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Assessment Of Natural Radioactivity And Radiological Health Risk In Soil Samples From South AL-Diwaniyah Governorate, Iraq

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Abstract
This study aimed to evaluate the concentrations of the naturally occurring radionuclides uranium-238, thorium-232, and potassium-40 in soil samples taken from 20 sites in the Diwaniyah Governorate, Iraq. Using a high-purity germanium detector (HPGE), the lifetime cancer risk (ELCR) was calculated based on the measured radioactivity. The results showed clear differences in the concentrations of radioactive elements between sites, where 10.38, 11.45 and 201.31 (Bq/kg) respectively for U-238, Th-232 and K-40. The ELCR value ranged from 0.00019 in the Karamah area to 0.00030 in the Al-Sudair border area. When these values are compared with the internationally permitted (ELCR) value of 0.00029, as recommended by the International Commission on Radiological Protection (ICRP), we find that some sites exceeded this permissible limit, indicating potential radiological health risks in those areas. Accordingly, the study concluded that ongoing assessments are necessary, along with the development of strategies to reduce radiation exposure in areas with high values.

Keywords: *Uranium-238, Thirium-232, Potassium-40, HPGE, ELCR*

INTRODUCTION

Naturally occurring radionuclides such as ^{40}K, ^{238}U, and ^{232}Th have existed in the Earth's crust since its formation and are key contributors to natural background radiation [1-4]. These radionuclides are present in soil, water, air, and vegetation, with soil being a major source of human exposure through both external irradiation and internal pathways like inhalation or ingestion [5]. About 85% of terrestrial gamma radiation originates from these natural sources, primarily through bedrock weathering that releases radionuclides into the soil matrix [6, 7]. Human activities, such as mining and nuclear industry operations, can further elevate radionuclide concentrations in the environment [8].

Radionuclide exposure occurs via inhalation of dust, ingestion of contaminated materials, or direct radiation from soil, especially the top 30 cm [9, 10]. Building materials derived from natural soil can also contribute to radiation exposure, with gamma rays from ^{238}U, ^{232}Th, and ^{40}K causing external exposure, and alpha-emitting radon daughters causing internal risks [11, 12]. Radon inhalation, particularly from aerosols, poses significant health hazards like lung cancer, while radionuclide ingestion through food and water can lead to long-term health effects [13 -16]. This study assesses the concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil samples from Al-Sadeir and Al-Hamzah areas in Al-Diwaniyah Governorate, Iraq, using gamma spectroscopy to evaluate radiological health risks.

RESEARCH AREA

Diwaniyah, the capital of Al-Qadisiyah Governorate, is located approximately 180 km south of Baghdad in central Iraq, as shown in Figure 1. It lies at latitude 31°59′ north and longitude 44°55′ east[17]. Samples were collected from various locations in the governorate, as shown in Table 1.

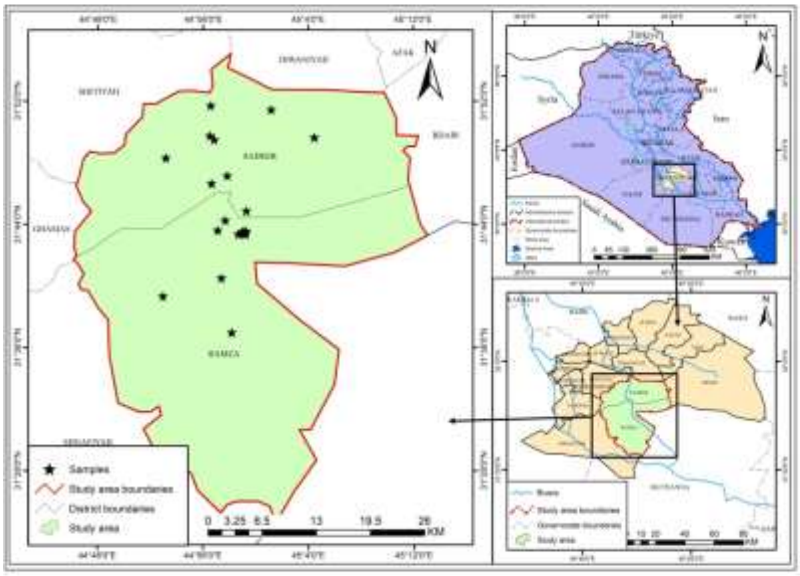

Figure1. Radiological Map of the Research area.

