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# Evaluation of Radiation Rates and Health Hazards from Different Cement Types in Pakistan

**Muhammad Waseem [1], Hannan Younis [1,*], Moustafa Salouci [2], Mian Mateen Ullah [3], Muhammad Adil Khan [3], Ouazir Salem [4], Atef Abdelkader [4] and Abd Haj Ismail [4,*]**

[1] Radiation Physics Lab, Department of Physics, COMSATS University Islamabad, Islamabad 45550, Pakistan
[2] Strategic Planning and Institutional Identity Administration, King Faisal University, Al-Ahsaa 31982, Saudi Arabia
[3] Department of Physics, Islamia College Peshawar, Peshawar 25120, Pakistan
[4] College of Humanities and Sciences, Ajman University, Ajman P.O. Box 346, United Arab Emirates
* Correspondence: hannan.younis@comsats.edu.pk (H.Y.); a.hajismail@ajman.ac.ae (A.H.I.)

**Abstract:** The raw materials of cement contain radioactive elements that come from natural sources. Members of the decay chains of uranium, thorium, and potassium radioisotope $^{40}$K are the primary sources of this radioactivity. The natural radionuclide concentration levels in cement differ greatly depending on different geographic areas. To estimate the radionuclides concentration in cement specimens from twelve diverse Pakistani companies, gamma-ray spectroscopy analysis was used in the study. $^{226}$Ra, $^{232}$Th, and $^{40}$K had activity concentration levels ranging from 18.08 to 43.18 Bq/kg, 16.73 to 23.53 Bq/kg, and 14.24 to 315.22 Bq/kg, respectively. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) threshold for the $^{226}$Ra was surpassed by five of the studied samples. The indoor and outdoor dose rates as well as different radiological health hazard indices were also examined. The Indoor Absorbed Dosage ($D_{in}$) for some of the samples exceeded the permissible limit. These samples also had a high Indoor Effective Lifetime Cancer Risk (ELCR) factor, which makes them unsafe for interior construction purposes. The outdoor dosages as well as the hazard indices were well within the permitted ranges. The outdoor ELCR factor is low for all the cement brands, which makes them safe for exterior construction purposes. The findings were compared with published data from other countries around the globe. Finally, a thorough statistical analysis was performed and Pearson's Correlation Coefficient (r) exhibited a very strong correlation between the different outdoor and indoor radiological health hazard indices.

**Keywords:** cement; specific activity; gamma spectroscopy; dose rate; radiological health hazards; Pearson's correlation coefficient

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## 1. Introduction

Among the most crucial construction products, cement is a coagulant that binds the aggregate to cling to structural components like rocks, blocks, and tiling. There are several varieties of cement, each with its own chemical makeup and hydraulic qualities. The most widely utilized type of cement for construction purposes globally is Portland cement. It is regarded as a crucial component in the production of concrete blocks when combined in the ideal ratio with both fine and coarse aggregates. This cement is manufactured using a chemical process that combines natural components from rocks and soils like clay, calcium carbonate, and gypsum [1].

Naturally occurring radioactive materials (NORMs) can be found in the raw materials required to make cement, including soil and rocks. The main sources of this radioactivity are the decay chains of radium, thorium, and the potassium radioisotope $^{40}$K. The quantity of these naturally occurring radionuclides in cement depends upon the geological source of the raw materials used [2,3]. The substantial presence of these radioisotopes has the potential to expose the building occupants to radiation both internally and externally [4].

Internal exposure primarily affects the lungs and other tissues in the human body, caused by the short-lived progenies of radon adhering to and depositing themselves in the respiratory tract. External exposure is brought on by direct gamma ray ionizing radiation [5–7].

Variables such as radiation type, area of exposure, aging, dose, duration of treatment, and individual health play a role [8]. While people spend the majority of their time within the house, laborers in cement mines and production facilities are frequently exposed to cement or its raw components. It is potentially possible for cement-based building materials to be carcinogenic if NORM concentrations are high. In order to ensure the protection of the environment from radiation, it is critical to monitor radioactive substances in cement [9]. Numerous researchers from all around the world have reported on their investigations on radioactivity in construction materials and cement specifically [10–15]. The radioactive concentrations varied greatly between countries and were generally below the permitted levels.

The use of cement is closely tied to socioeconomic and sociological development. Due to infrastructure expansion, the cement sector has seen substantial growth everywhere, including in Pakistan. With such a wealth of available raw materials, Pakistan has an established cement manufacturing industry. The nation is ranked as one of the top five suppliers as well as the planet's 14th leading cement manufacturer.

The article demonstrates the activity concentrations of NORM and its associated radiological hazards for 12 distinct brands of cement that are sold in Pakistan by gamma ray spectroscopy. For each brand, three samples were obtained and the mean values were calculated. The acquired data were then compared to global benchmark values suggested by the United Nations Committee on the Effects of Ionizing Radiation (UNSCEAR, 2008) [16].

The information garnered from this investigation may be used to assist with developing proper radiation protection guidelines and guarantee the safety of employees, residents, and the environment. We can minimize possible health risks by advocating appropriate cement use in order to improve social and economic growth by monitoring and evaluating radiation levels.

## 2. Material and Methods

### *2.1. Sample Collection and Preparation*

Cement specimens from 12 different brands were obtained from multiple factories and neighborhood stores. We ensured that all cement brands produced in Pakistan were included in our analysis. Others were imported samples that were not considered; we only used local brands of cement and their origin. There is a maximum of 12 brands in Pakistan, and we collected all 12 brands and 3 samples from each brand from the factory for statistical purposes. So, if we add all together, there were 36 samples to be analyzed for the current study. Moreover, a similar type of study like [17] revealed that the author took 11 samples to investigate the radioactivity measurements in cements. In order to completely eliminate all moisture, the specimens were heated at 105 °C for 4 h. After the necessary cooling time, the dehydrated specimens were put in cylindrical Marinelli beakers of a 154 mm height and a 120 mm diameter and weighed. Within these beakers, each 1 kg specimen was securely wrapped. Before performing the HPGe analysis, we waited for 40 days for the cement specimens within these Marinelli beakers in order to achieve secular equilibrium between radium and its progeny radon.

### *2.2. Activity Measurements*

A High Purity Germanium-Ray Detector (HPGe) (DSG Detector Systems GmbH, Mainz, Germany) was used to quantify the radionuclide activity concentration levels. The detector had an excellent resolution of 1.85 keV and had an efficiency of about 52.4%. The HPGe detector must be calibrated to take reliable measurements of the activity. Therefore, the system was calibrated using the known point sources of $^{137}Cs$, $^{60}Co$, $^{57}Co$, and $^{22}Na$. A computer-based multi-channel analyzer was connected to the HPGe. The HPGe gamma-ray spectrometer's vertically oriented detector was cooled using liquid nitrogen. The

HPGe detectors must function at extremely cold temperatures of liquid nitrogen (−196 °C) in order to work at their best since the noise caused by thermal stimulation is fairly considerable at ambient temperature [17,18].

