Natural radioactivity in soil samples at the University of Kufa

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Abstract. Humans are continuously exposed to environmental radioactivity from both natural and artificial radionuclides. Soil is one of the most significant contributors to terrestrial radioactivity. The purpose of this study is to determine the levels of natural radioactivity in radionuclide concentrations ^{238}U, ^{232}Th, and ^{40}K, as well as the radiological hazard factors, in soil samples collected from five faculties at the University of Kufa, Al-Najaf governorate, Iraq, using the gamma-ray spectroscopy. In the study area, the mean specific activities of ^{238}U, ^{232}Th, and ^{40}K, in Bq kg^{-1} , were 12.72±4.82, 5.15±1.70, and 277.54±73.52, respectively. The mean values for various radiological risk indices – including the gamma exposure rate (X), external hazard (H_{ex}), absorbed dose rate (D_r), annual effective dose equivalent (outdoor) (AEDE), and excess lifetime cancer risk (ELCR×10^{-3}) were 93.37±16.31 μR/h, 0.11±0.02, 20.56±3.56 nGy/h, 0.03±0.004 mSv/year, and 0.09±0.02, respectively. All measured specific activities and calculated radiological hazard indices were found to be below the corresponding world average values and recommended safety limits.

1 Introduction

Humans are exposed to radiation in their living situations from both artificial and natural sources [1,2]. Natural radiation originates from terrestrial or extraterrestrial sources, whereas artificial radiation stems from anthropogenic activities [3]. The environment hosts both natural and manufactured radioactive isotopes. Radionuclides, which have various biogeochemical cycles and high mobility, can influence the environment through bioaccumulation and are detrimental to both the environment and human health. The external radiation dose to humans is caused by radioactive isotopes in the environment, whereas the internal dose results from the ingestion or inhalation of isotopes. Studies on the dose-effect relationships of radioactive materials have contributed to a better understanding of radiation-related hazards as well as played a significant role in formulating radiation protection laws [4,5]. Natural radioactivity in rock and soil is mostly caused by such radionuclides as uranium, thorium, and potassium, specifically the uranium-238, thorium-232 decay chains, and potassium-40. The released radiation is caused by the decay of the parent and daughter radionuclides. The natural radiation of soil and rock is determined by their mineralogical makeup. Rocks containing relatively high quantities of uranium, thorium, and potassium have a high natural radioactivity. Soils often mirror the radioelement concentrations of the

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parent rock [6]. The radioactivity levels in soil provide data on both natural and artificial sources, which is crucial for environmental monitoring and public exposure assessment. Assessment of natural radioactivity in soil is critical for determining the degree of variation in natural activity over time due to radioactivity emission.

Though natural radioactivity exists in soils and rocks across the globe, the amount in certain locations fluctuates significantly [7]. From an environmental perspective, soil can be considered a source of radioactive hazard as it exposes people to radiation all the time. Agricultural soil acts as a primary reservoir for radionuclides, facilitating their uptake by crops and subsequent entry into the human food chain. [8]. Radioactive contamination is a significant issue because of the harm it inflicts on the environment, diverse organisms, and human health. Numerous investigations have looked into natural radioactivity [9-11]. This study aimed to assess the concentrations of ^{238}U, ^{232}Th, and ^{40}K in the soil samples collected from five faculties at the University of Kufa using the gamma ray spectroscopy.

2 Materials and methods

2.1 Area of study

Najaf Governorate is located in southwestern Iraq, approximately 160 km southwest of Baghdad, at about 31°59′N latitude and 44°19′E longitude. It is rising seventy meters above sea level. The University of Kufa, one of the Iraqi universities that is positioned in the Al-Najaf governorate, includes 21 faculties and residential buildings for its professors and staff. The examination was conducted at 17 sites in the five faculties at the University of Kufa to determine the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K using a NaI (Tl) detector.