Table 1: Geographical locations for sample collection.

Sample code	Location name	Location Coordinates	
		Longitudes	Latitudes
J_1	Al-Karama	44.985152	31.724313
J_2	Al-Hamza Preparatory School	44.982627	31.725402
J_3	Al-Marsool	44.987452	31.725402
J_4	Al-Hussain	44.951855	31.727167
J_5	Al-Waiely	44.961348	31.763594
J_6	Third Health Center-Alhamzah	44.986753	31.722987
J_7	Al-Ameal	44.961348	31.737894
J_8	Al-Jazar	44.980754	31.737894
J_9	Alrasool	44.986753	31.726506
J_{10}	Hamza border near Stadium	44.977891	31.722987
J_{11}	Al-Sheblweat	44.980624	31.735953
J_{12}	Al-Hamada	44.988244	31.748126
J_{13}	Central park of Sadeer	44.941828	31.829573
J_{14}	Alhour	44.965839	31.765442
J_{15}	Al-Sadeer Border	44.958777	31.731472
J_{16}	Al-Zahraa	44.955338	31.746781
J_{17}	Al-Oqaily	44.950336	31.752621
J_{18}	Um Alfattam health center	44.94704	31.825575
J_{19}	Al-Moukhtar	44.94399	31.777719
J_{20}	Alhamadi village	44,943016	31.862028

MATERIALS AND METHODS

1- Collection and Preparation of Sample

Using a hand drill, twenty soil samples were taken from the Al-Hamzah and Al-Sadier Areas in Diwaniyah Governorate, reaching a depth of 15 cm. The samples was collected by five points were dug within the designated marks for each sample, one meter long and one meter wide. Using a calibrated scale, one kilogram of soil was taken from each sample. Each sample was stored in a designated bag, and its location and other relevant details were recorded. To ensure the accuracy of each sample's location, the geographical coordinates (latitude and longitude) were calculated using Google Maps. The samples were then oven-dried for two hours at 110°C. Each sample was dried, sieved, and ground into a powder. The weight of each sample was determined to be 750 grams and stored in a labeled bag for four weeks to obtain a uranium-thorium balance [18, 19].

2- Instrumentation

High purity germanium detector (HPGE) is one of the most accurate devices for measuring the radioactivity of radioactive elements such as uranium-238, thorium-232, and potassium-40 in environmental samples, such as soil. This detector uses a technique known as gamma ray spectroscopy, which relies on the precise detection of gamma ray photons emitted by radioactive isotopes. The analysis process begins with sample preparation. The soil sample is dried and ground until homogeneous, then accurately weighed and packed into standard containers. The sample is placed inside a lead-lined chamber, shielded from external radiation, and connected to a high-purity germanium detector, which converts the gamma ray photons from the radioactive isotope into electrical pulses. These pulses are recorded and analyzed using specialized software such as Genie 2000, which produces a gamma ray spectrum containing the characteristic energy peaks of each radioactive isotope present in the sample. This allows for the precise identification of radioactive elements based on their different energy lines. For example, potassium-40 is identified via a characteristic line at 1406.8 keV, thorium is identified using an energy line at 583 keV, and uranium is identified via an energy line at 609 keV. This technique is considered highly accurate in measuring low levels of radiation, making it an effective tool in environmental studies, especially in assessing radioactive contamination in soil and its risks to human health [19].

3. CALCULATIONS OF RADIOLOGICAL HAZARD PARAMETERS

3.1. Radium Equivalent Activity (R_{aeq})

Radium equivalent activity model is introduced and used for the assessment of the radiological hazard impacts in soil and other environmental samples containing the unevenly distributed radionuclides ^{238}U, ^{232}Th, and ^{40}K [10, 12].

$$R_{a_{eq}}(Bq/kg) = C_U + 1.344C_{Th} + 0.077C_K \quad (1)$$

Where, C_U, C_{Th}, and C_K represent the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K nuclides respectively. As listed in UNSCEAR report, the recommended limit for safe usage of Ra_{eq} is < 370 Bq/kg [20].

