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Research article

Determination of dose derived from building materials and radiological health related effects from the indoor environment of Dessie city, Wollo, Ethiopia

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ABSTRACT

The eight most common construction materials in Dessie City were collected in order to determine the amount of natural radiation released and its effects on humans. This is the first time that such research has been conducted. A B13010 Gamma-ray spectrometry was used to determine the concentration of the daughter element photo peak (High Purity Germanium detector). These studies can be used to track changes in radioactivity caused by industrial and other human activities. The mean radioactivity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were calculated to be 26.59 ± 3.26, 26.59 ± 2.76, and 115.65 ± 2.73 Bq kg^{-1}, respectively. The calculated Radium equivalent activity (Raeq) and absorbed dose were lower than the global average. The estimated annual effective dose equivalent was 0.08 ± 0.01 mSv y^{-1}. External and internal radiation hazard indices (Hex and Hin), activity utilization indices, alpha indices, and gamma representative indices are all lower than the world's recommended standards. The mean of the ELCR is lower than the global mean. The annual effective dose equivalent is slightly above the global average.

1. Introduction

Natural radionuclides of both terrestrial and cosmogenic origin account for approximately 85% of an individual's annual total radiation dose [1]. Natural radionuclides from the uranium (^{238}U) and thorium (^{232}Th) families, as well as the radioactive isotope potassium, are present in varying concentrations in all building raw materials and products derived from rock and soil. Because the most important radiologically significant decay chain segment in the ^{238}U series begins with radium (^{226}Ra), 226Ra is frequently used instead of ^{238}U [2]. Despite their widespread distribution, these radionuclides' amounts have been found to be highly dependent on local geological conditions [3, 4, 5]. Radioactivity facts and figures can be used to assess and monitor the risk of radiation exposure to humans. Environmental radioactivity is caused by two types of construction materials. Due to a buildup of radon decay products in the human respiratory tract, radon exhalation causes an internal dose [6]; second, gamma and beta radiation from ^{226}Ra, ^{232}Th, and ^{40}K, and their progenies, causes a whole-body dose [7, 8, 9]. Because most people spend 80% of their time indoors, the concentration of radioelements in construction materials and their components is critical in determining population exposures [9, 10]. The average indoor absorbed dose rate from terrestrial radiation sources in the air is estimated to be 70 $nGyh^{-1}$. Many countries are interested in assessing radionuclide concentrations in building materials [7, 8, 9]. Natural radionuclides in construction materials are highly active, which may result in higher dose rates indoors. The levels of natural radiation in building materials can vary greatly depending on geological location and geochemical properties. As a result, the natural radioactivity level of various construction materials from various markets must be determined [3, 10, 11].

However, there is no level of reference in Ethiopia, particularly in the north, and most people have built their homes from various building materials extracted primarily from rocks. The area is mostly under igneous and sedimentary rock, which means high radionuclides exist on such rocks. As a result of growing public concern, natural radiation levels in construction materials have been measured in a number of countries [12, 13, 14, 15, 16]. The purpose of this study is to look at the levels of radioactivity of ^{226}Ra, ^{232}Th, and ^{40}K in a building material used in Dessie, to determine exposure level of such

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Figure 1. Sampling areas taken from a Google map satellite image.

Table 1. Results of specific activity, radium equivalent activity, and radiological hazards in construction materials of the Dessie city.

Sample code	Activity (Bq.kg^{-1})			Radium equivalent Raeq (Bqkg^{-1})	Absorbed does D (nGyh^{-1})	Annual effective dose equivalent AEDE (mSvy^{-1})
	^{226}Ra	^{232}Th	^{40}K			
BM1	29.45 ± 2.02	22.99 ± 0.71	45.16 ± 0.25	65.80 ± 3.04	29.38 ± 1.31	0.04 ± 0.002
BM2	23.19 ± 1.02	31.63 ± 1.67	44.13 ± 0.99	71.82 ± 1.02	33.22 ± 1.52	0.04 ± 0.001
WM1	24.73 ± 1.28	14.73 ± 00	45.55 ± 0.34	49.02 ± 1.28	22.10 ± 0.55	0.27 ± 0.001
DERC	27.44 ± 5.91	34.29 ± 4.83	406.75 ± 6.72	107.46 ± 10.92	50.43 ± 4.79	0.06 ± 0.01
WM2	20.17 ± 0.87	10.07 ± 0.55	70.92 ± 1.05	40.03 ± 2.43	18.36 ± 0.76	0.02 ± 0.001
DANC	35.60 ± 4.93	50.29 ± 6.39	378.35 ± 6.13	136.65 ± 14.53	62.80 ± 6.35	0.08 ± 0.01
CHUNGC	29.77 ± 4.11	29.89 ± 4.41	159 ± 3.02	84.79 ± 10.15	38.19 ± 4.42	0.05 ± 0.01
CAPC	22.44 ± 5.91	18.81 ± 3.49	182.09 ± 3.95	63.36 ± 11.21	29.32 ± 4.84	0.04 ± 0.01
mean value	26.59 ± 3.26	26.59 ± 2.76	115.65 ± 2.73	77.37 ± 6.82	35.48 ± 3.02	0.08 ± 0.01