2.2 Sample collection and preparation

Seventeen soil samples were collected from five faculties at the University of Kufa, Al-Najaf Province, Iraq, from July to August 2024. The GPS was used to locate and record sample sites' positions, as depicted in Table 1. 3-4 soil samples were taken from each site from multiple points around the perimeter of the building (front, back, right, left). Each soil sample was collected at 15 cm deep. After being collected, the soil samples were placed in polypropylene plastic bags with corresponding labeling. Subsequently, the bags were conveyed to the nuclear laboratory of the Department of Physics, Kufa University, for additional processing and examination. The samples were oven-dried at 100°C for 24 hours to remove moisture and achieve a constant dry weight. Afterward, the dried samples were crushed into a fine powder using an electric blender and passed through a 1 mm mesh screen. Subsequently, the specimens were carefully contained and relocated into Marinelli beakers (500 ml). The samples were affixed with appropriate codes that indicated the sample name and pertinent information. Following that, the samples were then sealed and stored for four weeks to allow secular equilibrium to be established between the ^{238}U and ^{232}Th, along with their short-lived daughters [12, 13].

Table 1. Locations coordinates in the study area.

Name of faculty	Sample code	Direction of sample	Coordinates	
			latitude	longitude
Faculty of Languages	front	A1	32.001355	44.022238
	behind	A2	32.001383	44.022233
	right	A3	32.001374	44.022218

Continuation of Table 1.

Name of faculty	Sample code	Direction of sample	Coordinates	
			latitude	longitude
Faculty of Arts	right	A4	32.001368	44.022258
	left	A5	32.001389	44.022326
	behind	A6	32.001384	44.022236
	front	A7	32.001366	44.022268
Faculty of Engineering	front	A8	32.001481	44.022155
	left	A9	32.001473	44.022159
	behind	A10	32.001492	44.022144
	right	A11	32.001525	44.022157
Faculty of Computer Science and Mathematics	front	A12	32.001493	44.022196
	left	A13	32.001497	44.022213
	behind	A14	32.001533	44.022182
Faculty of Physical Education and Sports Science	front	A15	32.001443	44.022118
	left	A16	32.001461	44.022087
	right	A17	32.001420	44.022118

2.3 Detection systems

A gamma spectrometry apparatus was utilized to measure the concentrations of ^{238}U, ^{232}Th, and ^{40}K in the soil samples. The system utilized a gamma-ray detector, namely a scintillation detector, which incorporated a NaI (Tl) crystal measuring "3 x 3" in size. The detector was supplied by Alpha Spectra, Inc. (Model 12I12/3). The gadget was connected to a multi-channel analyzer (MCA), the ORTEC Digi Base, featuring a 4096-channel Analog Digital Converter (ADC). The system utilized the "MAESTRO-32" software program on the laboratory PC to acquire and analyze data. The voltage utilized in this study was set at 788 V, which is within the stable operating range of the detector. The spectrometer was calibrated for gamma-ray energy by obtaining spectra from well-known radioactive reference sources, such as ^{137}Cs, ^{54}Mn, ^{60}Co, ^{22}Na, and ^{152}Eu. During the calibration phase, a strong linear relationship was seen between gamma energy and channel number, with a high correlation coefficient of 0.99. The detector's energy resolution in this work was 7.9% for the 661.66 keV energy emitted by the ^{137}C standard source. By contrast, NaI(Tl) detectors have a resolution range of 5-10% when measuring the 661.66 keV gamma energy of ^{137}Cs. As a consequence of the poor resolution of a NaI(Tl) system at low energies of the gamma-ray, which do not have well-separated photo-peaks, it is only possible to measure the specific activity at high gamma energies, such as those gained in our results from the gamma rays released by the daughters of ^{238}U and ^{232}Th, which are in a state of secular equilibrium with them. The activity of ^{40}K was measured directly via its 1460.8 keV gamma-ray peak. As a result, the specific activity of ^{238}U was calculated using the gamma-lines 1764.5 keV (^{214}Bi). The activity of ^{232}Th was derived from the 2614.5 keV gamma-ray line of its daughter nuclide ^{208}Tl. The five specified calibrations established a linear correlation with a high correlation coefficient of 0.98 when calibrating the link between the absolute efficiency of the photo-peak detector and the energy of gamma rays. All samples were exposed for a length of 18,000 seconds. Before conducting the sample tests, the laboratory assessed the background gamma radiation level at the location. This was done by using an empty Marinelli beaker with a plastic container identical to the ones used for measuring the samples. A background spectrum was acquired for an equal counting time and subtracted from the sample spectra.

