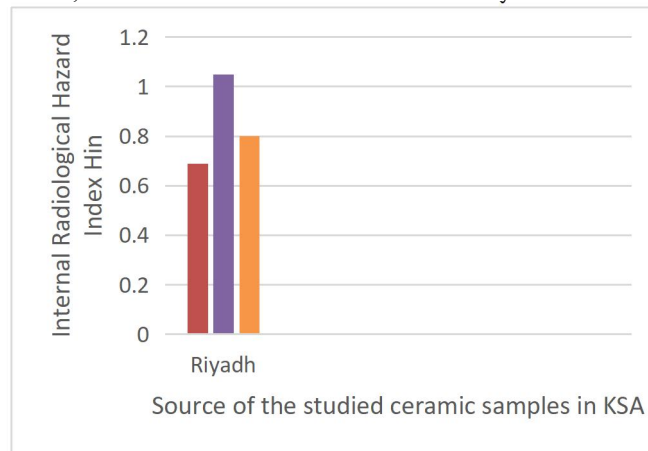


Fig.6. (b): Internal Hazard Index (Hin) values for ceramic samples collected from different cities in Saudi Arabia [23, 39,40]

Most results showed that the internal and external hazard indices for sand were within the safe range, as the values should not exceed unity. However, a study conducted in Rabigh is an exception; the use of this material is not recommended because the internal hazard index showed an elevated value of 1.83, which exceeds the permissible limit for building materials. The results also indicate that the internal and external radiological hazard indices (H_{in} and H_{ex}) for all analyzed gypsum samples are within the recommended safety limits, as none of the calculated values exceeded unity. This confirms that the investigated materials are radiologically safe for use as building materials. In previous studies, we evaluated the internal and external radiological hazard indices, H_{in} and H_{ex} , in cement, and found that most sample values were well below the recommended limit, with many below 0.5. Except for two studies, a study by Omer et al. reported relatively high H_{in} and H_{ex} values that warrant caution regarding the use of specific cement samples [45].

These elevated values could be attributed to the specific properties of the raw materials used. These findings warrant caution and suggest that the use of these materials should be restricted unless verified by high-precision measurements. However, all other reported values remained low, indicating that cement can be safely used in construction without significant radiological concerns.

Most results showed that the internal and external hazard indices for marble were within the safe range, as the values should not exceed unity. However, a study conducted in Al-Jouf [47] is an exception; the use of this material is not recommended because the internal hazard index showed an elevated value of 1.0931, which exceeds the permissible limit for building materials. The majority of the results demonstrated that the internal and external radiological

Nevertheless, studies conducted in the regions of Hail, Tawlah, Hamra Alkali, and Abu Al-Dod constitute notable exceptions. In these cases, the use of this material is not recommended due to elevated internal hazard index values of 2.58, 2.4, 1.3, and 22.34, all of which exceed the permissible limits for building materials. Most results showed that the internal and external hazard indices for ceramics were within the safe range, as the values should not exceed unity. However, a study conducted in Riyadh [39] is an exception; the use of this material is not recommended because the internal hazard index showed an elevated value of 1.049, which exceeds the permissible limit for building materials.

5 Conclusion

The radiological risks associated with the use of building materials in Saudi Arabia were evaluated to assess their compliance with recommended safety limits. This research was conducted within a comprehensive framework that addresses the fundamentals of radioactivity, its interaction with matter and the characteristics of commonly used building materials. The ^{226}Ra , ^{232}Th , ^{234}Th , and ^{40}K content,

Radium equivalent (Ra_{eq}), external radiation hazard (H_{ex}), internal radiation hazard (H_{in}), absorbed dose rate (D), indoor annual effective dose (E_{in}), and outdoor annual effective dose (E_{out}) were determined for materials including sand, gypsum, cement, marble, granite, and ceramic in KSA. Results showed that granite, cement, and ceramic had higher radiological values, sometimes exceeding recommended limits, whereas marble, sand, and gypsum were within safe ranges. Radium equivalent (Ra_{eq}) activities exceeded the maximum value in granite with an average of 587.74 Bq/kg, while other materials were under the recommended limit of 370 Bq/kg. In conclusion, the

obtained results indicate that the investigated building materials were safe for construction purposes and pose a low radiological hazard for inhabitants, except certain granite samples, which were deemed suitable only for exterior use.

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