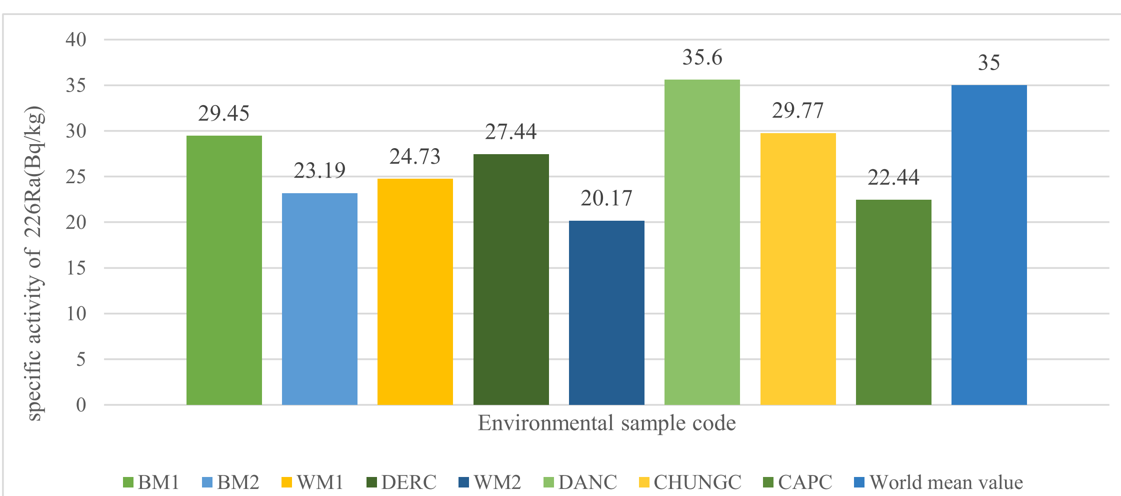

Figure 2. The activity concentration of ^{226}Ra in various environmental samples.

radiation and to evaluate the long term effects of the ionization radiation released using gamma ray spectrometry. The other sections of this paper deals with the methodology, measurements and average values of measured activities. Also radiological hazarods are discussed.

2. Methodology and method

2.1. Selection and preparation of samples

Dessie is a town in north-central Ethiopia. Located in Dessie is a town in Ethiopia's north-central region. It is located at 11°8′N 39°38′E,

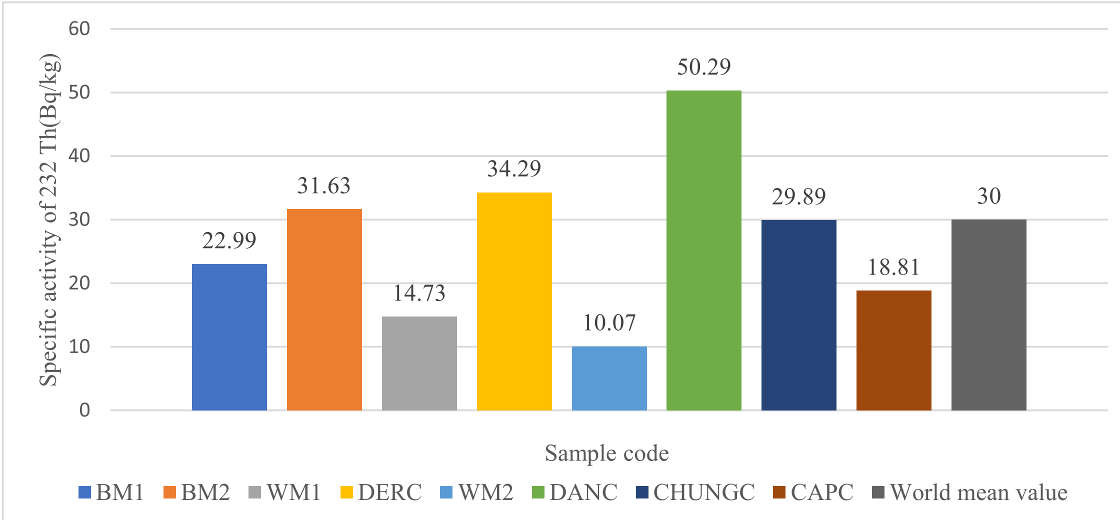

Figure 3. The activity concentration of ^{232}Th in various construction materials.