2.4 Radiological hazard indicators

The following formula calculates the soil sample-specific activity in Bq kg^{-1}:

$$A = \frac{Net\ area}{I_\gamma\ \varepsilon\ M\ T} \quad (1)$$

The count obtained by subtracting the background for the gamma radiation peak corresponds to the net area. The symbol T represents the duration of spectrum capture, measured in seconds. The symbol M represents the mass of the dried sample, measured in Kg. The symbol ε represents the absolute efficiency of the detector. In addition, some radiological characteristics are linked with the existence of ^{238}U, ^{232}Th, and ^{40}K, including "Radium Equivalent Activity (Ra_{eq})", "External Hazard Index (H_{ex})", "Absorbed dose rate in the air (D_r)", "Annual Effective Dose Equivalent (AEDE)", "exposure rate of gamma-ray ($\dot{X}$)," "the representative level index ($I_{\gamma r}$)", and "Excess Lifetime Cancer Risk (ELCR)" have been evaluated by employing mathematical equations (2-8)

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

$$H_{ex} = \frac{A_u}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3)$$

$$D_r\ = 0.462\ A_U + 0.604\ A_{Th} + 0.0417 A_K \quad (4)$$

$$AEDE = [D_r \times 8760\ \times OF \times 0.7] \times 10^{-6} \quad (5)$$

$$\dot{X}\ = 1.90\ A_U + 2.82\ A_{Th} + 0.197 A_K \quad (6)$$

$$I_{\gamma r} = \left(\frac{1}{150}\right) A_U + \left(\frac{1}{100}\right)\ A_{Th} + \left(\frac{1}{1500}\right) A_K \quad (7)$$

$$ELCR = AEDE\ \times DL\ \times RF \quad (8)$$

The symbols A_U, A_{Th}, and A_k denote the specific activity of ^{238}U, ^{232}Th, and ^{40}K, respectively. The occupancy factor (OF) is 0.2 for outdoor spaces and 0.8 for indoor spaces. The abbreviation "DL" refers to "Mean Duration of Life," which is commonly estimated to be approximately 70 years. RF denotes the Risk Factor.

3 Results and discussion

The specific activity of ^{238}U, ^{232}Th, and ^{40}K for soil samples of Kufa University are listed in Table 2. The values provided are expressed in Bq kg^{-1} of dry weight. For the specific activity of ^{238}U, the minimum value was 5.38 Bq kg^{-1} in sample coded A9 (Faculty of Engineering), while the maximum value was 23.09 Bq kg^{-1} in sample coded A2 (Faculty of Languages) with a mean 12.72±4.82 Bq kg^{-1}. The activity concentration of ^{232}Th ranged from 2.29 Bq kg^{-1} (sample A13, Faculty of Computer Science and Mathematics), to 9.90 Bq kg^{-1} (sample A1, Faculty of Languages) with a mean value of 5.15±1.70 Bq kg^{-1}. The activity concentration of ^{40}K ranged from 127.48 Bq kg^{-1} (sample A15, Faculty of Physical Education and Sports Science), to 394.91 Bq kg^{-1} (sample A10, Faculty of Engineering), with a mean value of 277.54±73.52 Bq kg^{-1}. The data presented in Table 2 indicates that the specific activity of ^{40}K is greater than that of ^{238}U and ^{232}Th and can be expressed in the following order: ^{40}K > ^{238}U > ^{232}Th. All results of specific activity for ^{238}U, ^{232}Th, and ^{40}K are lower than the worldwide levels of 33 Bq kg^{-1}, 45 Bq kg^{-1}, and 420 Bq kg^{-1}, respectively, according to UNSCEAR [14].

Table 2. Results of specific activity for ^{238}U, ^{232}Th, and ^{40}K in the studied areas.