A spectrum was obtained for 15,000 s and used to examine each sample. By detecting the radioactive offspring, the activities of $^{226}Ra$ and $^{232}Th$ were evaluated. The 4 h (approx. 15,000 s) of the HPGe spectrum detector study for gamma analysis was considered sufficient, as the gamma spectrum has been studied in another research related to radioactivity in geologic and building materials and taken to be around 4 h (~15,000 s) or even less [17,19]. In most of the previous studies related to radioactivity in geologic and building materials, the measurement time took around 4 h (~15,000 s). In [19], the authors used only 5000 s for the analysis of building materials.

The following equation determines the specific activity concentration for every radionuclide [20]:

$$SA_{nuclide} = \frac{PA}{m_s \times \varepsilon \times \eta \times t_s} \quad (1)$$

where PA is the peak area for the corresponding peaks of interest, $m_s$ is the mass of sample, $\varepsilon$ is the efficiency of detector, $\eta$ is the abundance of nuclide, and $t_s$ is the spectrum acquisition time.

Table 1 lists the energies and percentage abundances of gamma rays that correspond to the relevant spectra peaks.

**Table 1.** Gamma ray energies and percentage abundances corresponding to the respective spectral peaks of interest.

| Parent Nuclide | Daughter Nuclide | Gamma Ray Energy (keV) | Abundance (%) |
|---|---|---|---|
| $Ra^{226}$ | $Pb^{214}$ | 351.92 | 35.1 |
| | $Pb^{214}$ | 295.21 | 19.2 |
| | $Pb^{214}$ | 241.98 | 7.12 |
| | $Bi^{214}$ | 609.32 | 44.6 |
| | $Bi^{214}$ | 1764.52 | 15.1 |
| | $Bi^{214}$ | 1120.28 | 14.7 |
| | $Bi^{214}$ | 1238.11 | 5.78 |
| | $Bi^{214}$ | 768.3 | 4.46 |
| $Th^{232}$ | $Pb^{212}$ | 238.63 | 43.5 |
| | $Ac^{228}$ | 911.16 | 26.6 |
| | $Ac^{228}$ | 968.97 | 16.23 |
| | $Ac^{228}$ | 338.42 | 11.26 |
| | $Tl^{208}$ | 583.19 | 84.5 |
| $K^{40}$ | $K^{40}$ | 1460.8 | 10.67 |

### *2.3. Radiological Hazard Indices Measurements*

The subsequent radiological indexes are computed with activity concentrations of $^{226}Ra$, $^{232}Th$, and $^{40}K$.

#### 2.3.1. Radium Equivalent Activity

The distribution of naturally occurring radioactive isotopes in specimens is uneven. As a result, the cumulative activity from the isotopes $^{226}Ra$, $^{232}Th$, and $^{40}K$ was measured in (Bq/kg) [21].

$$Ra_{eq} = \left[\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\right] \times 370 \quad (2)$$

where $A_{Ra}$, $A_{Th}$, and $A_K$ are the amounts of $^{226}Ra$, $^{232}Th$, and $^{40}K$ activities in a unit of measurement (Bq/kg). According to the Occupational Committee on Radiation Development (OECD) 1979, the maximum permissible limit of $Ra_{eq}$ for naturally found radioactive elements should be less than 369.9 Bq/kg.

2.3.2. Gamma Dose Rate Absorbed

The equation below was used to compute the absorbed gamma dose rates for the air 1 m above the earth's surface for the evenly distributed dispersion of naturally occurring radionuclides [16,22].

$$D_{in} = 0.92A_{Ra} + 1.1A_{Th} + 0.081A_k \quad (3)$$

$$D_{out} = 0.427A_{Ra} + 0.604ATh + 0.0417A_K \quad (4)$$

The S.I. unit of $D_{in}$ and $D_{out}$ S.I. is $nGyh^{-1}$.

2.3.3. Yearly Effective Dose

The following equations were used to compute the annual effective dose (AED) utilizing absorbed gamma dose rates, a dose conversion factor of 0.7 Sv/Gy, and the associated outside and inside occupancy factors of 0.2 and 0.8 [23].

$$E_{in} = D_{in} \times 8760 \times 0.8 \times 0.7 \times 10^{-6} \quad (5)$$

$$E_{out} = D_{out} \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (6)$$

The S.I. unit of $E_{in}$ and $E_{out}$ is mSv/yr.

2.3.4. Hazards to External and Internal Health

The following formula yields the external hazard index (Hex), where $A_{Th}$, $A_{Ra}$, and $A_K$ are the activity of $^{232}Th$, $^{226}Ra$, and $^{40}K$, respectively, in $Bqkg^{-1}$ [24].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (7)$$

To maintain the radiation dosage under 1.51 $mSvy^{-1}$, the external hazard index must be less than 1. Radon and the byproducts of its rapid degradation chain pose a threat to the respiratory system as well. An internal hazard index ($H_{in}$) that is computed as follows is used to evaluate the internal exposure to radon and the products of its degradation [25]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (8)$$

The internal hazard index must also be less than 1.

2.3.5. Gamma Index

The radioactive hazard index recommended by the European Commission can be employed to assess the risk levels of gamma radiation typically linked to natural radioactive elements. This index, which is provided as follows, takes into account the methods and amounts of materials utilized during building [26]:

$$I\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (9)$$

It is advisable to steer clear of materials with a Gamma Index > 1.0 while building structures. Such buildings' occupants will receive an equivalent effective dose greater than 1 $mSvy^{-1}$.

#### 2.3.6. Alpha Index

The radon intake caused by the construction components is measured using the alpha index, which measures excessive alpha radiation. The formula is provided below [27]:

$$I_{\propto} = \frac{A_{Ra}}{200} \tag{10}$$

wherein $A_{Ra}$ represents the activity of $^{226}Ra$. The maximum permissible concentration of $^{226}Ra$ is 200 $Bqkg^{-1}$, which results in Gamma Index = 1. Any building material whose $^{226}Ra$ concentration level exceeds this acceptable level (200 $Bqkg^{-1}$) is deemed hazardous.

#### 2.3.7. Cancer Risk in Excess of Lifetime

The additional cancer danger posed by ionizing radiation exposure is measured as excess lifetime cancer risk [27].

$$ELCR_{(in)} = E_{in} \times LE \times RF \tag{11}$$

$$ELCR_{(out)} = E_{out} \times LE \times RF \tag{12}$$

Life expectancy, on average, is 70 years, and the risk factor, RF, is 0.051 according to the ICRP.