(Figure 1) with an elevation of between 2,470 and 2,550 m above sea level. Dessie is located 400 km of Addis Abeba. In this paper, the natural radioactivity levels of building materials in Dessie City are determined using a model of B13010 HPGe detector. This work is being done for the first time in the study region, and it will be of great interest to the residents because knowing the levels of radioactivity in construction materials will raise their awareness of the radiological consequences on their health. The selected samples of construction materials (Dangote cement, Derban cement are Ethiopia's first rank cements) were regularly used in the construction of most houses. The detailed sample preparation for different samples was listed in our earlier published paper [17].

3. Radiological hazards variables

3.1. Natural radionuclides in environmental samples

The specific activity of the natural radionuclide was calculated using Eq. (1), where Nc is net counts, ε_γ is detector photo-peak efficiency, I_γ is the probability of the radionuclide of interest transitioning at the respective gamma energy, m is sample mass in kg, and t is sample counting time in sec. NORM (naturally occurring radionuclide materials) activity can be expressed in terms of their unique activity (Bq kg-1) [17, 18,19,20].

$$A = \frac{N_C}{m\varepsilon_\gamma I_\gamma t} \quad (1)$$

The calculated specific activity of ^{232}Th, 226Ra, and 40K are indicated in Table 1.

3.2. Radium equivalent activity (Ra_{eq})

Gamma radiation exposure is typically measured in terms of radium equivalent activity. Raeq can be calculated using Eq. (2) [11, 20].

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

3.3. Dose rate and annual outdoor effective dose

For terrestrial gamma radiation, the external absorbed dose rate (D) in the air at a height of 1m above the ground [11, 21].

$$D = 0.462\,A_{Ra} + 0.603A_{Th} + 0.0417A_K \quad (3)$$

3.4. Annual outdoor effective dose (AEDE)

The average outdoor conversion coefficient from (CF) of 0.7 Sv/Gy [23], the outdoor occupancy factor (OF) is 0.2, and the time spent exposed to gamma rays during a year (T) is 8760 h/y [23, 24, 25].

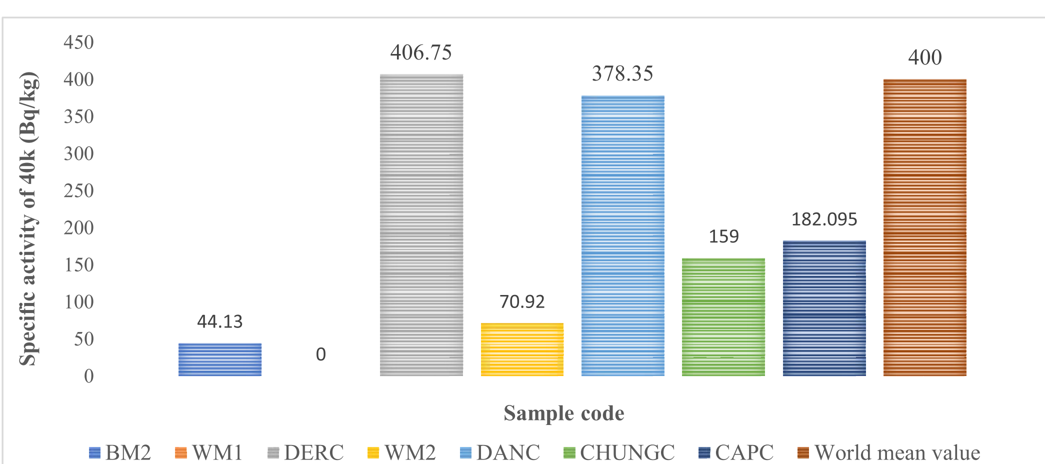

Figure 4. Activity concentration of ^{40}K.

Table 2. Comparison of activity concentrations and radium equivalents of construction materials from around the world.