3.2. Absorbed Dose (D_{out})

The absorbed dose rate refers to energy amount of deposited by radiation in a specific organ or tissue mass over a given time period. It is widely utilized to estimate the potential health risks associated with exposure to ionizing radiation from naturally occurring radionuclides. The activity concentrations of the ^{238}U and ^{232}Th, and ^{40}K, in Bq/kg, were employed to calculate the dose rate in nGy/h at 1 meter above plan level through the use of the following equation [21]

$$D_{out} = 0.461 \times C_{Ra} + 0.623 \times C_{Th} + 0.0414 \times C_K \quad (2)$$

$$D_{in} = 1.4D_{out} \quad (3)$$

3.3. Annual Outdoor Effective Dose Equivalent (E_{out})

The outdoor annual effective dose is a metric utilized in radiometric studies to estimate the yearly radiation exposure individuals receive from natural background radiation present in outdoor environments. , calculated from the outdoor absorbed dose rate in air by applying the outdoor occupancy factor of 0.2 and conversion factor of 0.7 Sv/Gy [15, 16]. The annual effective dose received by an individual has been calculated through the use of the aforementioned equation [19]:

$$E_{out}(mSv/y) = D_{out}(nGy/h) \times 8760(h/y) \times 0.7(sv/Gy) \times 0.2 \times 10^{-6} \quad (4)$$

3.4. Representative gamma level index

Gamma level index is among the commonly accepted parameters utilized in the quantification of radiological hazards, particularly where the evaluation of the natural radioactive material hazards within the soil is concerned. Gamma level index can further be applied as a screen for materials that are capable of posing health issues upon their use in the construction field [21]. For the determination of the equivalent gamma level index in the soil, the following was utilized [22]:

$$I_{\gamma} = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_k}{1500} \quad (4)$$

3.5. External (H_{ex}) and Internal (H_{in}) hazard index

Exposure to radiation of gamma from the environment and building materials that contain naturally occurring radionuclides like ^{238}U, ^{232}Th, and ^{40}K. For the protection against health risk is associated with the external and internal hazard index., the aim is to restrict the radiation dose from these sources to a permissible amount of 1(mSv/y) for individual of the public [15, 23]. It is calculated and justified based on the following equation: [20]:

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (5)$$

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (6)$$

3.6 Lifetime Cancer Concentration Ratio (ELCR)

The lifetime cancer risk (ELCR) is a quantitative measure used to assess the risk of cancer resulting from excessive exposure to ionizing radiation throughout an individual's lifetime. The following formula (1) was used to determine the lifetime cancer concentration risk ratio.[20,21]

$ELCR = E_{out} \times A_{lf} \times R_f$ (7)

where E_{out} is the annual external effective dose equivalent. A_{lf} is the random effects risk factor for cancer, which is equal to 0.05 per sievert (Sv). R_f is the life expectancy over 70 years, according to ICRP Report No. 60 for the general population [22].

4- STATISTICAL ANALYSIS

SPSS version 25 was used to conduct appropriate statistical analyses, such as the t-test and calculation of arithmetic means. Standard deviations were calculated. Pearson's correlation coefficient was also used to determine the relationship between radioactive elements.

5. RESULTS AND DISCUSSION

Table 2, indicate that there is a noticeable variation in the concentrations of natural radioactive elements in the soil, represented by uranium-238, uranium-232, and potassium-40, between different sites in the Diwaniyah Governorate, and the results of the current study, as shown in Table 3 which is illustrate the Radiological hazard .This variation is reflected in the values of the increased risk of cancer. The highest recorded concentration of uranium-238 was 13.65 Bq/kg at the Al-Sadeer site, while the lowest concentration was 7.85 Bq/kg at the Al-Karama site. As for thorium-232, the highest concentration was 16.3 Bq/kg in the Al-Zahra site, and the lowest concentration was in the Al-Karamahsite, which recorded 6.425 Bq/kg, while the highest concentration of potassium was 247.6 Bq/kg in the Al-Hoursite, and the lowest concentration was 154.5 Bq/kg in Al-Waiely site, as shown in Figure 2 These values are generally within Normal levels are recognized by the United Nations International Commission on the Effects of Atomic Radiation, which indicates that the global average concentrations of these elements are approximately 35 Bq/kg for uranium, 30 Bq/kg for thorium, and 400 Bq/kg for potassium[23]. They also agree with the findings of some researchers [24]. In terms of health risk assessment for cancer, the ELCR value ranged from 0.000189in the Al-Karama area as the lowest value, and 0.000294 in the Al-Sadeer site as the highest value. Although all of these values may fall within the safe limits set by the International Commission on Radiological Protection, the fact that some sites approach the upper limit indicates the importance of caution, especially in areas containing relatively high concentrations of radioactive elements. The accumulation of radiation dose over a lifetime, even if within permissible limits, may increase the likelihood of biological effects Long-term effects through cellular transformations or cancers, as many studies have indicated statistical associations between increased concentrations of radioactive isotopes in the soil, and the risk of developing some types of cancer, especially chronic exposure. This variation in concentrations is attributed to the nature of the geological composition of the soil in some areas. In addition to physical properties such as granular structure, moisture, and clay content, which affect the soil's ability to retain radioactive elements, human activities such as construction, grazing, and fertilizer use also play a role in redistributing these elements to the surface layer of the soil, and thus in affecting the potential exposure of the population