### *2.4. Pearson Correlation Coefficient*

A Pearson's correlation test is used to measure the strength and direction of the linear covariation between two variables. Pearson's correlation tests were performed among the different radionuclide's specific activities, dose measurements, and radiological health indices.

Pearson's correlation coefficient (r) is calculated by the formula

$$r = \frac{\sum\left(x_i - \overline{x}\right)(y_i - \overline{y})}{\sqrt{\sum(x_i - \overline{x})^2 (y_i - \overline{y})^2}} \tag{13}$$

where $x_i$ is the value of the first variable, $\overline{x}$ is the mean of all values of the first variable, $y_i$ is the value of the second variable, and $\overline{y}$ is the mean of all values of the second variable.

## 3. Results and Discussion

### *3.1. Specific Activity of Radium, Thorium, and Potassium*

Average radium, thorium, and potassium activity concentrations for each variety of cement are shown in Table 2.

The Minimum Detectable Activity (MDA) or Minimum Detectable Concentration (MDC) of the $\gamma$-ray spectroscopy was calculated using the following equation:

$$MDA = \frac{2.71 + 4.65B^{\frac{1}{2}}}{\varepsilon \times t} \tag{14}$$

where B is the background counts, $\varepsilon$ is the counting efficiency, and t is the counting time in seconds. In our case, the Minimum Detectable Activity was 2.5 Bq/kg.

The UNSCEAR criterion for the said concentration levels of $^{226}Ra$, $^{232}Th$, and $^{40}K$ is displayed in the final row while the mean activity levels are displayed in the second-to-last row of Table 2. The mean SA of all the radioactive nuclides is lesser than the UNSCEAR risk criterion.

**Table 2.** Calculated mean SA's of NORMs.

| Sample Code | Type | $^{226}$Ra (Bqkg$^{-1}$) | $^{232}$Th (Bqkg$^{-1}$) | $^{40}$K (Bqkg$^{-1}$) |
|---|---|---|---|---|
| CEM1 | Portland | 25.79 ± 0.42 | 20.24 ± 0.04 | 222.93 ± 1.57 |
| CEM2 | Portland | 21.38 ± 0.80 | 18.86 ± 0.16 | 315.22 ± 9.60 |
| CEM3 | Portland | 37.65 ± 0.61 | 22.04 ± 0.12 | 234.13 ± 2.54 |
| CEM4 | Portland | 38.17 ± 0.66 | 20.97 ± 0.03 | 232.08 ± 2.36 |
| CEM5 | Portland | 37.19 ± 0.57 | 20.96 ± 0.03 | 234.70 ± 2.59 |
| CEM6 | Portland | 25.69 ± 0.43 | 18.88 ± 0.16 | 231.65 ± 2.32 |
| CEM7 | Portland | 18.08 ± 1.09 | 16.73 ± 0.34 | 191.39 ± 1.18 |
| CEM8 | Portland | 31.11 ± 0.04 | 19.58 ± 0.09 | 184.87 ± 1.75 |
| CEM9 | Portland | 43.18 ± 1.09 | 22.09 ± 0.12 | 173.45 ± 2.74 |
| CEM10 | White | 35.58 ± 0.43 | 23.53 ± 0.25 | 14.25 ± 0.26 |
| CEM11 | Portland | 29.37 ± 0.11 | 21.71 ± 0.09 | 174.30 ± 2.67 |
| CEM12 | Portland | 24.19 ± 0.56 | 22.37 ± 0.15 | 250.36 ± 3.95 |
| Average | - | 30.61 ± 0.57 | 20.66 ± 0.13 | 204.94 ± 2.79 |
| UNSCEAR | - | 35.00 | 30.00 | 400.00 |

The illustrated description of the radium activity concentrations, as well as the UNSCEAR-recommended limit, is shown in Figure 1.

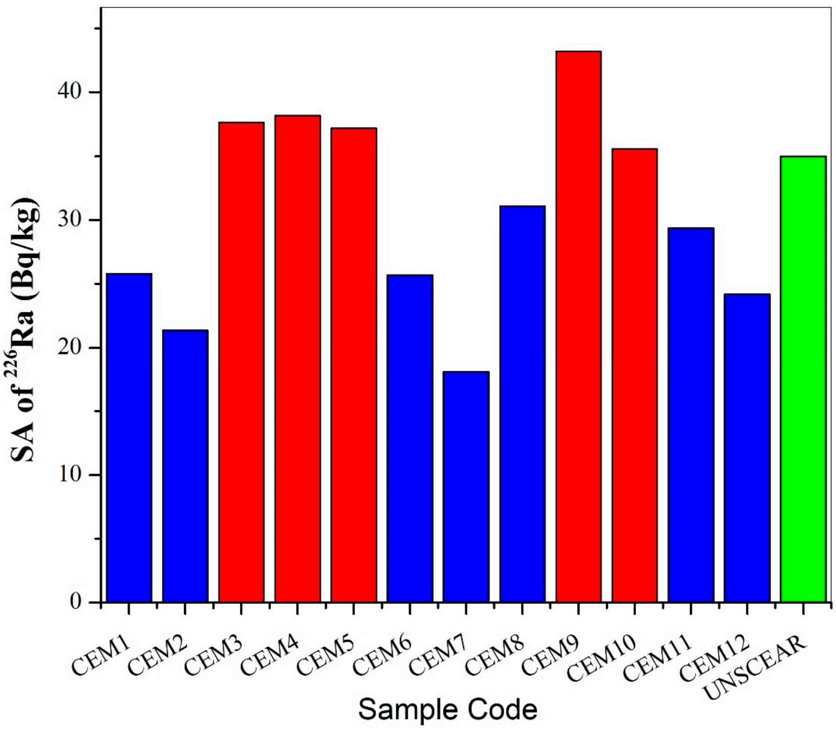


**Figure 1.** Comparison of calculated radium concentration with UNSCEAR safe limit.

Radium activity varies between specimens CEM7 (18.03 Bqkg$^{-1}$) and CEM9 (43.18 Bqkg$^{-1}$), with CEM9 having the highest activity. The greater concentration indicates that more radium is present. The radium SAs for CEM3, CEM4, CEM5, CEM9, and CEM10 exceed the safe recommendation criterion by UNSCEAR.

Figure 2 displays an illustrated depiction of the thorium activity concentrations together with the UNSCEAR-recommended limit.