Country	^{226}Ra/^{238}U (Bq kg^{-1})	^{232}Th(Bq kg^{-1})	^{40}K(Bq kg^{-1})	Ra_{eq} (Bq kg^{-1})	Reference
Saudi Arbia	12.7 ± 3.4	13.2 ± 1.4	64 ± 11.9	39.4	[12]
Bangladesh	60.5 ± 2.1	64.7 ± 2.6	952.2 ± 12.6	226.2 ± 19.5	[34]
Qatar	23.4 ± 0.6	12.2 ± 0.2	158.8 ± 4.3	52.35 ± 1.13	[10]
Vietnam	50 ± 32	43 ± 20	486 ± 228	149 ± 62	[36]
Saudi Arabia	28.82	34.83	665.08	129.84	[35]
Egypt	14.15 ± 0.25	2.75 ± 0.01	7.35 ± 0.03	18.64	[37]
India	25.88	42.82	560.69	130.29	[43]
Iraq	128.75 ± 3.21	7.62 ± 0.42	480.72 ± 7.38	175.67	[13]
Brazil	169	963	824	669	[38]
Pakistan (Punjab)	37 ± 3	28 ± 3	200 ± 14	83.95	[42]
China (Urumqi)	29.1 ± 2.1	15.8 ± 1.9	333.3 ± 83.2	No information	[39]
Nigeria	43.8	21.5	71.7	258	[40]
Algeria	23 ± 5.7	18 ± 2	310 ± 3	73 ± 4.1	[41]
Cameron	8	0.35	19	172.33	[16]
Ethiopia	26.59 ± 3.26	26.59 ± 2.76	115.65 ± 2.73	35.48 ± 3.07	Present Study
World average	35	30	400	370	[21]

$$AEDE = D \times CF \times OF \times T \tag{4}$$

3.5. External hazard index (Hex)

The external radiation hazard index is [12, 22, 26].

$$H_{ext} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \le 1 \tag{5}$$

3.6. Internal hazard index (H_{int})

This hazard can be controlled using the internal hazard index (Hint) provided by [28].

$$H_{int} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \le 1 \tag{6}$$

3.7. External (γ radioactivity) level index (I_γ)

This index, also known as a representative level index, was computed using the following relation [29, 30].

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \le 1 \tag{7}$$

$I_\gamma = 1$ as an upper limit, $I_\gamma \le 1$ corresponds to 0.3 mSv/y, $I_\gamma \le 3$ corresponds to 1mSv/y [22].

3.8. Internal (α radioactivity) level index I_α

The alpha radiation caused by radon inhalation from building materials is calculated using the equation below [31].

$$I_\alpha = \frac{A_{Ra}}{200} \le 1 \tag{8}$$

3.9. Activity utilization index (AUI)

An activity utilization index (AUI) is constructed to make it easier to calculate dose rates in air from different combinations of the three radionuclides in sediments. It is given by the expression [32].

$$AUI = \frac{A_{Ra}}{50} f_{Ra} + \frac{A_{Th}}{50} f_{Th} + \frac{A_K}{500} f_K \le 1 \tag{9}$$

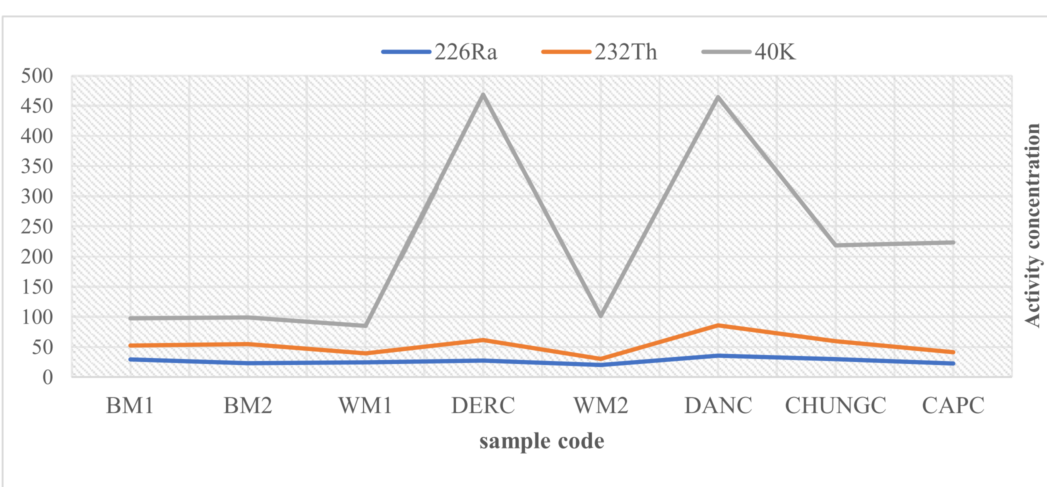

Figure 5. Activity concentration for various construction materials ^{226}Ra, ^{232}Th, ^{40}K.

Table 3. Dessie's radiological hazards index for various building materials.