Table 2: Concentrations of ^{238}U, $^{232}Th$and ^{40}K in soil samples, with cancer risk assessment

Code	Location	U-238	Th -232	K-40	ELCR
J_1	Al-Karama	7.85	6.425	7.85	0.000189
J_2	Al-Hamza Preparatory School	9.4	9.1	9.4	0.000231
J_3	Al-Marsool	10.7	9.85	10.7	0.000242
J_4	Al-Hussain	10.8	15.45	10.8	0.000284
J_5	Al-Waiely	8.75	8.7	8.75	0.0002
J_6	Third Health Center-Alhamzah	9.4	9.1	9.4	0.00021
J_7	Al-Ameal	9.25	10.75	9.25	0.000231
J_8	Al-Jazar	10.9	10.375	10.9	0.000242
J_9	Alrasool	10.5	9.225	10.5	0.000242
J_{10}	Hamza border near Stadium	10.6	13.75	10.6	0.000273
J_{11}	Al-Sheblweat	11.05	13.625	11.05	0.000273
J_{12}	Al-Hamada	12	11.05	12	0.000263
J_{13}	Central park of Sadeer	11.3	10.2	11.3	0.000252
J_{14}	Alhour	10.65	12.675	10.65	0.000294
J_{15}	Al-Sadeer Border	13.65	12.5	13.65	0.000294
J_{16}	Al-Zahraa	10.65	16.3	10.65	0.000284
J_{17}	Al-Oqaily	10.2	9.85	10.2	0.000231
J_{18}	Um Alfattam health center	10.1	10.825	10.1	0.000252
J_{19}	Al-Moukhtar	10.2	9.8	10.2	0.000231
J_{20}	Alhamadi village	8.5	12.025	8.5	0.000231

Table 3: Radiological Hazard for Soil Samples in Area of Study

Code	H_{ex}	H_{in}	I_{γ}	D(ngy.h^{-1})	D in (ngy.h^{-1})	AEDE out(msv.y^{-1})	AEDE in(msv.y^{-1})	R_{eaq} (Bq/kg)
J_1	0.082	0.104	0.234	14.89	20.84	0.018	0.073	30.67
J_2	0.102	0.128	0.289	18.30	25.62	0.022	0.089	38.04
J_3	0.106	0.135	0.297	18.89	26.45	0.023	0.092	39.56
J_4	0.129	0.158	0.355	22.41	31.37	0.027	0.109	47.83
J_5	0.089	0.113	0.248	15.73	22.03	0.019	0.077	33.08
J_6	0.095	0.120	0.264	16.78	23.49	0.020	0.082	35.23
J_7	0.104	0.129	0.289	18.31	25.63	0.022	0.089	38.55
J_8	0.108	0.137	0.301	19.10	26.74	0.023	0.093	40.13
J_9	0.106	0.134	0.298	18.92	26.50	0.023	0.092	39.39
J_{10}	0.121	0.150	0.337	21.27	29.78	0.026	0.104	45.16
J_{11}	0.122	0.152	0.339	21.46	30.04	0.026	0.105	45.54
J_{12}	0.117	0.149	0.326	20.70	28.98	0.025	0.101	43.47
J_{13}	0.112	0.142	0.312	19.82	27.76	0.024	0.097	41.48
J_{14}	0.129	0.157	0.362	22.90	32.06	0.028	0.112	47.84
J_{15}	0.133	0.169	0.369	23.47	32.86	0.028	0.115	49.28
J_{16}	0.130	0.159	0.359	22.58	31.61	0.027	0.110	48.39
J_{17}	0.103	0.131	0.289	18.35	25.70	0.022	0.090	38.49
J_{18}	0.112	0.139	0.313	19.83	27.77	0.024	0.097	41.51
J_{19}	0.103	0.131	0.288	18.26	25.56	0.022	0.089	38.30
J_{20}	0.105	0.128	0.291	18.36	25.70	0.022	0.090	38.93