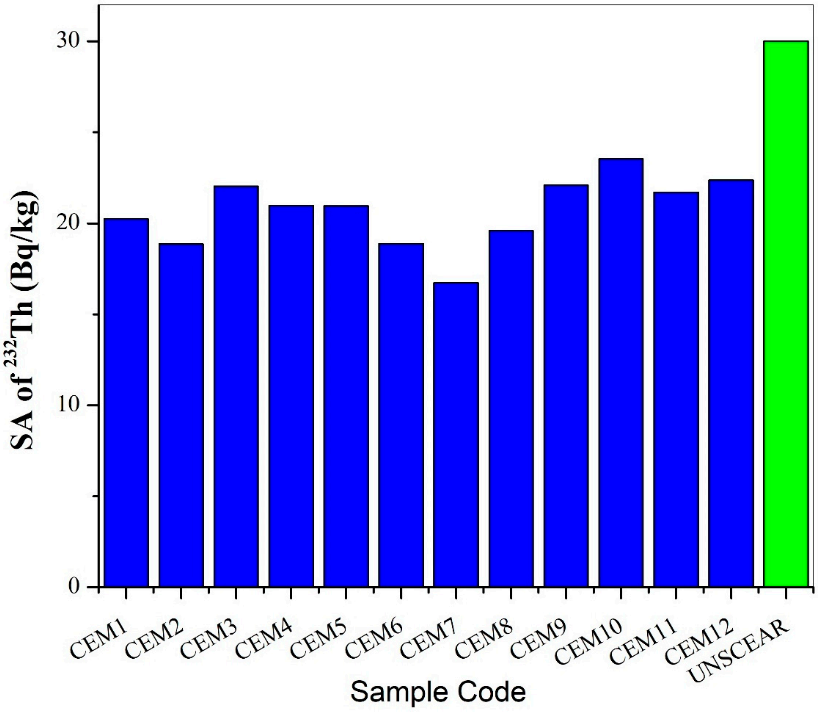


**Figure 2.** Comparison of calculated thorium concentration with UNSCEAR safe limit.

Among both specimens, CEM7 and CEM10, thorium activity fluctuates, with CEM10 having the maximum activity and CEM7 having lowest activity. The higher concentration implies that more thorium is present in the stated product, whilst the lower concentration indicates that less thorium is present. All cement kinds have SA values that are considerably below the UNSCEAR safe level.

The potassium activity concentrations and the UNSCEAR-recommended limits are shown in an illustrated representation in Figure 3.

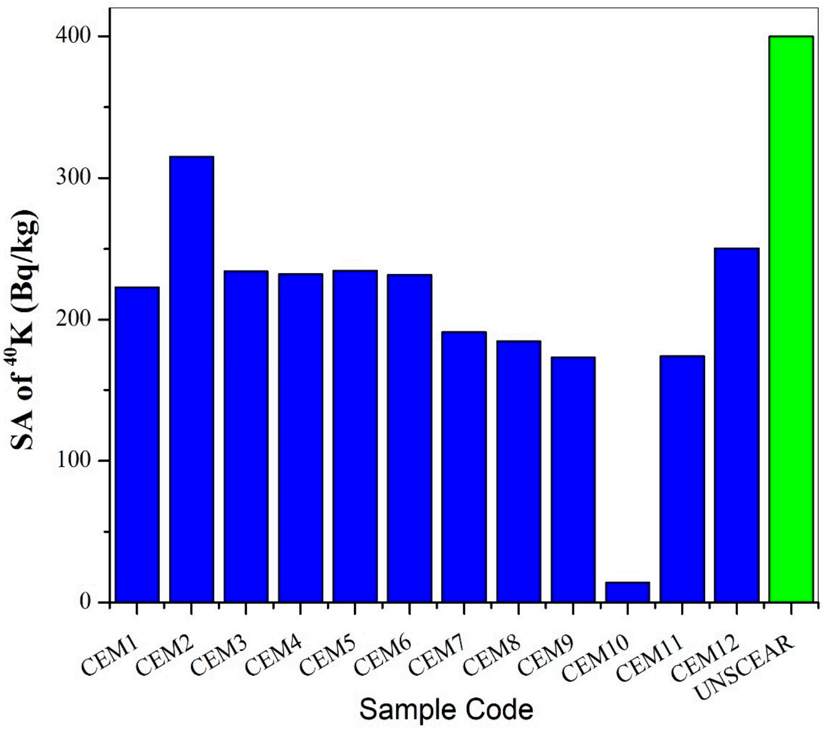


**Figure 3.** Comparison of calculated potassium concentration with UNSCEAR safe limit.

Potassium activity changes between specimens CEM10 and CEM12, with CEM12 having the higher activity. All varieties of cement have SA values that are far lower than the UNSCEAR safe standard.

*3.2. Radiological Health Hazard Indices*

Different indoor and outdoor radiological health hazards were evaluated and are given in Table 3 utilizing the specific activity levels of Radium-226, Thorium-232, and Potassium-40.

**Table 3.** Radiological health hazard indices for 12 Pakistani cement specimens.

| S.Code | $Ra_{eq}$ | $H_{ex}$ | $H_{in}$ | $I_{\alpha}$ | $I_{\gamma}$ | $D_{in}$ | $D_{out}$ | $E_{in}$ | $E_{out}$ | $ELCR_{in}$ | $ELCR_{out}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CEM1 | 71.85 | 0.19 | 0.26 | 0.13 | 0.26 | 63.82 | 33.43 | 0.31 | 0.04 | 1.10 | 0.14 |
| CEM2 | 72.57 | 0.20 | 0.25 | 0.11 | 0.27 | 65.63 | 34.41 | 0.32 | 0.04 | 1.13 | 0.15 |
| CEM3 | 87.15 | 0.24 | 0.34 | 0.19 | 0.31 | 77.61 | 40.47 | 0.38 | 0.05 | 1.33 | 0.17 |
| CEM4 | 85.98 | 0.23 | 0.34 | 0.19 | 0.31 | 76.75 | 39.98 | 0.38 | 0.05 | 1.32 | 0.17 |
| CEM5 | 85.19 | 0.23 | 0.33 | 0.19 | 0.31 | 76.05 | 39.63 | 0.37 | 0.05 | 1.31 | 0.17 |
| CEM6 | 70.47 | 0.19 | 0.26 | 0.13 | 0.26 | 62.93 | 32.93 | 0.31 | 0.04 | 1.08 | 0.14 |
| CEM7 | 56.71 | 0.15 | 0.20 | 0.09 | 0.21 | 50.35 | 26.44 | 0.25 | 0.03 | 0.86 | 0.11 |
| CEM8 | 73.30 | 0.20 | 0.28 | 0.16 | 0.26 | 64.95 | 33.91 | 0.32 | 0.04 | 1.12 | 0.15 |
| CEM9 | 88.08 | 0.24 | 0.35 | 0.22 | 0.31 | 77.90 | 40.52 | 0.38 | 0.05 | 1.34 | 0.17 |
| CEM10 | 70.30 | 0.19 | 0.29 | 0.18 | 0.24 | 59.76 | 31.25 | 0.29 | 0.04 | 1.03 | 0.13 |
| CEM11 | 73.79 | 0.20 | 0.28 | 0.15 | 0.26 | 64.84 | 33.95 | 0.32 | 0.04 | 1.11 | 0.15 |
| CEM12 | 75.40 | 0.20 | 0.27 | 0.12 | 0.28 | 66.88 | 35.12 | 0.33 | 0.04 | 1.15 | 0.15 |
| UNSCEAR | 370.00 | 1.00 | 1.00 | 1.00 | 1.00 | 75.00 | 57.00 | 0.41 | 0.07 | 1.16 | 0.29 |
| Average | 75.90 | 0.21 | 0.29 | 0.15 | 0.27 | 67.29 | 35.17 | 0.33 | 0.04 | 1.16 | 0.15 |