Samples code	H_{ext}	H_{int}	I_γ	I_α	AUI	ELCR ($\times 10^{-3}$)
BM1	0.18 ± 0.01	0.26 ± 0.01	0.23 ± 0.01	0.15 ± 0.01	0.55 ± 0.03	0.13 ± 0.007
BM2	0.19 ± 0.01	0.26 ± 0.01	0.25 ± 0.01	0.12 ± 0.005	0.59 ± 0.03	0.13 ± 0.003
WM1	0.13 ± 0.03	0.2 ± 0.007	0.17 ± 0.004	0.12 ± 0.006	0.41 ± 0.01	0.1 ± 0.03
DERC	0.29 ± 0.04	0.37 ± 0.05	0.39 ± 0.05	0.14 ± 0.03	0.7 ± 0.11	0.2 ± 0.03
WM2	0.11 ± 0.005	0.16 ± 0.007	0.14 ± 0.006	0.1 ± 0.004	0.31 ± 0.02	0.07 ± 0.003
DANC	0.37 ± 0.04	0.47 ± 0.05	0.49 ± 0.05	0.18 ± 0.03	0.97 ± 0.12	0.27 ± 0.03
CHUNGC	0.23 ± 0.03	0.31 ± 0.04	0.30 ± 0.04	0.15 ± 0.02	0.65 ± 0.09	0.17 ± 0.03
CAPC	0.17 ± 0.03	0.23 ± 0.05	0.23 ± 0.04	0.12 ± 0.03	0.45 ± 0.13	0.13 ± 0.03
Mean value	0.21 ± 0.02	0.28 ± 0.03	0.28 ± 0.03	0.14 ± 0.03	0.58 ± 0.07	0.15 ± 0.02

Where f_{Th} (0.604), f_{Ra} (0.462) and f_K (0.041) are the fractional contributions to the total dose rate in air due to gamma radiation [30].

4. Results and discussion

The mean activity concentrations of natural radionuclides in the eight most commonly used building materials in Dessie City are shown in

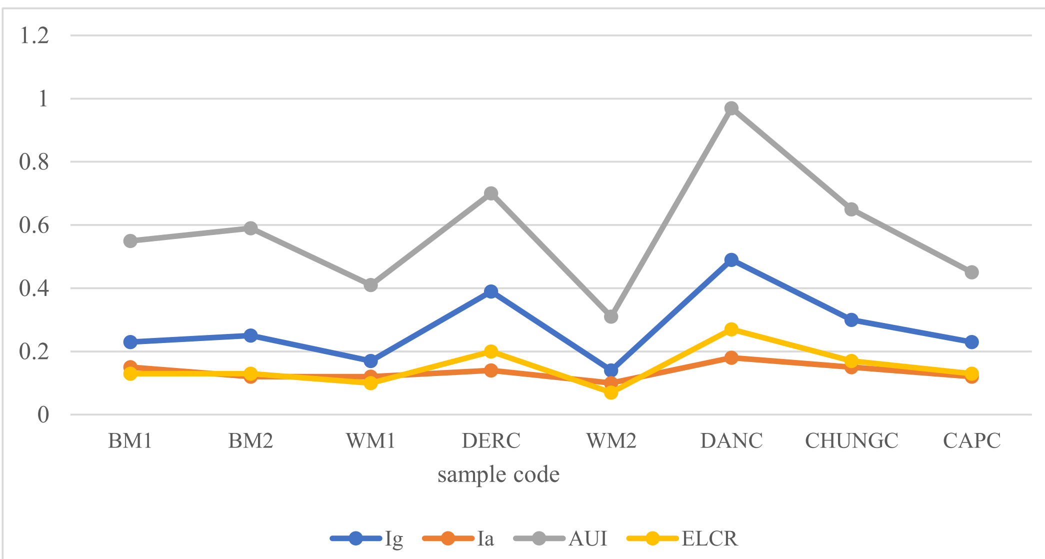

Figure 6. Gamma index, alpha index, activity utilization index, Excess life cancer risk for different building materials.