The radiological hazard assessment of soil samples from Al-Sadeir and Al-Hamzah areas in Al-Diwaniyah Governorate indicates that all measured parameters fall within internationally accepted safety limits. The radium equivalent activity (R_{aeq}) values, ranging from 30.67 to 49.31 Bq/kg, are significantly below the recommended maximum of 370 Bq/kg, suggesting no substantial radiological threat. Similarly, the external (H_{ex}) and internal (H_{in}) hazard indices, which vary between 0.082–0.133 and 0.104–0.169 respectively, are far less than the safety threshold of 1, indicating minimal risk of both external gamma exposure and internal exposure through radon inhalation. The gamma index (Iγ), used to assess the suitability of materials for building, also remained below the unity limit (0.234–0.369), affirming the soil's safety for construction purposes. Absorbed dose rates in air (D) ranged from 14.89 to 23.47 nGy/h, which is well below the global average of 59 nGy/h, while indoor dose rates (D_{in}) followed a similar trend. Annual effective dose equivalents (AEDE), both outdoor (0.018–0.028 mSv/y) and indoor (0.073–0.115 mSv/y), were substantially lower than the global safety threshold of 1.0 mSv/y, confirming negligible health risks. These results collectively suggest that the soils in these areas are radiological safe for public and environmental health.

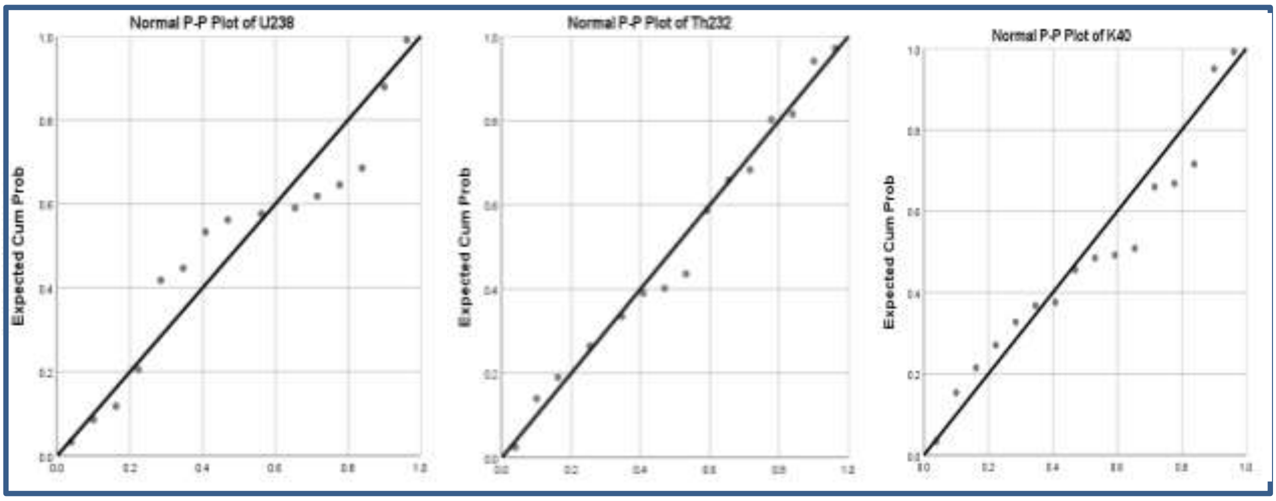

Figure 2:The moderate distribution of radioactive elements

In Table 4, the results of the Pierce correlation coefficient analysis between the common natural elements uranium-238, threium-232, and potassium-40 indicate a positive, strong, and statistically significant relationship at the significance level of 0.01 between the concentration of uranium in the soil and the concentration of potassium, as shown in Figure 4, which shows the regression line and the coefficient of determination R^2.