The estimated exterior and interior body indexes are displayed in the second and third columns of Table 3, together with the healthy maximum criterion value of 1. For the products being examined, the bodily dangers on the inside and outside were well within acceptable bounds. If either radiation they release touches a person's skin or is breathed in, they do not pose any imminent threat.

The calculated alpha and gamma indices are shown in the fourth and fifth columns of Table 3, along with the acceptable maximum criterion value of 1. Both the $\gamma$ and $\alpha$ coefficients for the items under review were below reasonable bounds. They do not currently constitute a concern if either the radon they release or the gamma radiation they emit is ingested.

A standard radiological measure, $Ra_{eq}$, is computed in order to evaluate the overall effect of radiation exposure brought on by radionuclides present in materials. $Ra_{eq}$ readings fall between 56.71 and 88.08 Bq/kg, as seen in the table. The Global UNSCEAR criterion cutoff is 370 Bq/kg.

Figure 4 displays the visual portrayal of radium equivalent activity detected in specimens. It is the end outcome of the interaction between the particular activities of $^{226}Ra$, $^{232}Th$, and $^{40}K$. All cement powders have $Ra_{eq}$ values that are far lower than the permissible limits.

The indoor absorbed dose rate ($D_{in}$) is computed for a regular room having specifications of 4 m $\times$ 5 m $\times$ 2.8 m as well as a wall thickness of 20 cm in order to choose non-radioactive or a little less hazardous building material. UNSCEAR has set a 75 nGy/h maximum safe threshold for indoor doses. The indoor absorption dosages calculated are visually represented in Figure 5.

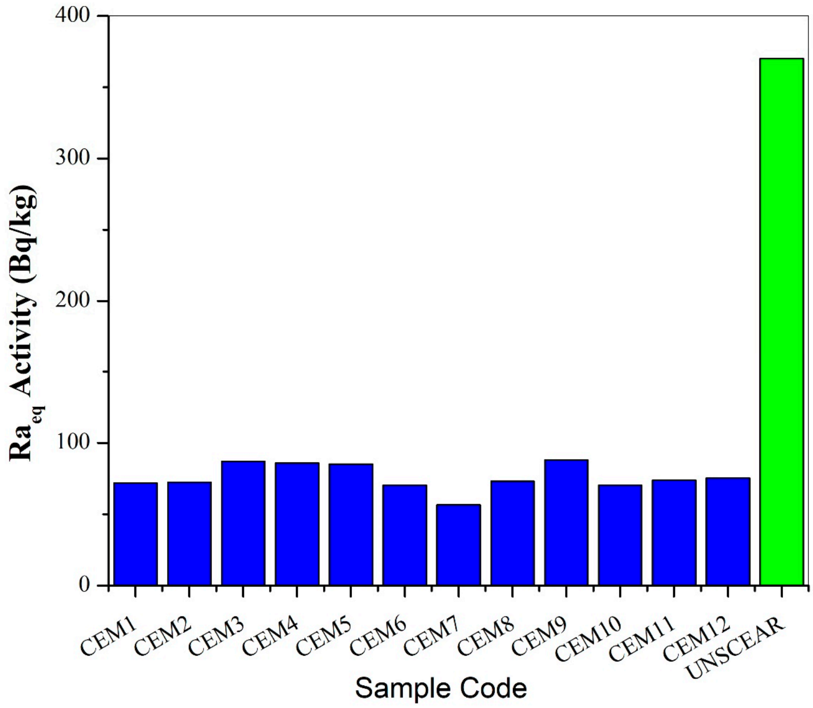


**Figure 4.** Graphical illustration of calculated $Ra_{eq}$ activity along with UNSCEAR safe limit.

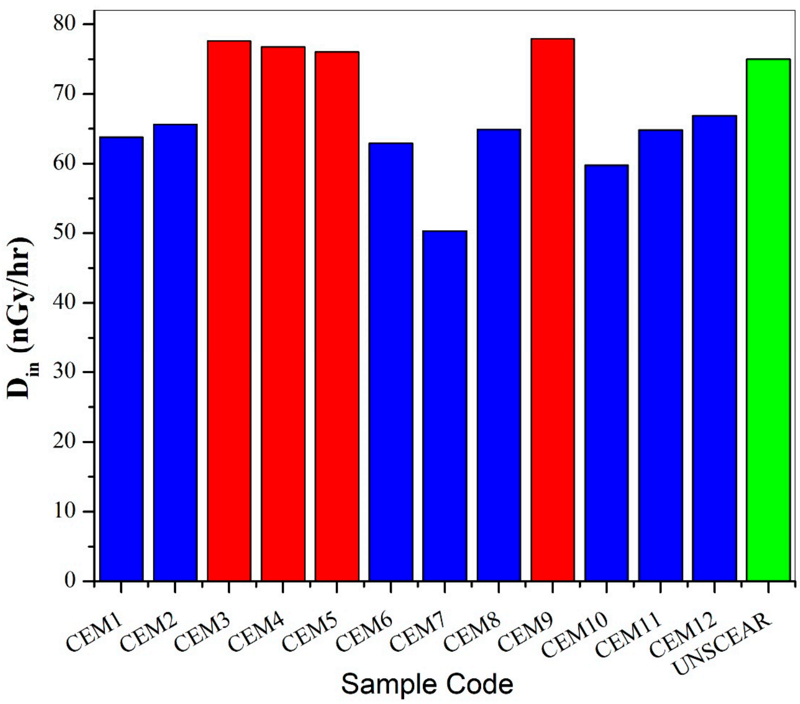


**Figure 5.** Assessed indoor dosage $D_{in}$ in comparison to the safe recommendation.

The interior absorption dosages for samples CEM3, CEM4, CEM5, and CEM9 were more than the acceptable parameters. As was previously mentioned, these cement brands included greater concentrations of radium. They are not supposed to be utilized in the fabrication of the inside of buildings.