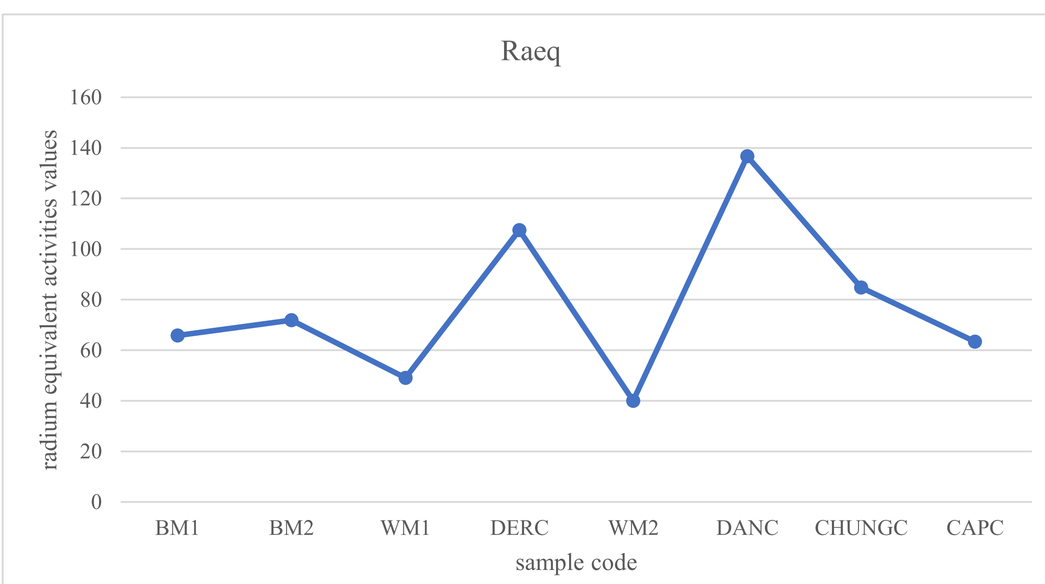

Figure 7. The radium equivalent activities of various construction materials.

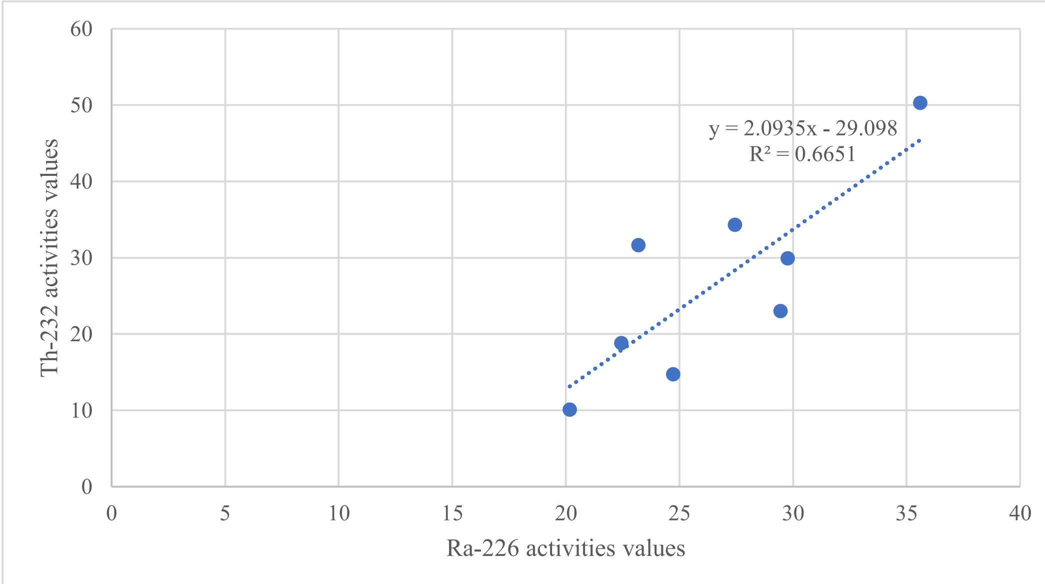

Figure 8. The Pearson correlation for ^{226}Ra and ^{232}Th in various building materials.

Table 4. Pearson correlation matrix between the calculated radionuclides and gamma dose rate.

	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	Raeq (Bqkg^{-1})	D (nGyh^{-1})	AEDE (mSvy^{-1})
^{226}Ra (Bqkg^{-1})	1					
^{232}Th (Bqkg^{-1})	0.82	1				
^{40}K (Bqkg^{-1})	0.56	0.71	1			
Raeq (Bqkg^{-1})	0.83	0.96	0.86	1		
D (nGyh^{-1})	0.81	0.96	0.88	0.99	1	
AEDE (mSvy^{-1})	0.04	-0.17	-0.15	-0.15	-0.16	1