Table 4: Pearson's correlation coefficient between radioactive elements

Correlations				
		U-238	Th-232	K-40
U238	Pearson Correlation	1	.457	.674**
	Sig. (2-tailed)		.075	.004
	N	20	20	20
Th232	Pearson Correlation	.457	1	.304
	Sig. (2-tailed)	.075		.253
	N	20	20	20
K40	Pearson Correlation	.674**	.304	1
	Sig. (2-tailed)	.004	.253	
	N	20	20	20
**. Correlation is significant at the 0.01 level (2-tailed).				

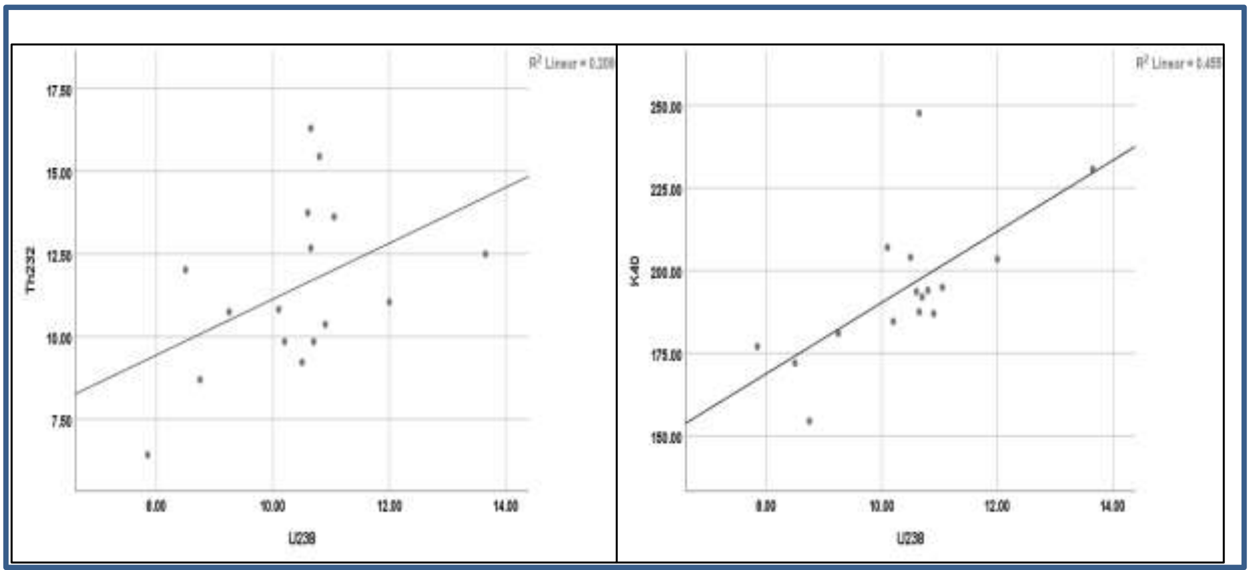

Figure 3: Regression line and coefficient of determination R^2 for uranium with threonine and potassium.

The concentrations of uranium-238, thorium-232, and potassium-40 have been compared to some studies that were calculated in different countries, as shown in Table 5.

Table 5. Comparison of concentrations (U-238, Th-232, and K-40) with other countries

country	U-238	Th-232	K-24	Reference
India	57.7	87.4	143	25
Kuwait	36	6	227	26
Pakistan	20.9	42.6	550	27
Jordan	39	23	233	28
Saudi Arabia	20	20.1	306	29
Iraq	10.38	11.45	201.31	Present study

CONCLUSION

Concentrations of uranium-238, threonium-232, and potassium-40, were measured. The results showed clear differences in the concentrations of radioactive elements between sites, where 10.38, 11.45 and 201.31 (Bq/kg) respectively for U-238, Th-232 and K-40. The ELCR value ranged from 0.00019 in the Karamah area to 0.00030 in the Al-Sudair border area. When these values are compared with the internationally permitted (ELCR) value of 0.00029, as recommended by the International Commission on Radiological Protection (ICRP), we find that some sites exceeded this permissible limit, indicating potential radiological health risks in those areas.

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CONFLICT OF INTEREST: I declare that the authors have no competing interests

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