The outdoor absorption dosages calculated for the cement brands under study are visually represented in Figure 6.

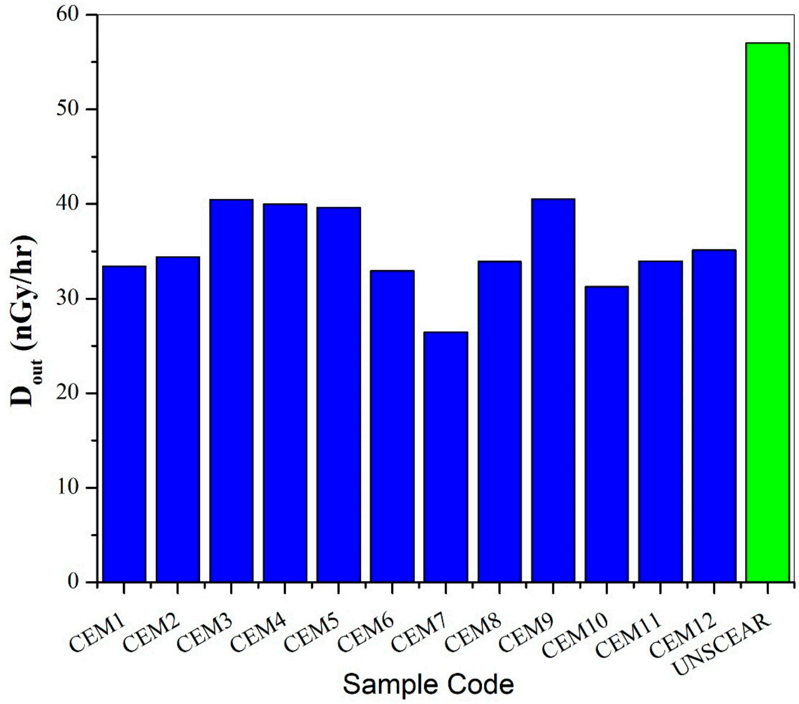


**Figure 6.** Assessed outdoor dosage $D_{out}$ in comparison to the safe recommendation.

The exterior absorption dosages for samples under observation were lower than the acceptable parameters. They are supposed to be safe to be utilized in the fabrication of outside buildings.

The UNSCEAR-recommended maximum of 0.41 mSv/yr and the interior yearly effective doses estimated for the cement manufacturers under examination are listed in the table.

Figure 7 displays the evaluated indoor annual effective dosages.

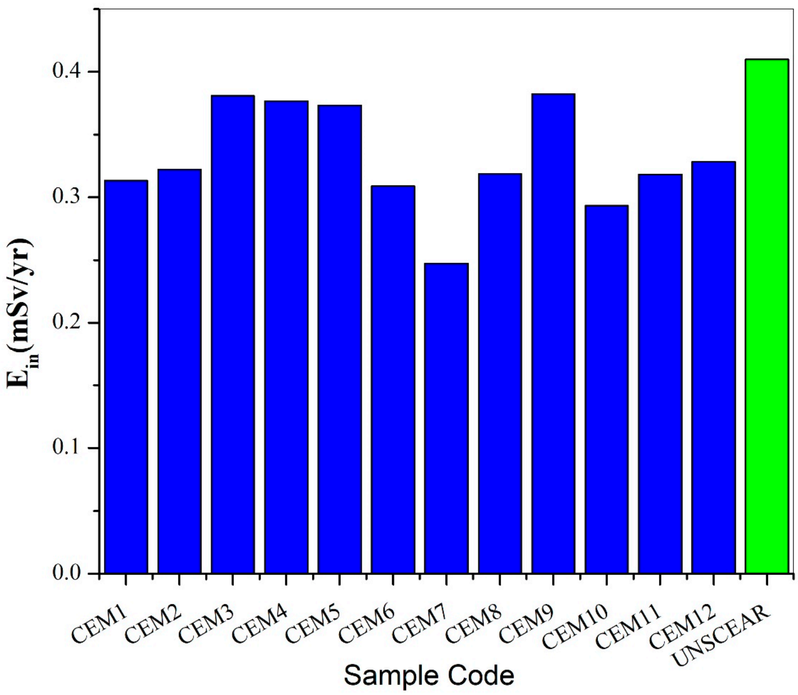


**Figure 7.** Evaluated indoor yearly effective dosage $E_{in}$ with UNSCEAR safe level.

The analysis shows that the interior yearly doses for the subjects under inspection were within the permitted limits.

Figure 8 indicates the projected outdoor annually effective dosages for the entire players in the industry under investigation as well as the UNSCEAR-recommended restriction of 0.07 mSv/yr.

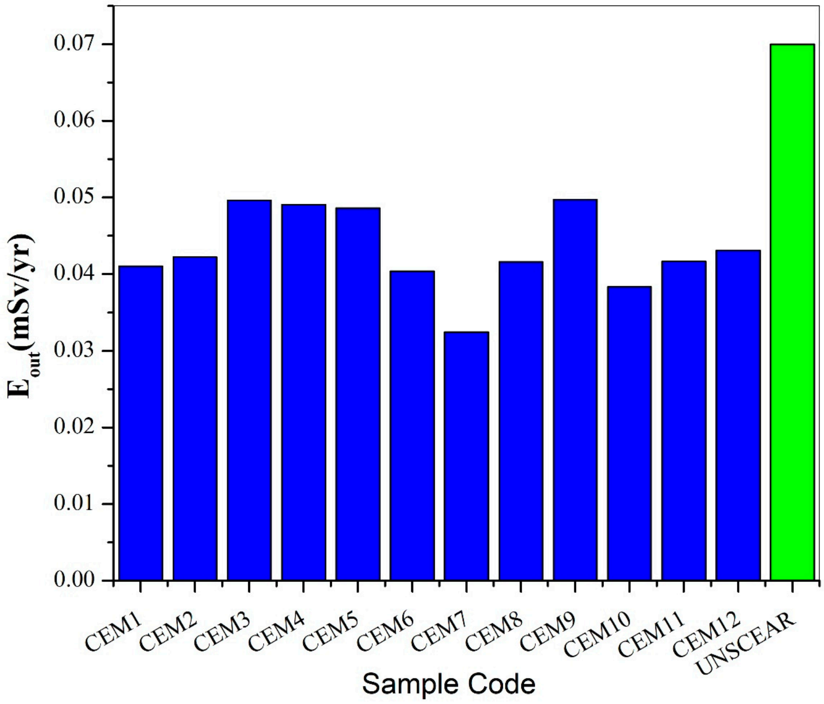


**Figure 8.** Evaluated outdoor yearly effective dosage $E_{out}$ with UNSCEAR safe level.

The annual exterior doses for the items undergoing examination were within the permissible limits. They are designed to be secure enough to be used in the construction of outdoor structures.