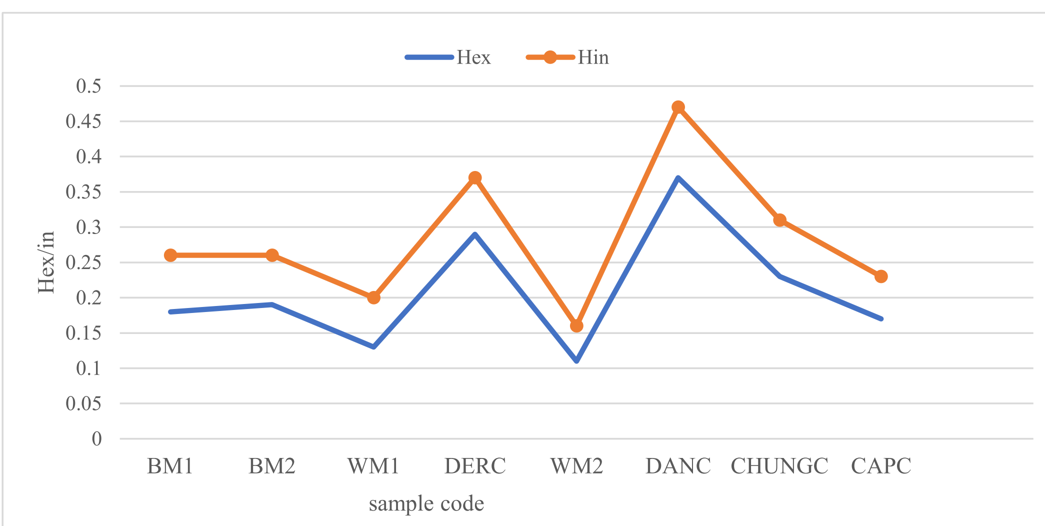

Figure 9. External and internal hazard index for different construction materials.

Table 1. The detection range of ^{226}Ra activity in building materials is depicted in Figure 2, with an average value of 26.59 ± 3.26 Bq kg^{-1}, which is less than the global average value. The sample coded WM2 had the lowest value of 226Ra, while the sample coded DANC had the highest as shown in Figure 5.

The ^{232}Th concentration range in the current samples is shown in Figure 3, with an average value of 26.59 ± 2.76 Bq kg-1, which is lower than the global mean value. Sample code WM2 produced the poorest results, while sample code DANC produced the best. Figure 4 depicts the ^{40}K activity concentration, which has a lower average value of 115.65 ± 2.73 Bq kg^{-1} than the global mean. The BM2 sample code found the lowest value, while the DERC sample code found the highest. Furthermore, as shown in Table 2, the average values we obtained are within the range of comparable global values and other published data [21]. The

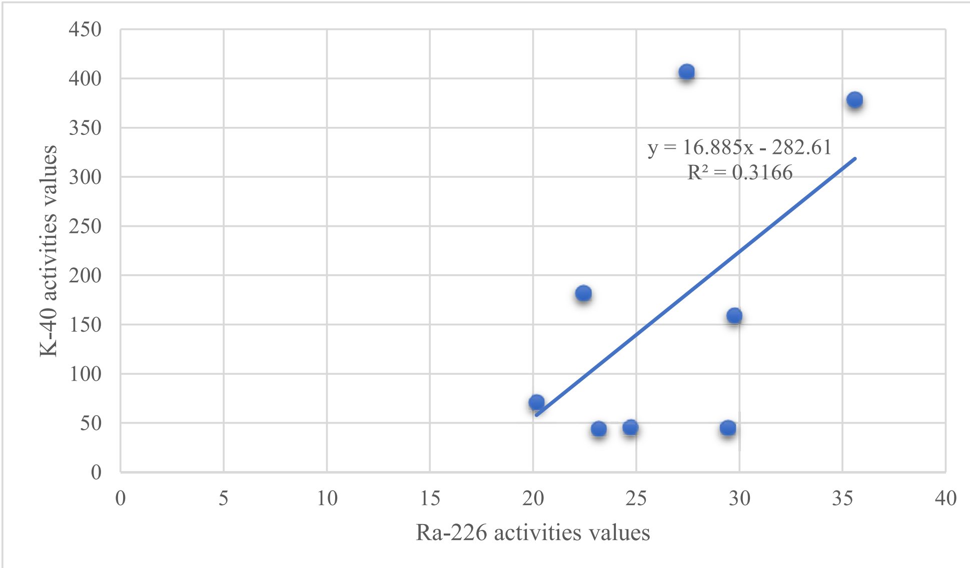

Figure 10. Regression for ^{226}Ra and ^{40}K for various construction materials.

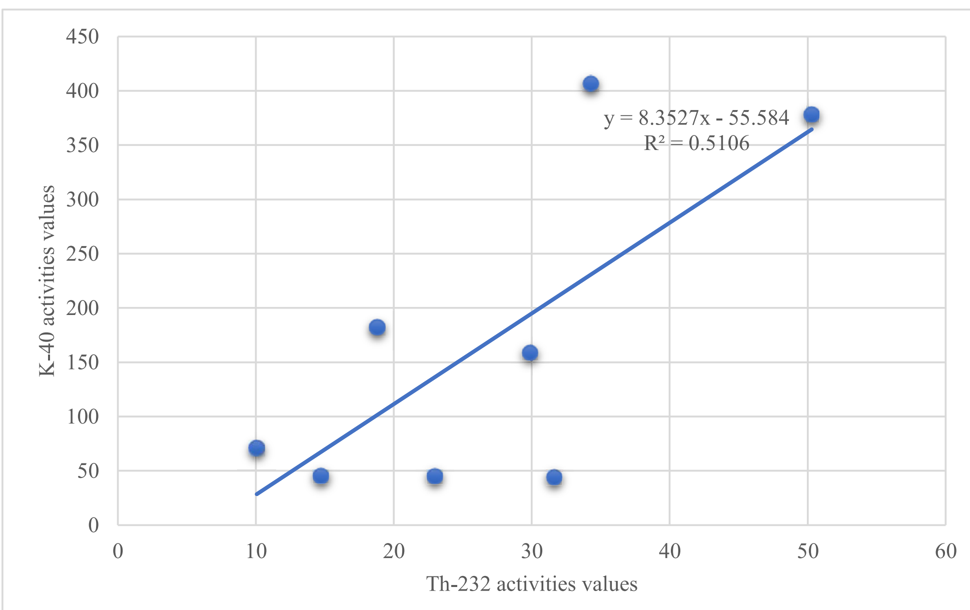

Figure 11. Regression for ^{232}Th and ^{40}K in various building materials.

activity concentrations for 232Th and 40K in the studied city were higher than the published work [21], according to the results of some samples. Table 1 and Figure 3 show that in all cement samples, thorium has a higher activity concentration than radium. The specific activities of ^{226}Ra in this study were higher than those reported for [10, 12, 16, 34, 37, 41, 43]. Table 2 shows that our founding ^{226}Ra activity is lower than that of other countries that have reported works, such as [13, 36, 38, 39, 42]. The specific activities of ^{232}Th in this study were higher than those reported by [10, 12, 13, 16, 37, 39, 41], as shown in Table 2. The specific activities observed by 40K were greater than those reported by [10, 12, 16, 37, 40, 41], according to our findings. It had a lower value than [34, 36, 43]' Iraq [13, 38, 39, 42], as shown in Table 2 (see Figure 5).

The calculated radiological impacts (radium equivalent, external and internal hazard index, alpha index, and activation utilization index) were lower than the global mean values, as shown in Tables 1 and 3, and Figures 6, 7, and 8. Figure 7 depicts the Raeq for construction materials, which has an average value of 35.48 ± 3.07 Bq kg^{-1}. It is less than the global average range values suggested (see Table 4).

Table 1 shows that the calculated absorbed dose rate ranged from 18.36 ± 0.76 to 62.80 ± 6.35 nGy h^{-1}, with an average of 35.48 ± 3.02 nGy h^{-1}. The obtained external hazard indexes (Hex), internal hazard indexes (Hint), gamma index (I), and alpha index of the building samples are shown in Table 3 and Figures 6 and 9. These radiological indices were lower than the recommended level and had no discernible health consequences. However, it will be the subject of future research. The values for outdoor AEDE are shown in Table 1. In the open air, the effective dose ranged from 0.08 to 0.01mSvy^{-1}. Its worth exceeds the global average. According to the Pearson correlation matrix, the correlation of ^{226}Ra with ^{232}Th, ^{226}Ra with D, ^{232}Th with Raeq, ^{232}Th with, ^{40}K with Raeq, ^{40}K with D, Raeq with D has a strong correlation greater than 0.8. It is within the 0.8 ≤ R ≤ 144 strong correlation range as shown in Table 4.

Figure 8 shows that the Pearson correlation for ^{226}Ra and ^{232}Th is close to one (R = 0.82), indicating that the two naturally radioactive elements have a strong positive relationship. This means that the existence of the element radium is dependent on the presence of thorium. In contrast, the relationship between 226Ra and 40K is quite weak (R = 0.56), which is less than one. The correlation between ^{232}Th and 4^{0}K is close to one (R = 0.72), as shown in Figures 8, 10, and 11.

The mean value of the alpha index, according to Table 3, is 0.14 ± 0.03, which is lower than the world recommended value. As a result, the materials used to construct such a city have little impact on the effects of indoor radiation. In the current study, the mean value of the activity utilization index of construction materials is lower than the global average value.

5. Conclusion

In Dessie City, the amount of indoor gamma radiation emitted by construction materials was measured. The activity of natural radioactive isotopes produced in the decay chains of ^{232}Th, ^{226}Ra, and ^{40}K was determined. The mean values of ^{226}Ra and ^{232}Th measured were lower than the global average values. In terms of specific activities, the ^{40}K outperformed the global average. The DANC sample code has higher levels of ^{226}Ra, ^{232}Th specific activity, and radiation danger than the WM2 sample code. In the current study, the average annual effective dosage equivalent was higher than the global mean values. The radiological index was lower than the global average. We found that the average absorbed dose rate of natural radionuclides was lower than the global average. This suggests that such materials have little effect on radon released into the atmosphere. However, because some hazard indexes show a small approach to the global range's minimum value, it necessitates regular monitoring and further investigation.

Declarations

Author contribution statement

Mekuanint Lemlem: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ashok K Chaubey: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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