Lifetime cancer refers to the likelihood of having cancer at any given moment. It is influenced by the values of each of the effects of radiation described above. A moral hazard of cancer development exists in specimens with a significant radiometric hazard level. The computed $ELCR_{in}$ values for each brand of cement that we looked at are shown in Figure 9.

Figure 9 shows that there is a considerable indoor cancer risk in the CEM3, CEM4, CEM5, and CEM9 samples. UNSCEAR deems $ELCR_{in}$ levels of approximately to 1.16 to be tolerable; however, these results demonstrate much larger levels of indoor cancer development.

Figure 10 shows the calculated $ELCR_{out}$ ratings for every variety of cement that was examined.

Figure 10 demonstrates that none of the samples had a significant outdoor risk of developing cancer. All of them are acceptable to be employed in outdoor construction since UNSCEAR considers $ELCR_{out}$ levels of around 0.29 to be acceptable, and these data show substantially lower levels of outdoor cancer development.

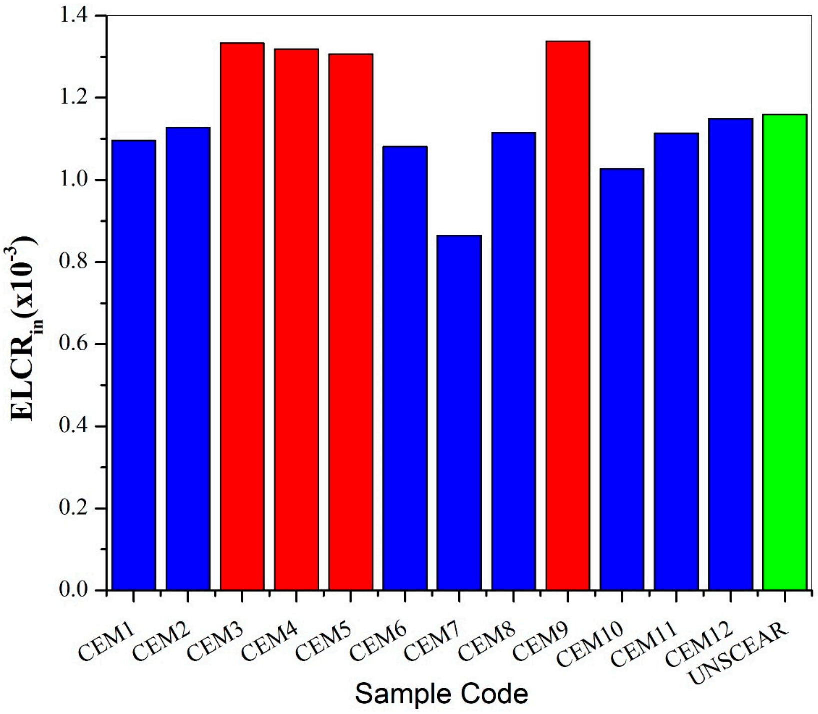


**Figure 9.** Lifetime cancer risk assessment in the indoor environment.

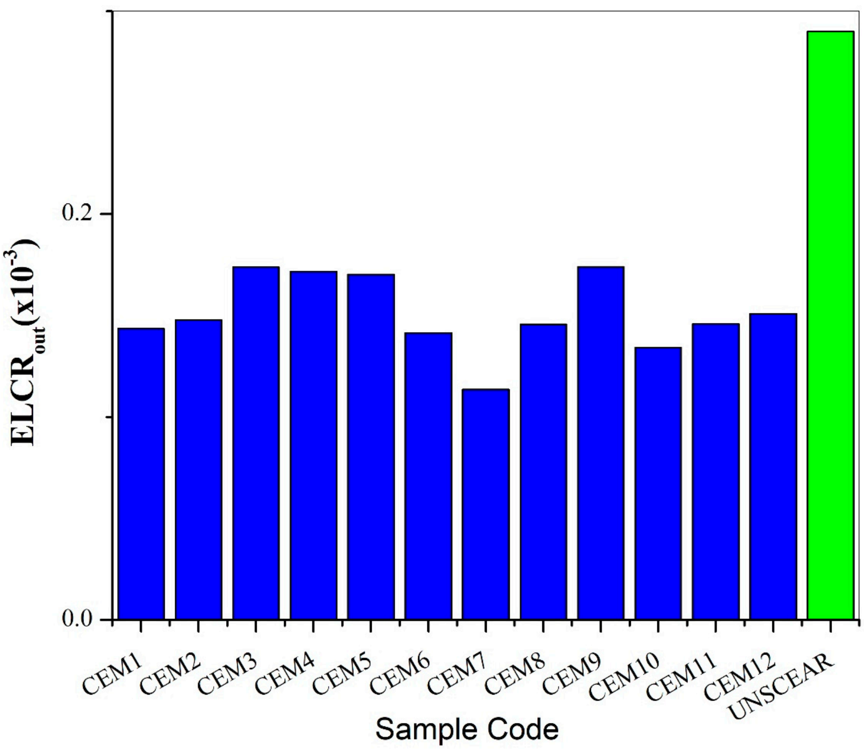


**Figure 10.** Lifetime cancer risk assessment in the outdoor environment.

### *3.3. Comparison with Similar Studies*

The specific activity concentrations as well as the radium equivalent activity in samples from the examined region were compared with published studies in other countries around the world, shown in Table 4.

**Table 4.** Comparison of mean values of $^{226}$Ra, $^{232}$Th, $^{40}$K, and radium equivalent ($Ra_{eq}$) activities in Pakistani cement samples with published data from other countries.

| Country/Region | Specific Activity ($Bqkg^{-1}$) | | | Raeq ($Bqkg^{-1}$) | Reference |
|---|---|---|---|---|---|
| | $^{226}$Ra | $^{232}$Th | $^{40}$K | | |
| Austria | 27 | 14 | 210 | 63 | [28] |
| Iraq | 31.3 | 16 | 168.2 | 67.1 | [13] |
| Solvakia | 12.6 | 25 | 269.2 | 69 | [29] |
| Netherlands | 27 | 19 | 230 | 72 | [17] |
| Pakistan | 31 | 21 | 205 | 76 | Present Study |
| Japan | 35.8 | 20.7 | 139.4 | 77 | [30] |
| Nigeria | 43.8 | 21.5 | 71.7 | 80.1 | [25] |
| Nepal | 23 | 27.3 | 336.5 | 87.8 | [15] |
| Finland | 40 | 20 | 251 | 88 | [31] |
| Pakistan | 26.7 | 28.6 | 273 | 88 | [32] |
| Italy | 38 | 22 | 218 | 92 | [33] |
| India | 35.8 | 33.2 | 199.1 | 98.7 | [12] |
| Turkey | 40 | 28 | 248 | 99 | [11] |
| India | 37 | 24.1 | 432.2 | 105 | [34] |
| Saudi Arabia | 38.4 | 45.3 | 86 | 108 | [35] |
| Algeria | 41 | 27 | 422 | 112 | [36] |
| Greece | 62.8 | 23.8 | 284.1 | 117 | [37] |
| China | 57 | 37 | 173 | 122 | [38] |
| Poland | 48 | 29 | 283 | 127 | [14] |
| Australia | 51.5 | 48.1 | 114.7 | 129 | [39] |
| Egypt | 78 | 33 | 337 | 151 | [40] |
| Bangladesh | 62.3 | 59.4 | 328.9 | 173 | [41] |
| Malaysia | 81 | 59 | 203 | 181 | [42] |
| Brazil | 61.7 | 58.5 | 564 | 189 | [43] |
| Ethiopia | 76.5 | 81.7 | 407 | 224 | [44] |
| UNSCEAR | 35 | 30 | 400 | 370 | [16] |

It is observed that there are significant variations in the mean values of specific activities and the $Ra_{eq}$ for cement samples from various nations, which may be linked to the kind of raw materials used in the production of cement. The comparison also reveals that the computed mean $Ra_{eq}$ in this research is greater than that calculated in Austria, Iraq, Solvakia, and Netherlands while lower than that calculated in most of the other countries like Australia, Algeria, Bangladesh, Brazil, Egypt, China, Finland, India, Malaysia, Turkey, Italy, Japan, Poland, and Greece.

### *3.4. Statistical Analysis*

Pearson Correlation Test Calculation

According to Pearson's coefficient test performed on our calculations, all the specific activities, doses, and radiological health hazards (indoor as well as outdoor) have a very high positive correlation with each other, which confirms the accuracy of our results.

The estimated Pearson's correlation coefficient r values for radioactive health hazards are displayed in Table 5. Calculations show that radiological health risks—both indoor and outdoor—have a very strong positive association with one another.

**Table 5.** Pearsons's correlation coefficient among different dose rates and radiological health hazards.

| | $I_\alpha$ | $H_{in}$ | $D_{in}$ | $E_{in}$ | $ELCR_{in}$ | $I_\gamma$ | $Ra_{eq}$ | $H_{ex}$ | $D_{out}$ | $E_{out}$ | $ELCR_{out}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $I_\alpha$ | 1 | | | | | | | | | | |
| $H_{in}$ | 0.953 | 1 | | | | | | | | | |
| $D_{in}$ | 0.791 | 0.938 | 1 | | | | | | | | |
| $E_{in}$ | 0.791 | 0.938 | 1.000 | 1 | | | | | | | |
| $ELCR_{in}$ | 0.791 | 0.938 | 1.000 | 1.000 | 1 | | | | | | |
| $I_\gamma$ | 0.751 | 0.953 | 0.998 | 0.998 | 0.998 | 1 | | | | | |
| $Ra_{eq}$ | 0.843 | 0.967 | 0.994 | 0.994 | 0.994 | 0.987 | 1 | | | | |
| $H_{ex}$ | 0.843 | 0.967 | 0.994 | 0.994 | 0.994 | 0.987 | 1.000 | 1 | | | |
| $D_{out}$ | 0.783 | 0.934 | 1.000 | 1.000 | 1.000 | 0.999 | 0.993 | 0.993 | 1 | | |
| $E_{out}$ | 0.783 | 0.934 | 1.000 | 1.000 | 1.000 | 0.999 | 0.993 | 0.993 | 1.000 | 1 | |
| $ELCR_{out}$ | 0.783 | 0.934 | 1.000 | 1.000 | 1.000 | 0.999 | 0.993 | 0.993 | 1.000 | 1.000 | 1 |

From Table 5, the correlation between absorbed dose indoors ($D_{in}$) and outdoors ($D_{out}$) measured in $nGyh^{-1}$, annual effective dose indoors ($E_{in}$) and outdoors ($E_{out}$) measured in $mSvy^{-1}$, and $ELCR_{in}$ and $ELCR_{out}$ can be seen. It can be seen that the correlation coefficient (r) is 1 for the indoor and outdoor absorbed doses, equivalent doses, and ELCR factors, which means that they are very strongly correlated with each other. The coefficient of determination ($R^2$) is 0.99, which means that 99% variability in one variable is explained by variability in the other one.

## 4. Conclusions

In the current study, specimens of cement from 12 different manufacturers spread across Pakistan were gathered, and the natural radioactivity in those samples was analyzed using a gamma-ray spectrometer. In the Pakistani cement samples, there were certain variations in the distribution of the specific activity of $^{226}Ra$, $^{232}Th$, and $^{40}K$. The raw ingredients used to make cement might be the source of these discrepancies. $^{226}Ra$, $^{232}Th$, and $^{40}K$ had average activity concentrations of 30.61 ± 0.57, 20.66 ± 0.13, and 204.94 ± 2.79 $Bqkg^{-1}$, respectively. According to the investigation, $^{226}Ra$-specific activity levels were found to be higher than the UNSCEAR permissible limit in five of the tested samples. Thorium and potassium both had SA levels that were well within the advised safe range. The alpha and gamma indices ($I_\alpha$ and $I_\gamma$), as well as the internal and external bodily hazard indices ($H_{in}$ and $H_{ex}$) and the radium equivalent ($Ra_{eq}$) activity, all stayed well within UNSCEAR-mandated levels of safety. Four of the samples (CEM3, CEM4, CEM5, and CEM9) had higher indoor absorbed dosages ($D_{in}$) and elevated indoor ELCR ($ELCR_{in}$) factors because of higher radium-specific activity levels, making it dangerous to use them for interior construction purposes. All four of them are Portland cements. However, the outdoor health hazard indices were all below the UNSCEAR acceptable limits, and there was no appreciable risk of cancer while using them for outdoor construction purposes. Through comparison with similar studies around the globe, it was observed that the mean values for Pakistani cement samples are less than most of the countries. Further, the perfect Pearsons correlation coefficient (r = 1) between the indoor and outdoor radiological health hazards confirms the accuracy of our results.

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