Sample code	Specific activity in Bq kg^{-1}		
	^{238}U	^{232}Th	^{40}K
A1	5.59±0.48	9.90±0.39	246.95±3.32
A2	23.09±0.97	4.11±0.25	261.26±3.42
A3	12.41±0.71	5.99±0.30	281.25±3.55
A4	12.36±0.71	4.73±0.27	253.88±3.37
A5	8.26±0.58	6.31±0.31	301.78±3.67
A6	11.62±0.69	5.59±0.29	361.81±4.02
A7	18.53±0.87	4.26±0.25	220.92±3.14
A8	19.59±0.90	5.03±0.28	257.86±3.40
A9	5.38±0.47	4.34±0.26	364.90±4.04
A10	10.47±0.66	6.87±0.32	394.91±4.20
A11	14.62±0.78	6.72±0.32	347.36±3.94
A12	14.62±0.78	3.73±0.24	327.68±3.83
A13	15.57±0.80	2.29±0.19	339.18±3.89
A14	7.56±0.56	3.87±0.24	195.37±2.96
A15	11.21±0.68	4.91±0.27	127.48±2.39
A16	10.72±0.66	4.76±0.27	264.84±3.44
A17	14.66±0.78	4.15±0.25	170.82±2.76
Mean±SD	12.72±4.82	5.15±1.70	277.54±73.52

While the measured activity concentrations of the examined radionuclides are essential, they alone are insufficient for a comprehensive assessment of radiological hazards. The assessment of radiation hazards holds significant importance in environmental protection studies due to the continuous influence of soil on inhabitants. Therefore, the calculation of radiological hazard indices is crucial for assessing the potential risks to students and staff in the studied areas. The radiological hazard indices ($\dot{X}$, H_{ex}, $I_{\gamma r}$, Ra_{eq}, D_r, AEDE, ELCR) for the soil samples have been determined and presented in Table 3. These indices were calculated based on ^{238}U, ^{232}Th, and ^{40}K specific activity. The range and average values (in parentheses) for $\dot{X}$, H_{ex}, $I_{\gamma r}$, Ra_{eq}, D_r, AEDE, ELCR are: 60.27 μR h^{-1} to 117.07 μR h^{-1} (93.37±16.31 μR h^{-1}), 0.08 to 0.14 (0.11±0.02), 0.21 to 0.40 (0.32±0.06), 28.05 Bq kg^{-1}to 50.98 Bq kg^{-1}(41.64±6.95 Bq kg^{-1}), 13.46 nGy h^{-1} to 25.46 nGy h^{-1} (20.56±3.56 nGy h^{-1}), 0.020 mSv year^{-1} to 0.030 mSv year^{-1} (0.03±0.004 mSv year^{-1}), and 0.06 to 0.11 (0.09±0.02), respectively. Ra_{eq} values in soil samples were lower than the global median of 370 Bq kg^{-1}. The values of AEDE are less than the worldwide results of 0.50 mSv y^{-1}. The results of H_{ex}, $I_{\gamma r}$ were lower than the worldwide limit set by ICRP which equals to 1 [15]. The results of the calculated absorbed dose rate (D_r) were lower than the world mean (55 nGy/h). The estimated results of ELCR were lower than the world average of 0.299 ×10^{-3} [4].

Table 3. Results of radiological hazard parameters of natural radioactivity in the study area.

Sample code	Exposure (μR h^{-1})	H_{ex}	$I_{\gamma r}$	Ra_{eq} (Bq kg^{-1})	D_r (nGy h^{-1})	AEDE (mSv y^{-1})	ELCR× 10^{-3}
A1	87.18	0.105	0.301	38.76	18.86	0.023	0.081
A2	106.92	0.133	0.369	49.08	24.04	0.029	0.103
A3	95.87	0.115	0.330	42.63	21.08	0.026	0.090
A4	86.85	0.104	0.299	38.68	19.16	0.023	0.082
A5	92.93	0.109	0.319	40.51	20.21	0.025	0.087
A6	109.14	0.128	0.375	47.48	23.84	0.029	0.102
A7	90.73	0.112	0.313	41.63	20.34	0.025	0.087
A8	102.22	0.126	0.353	46.65	22.85	0.028	0.098
A9	94.34	0.107	0.323	39.68	20.32	0.025	0.087

Continuation of Table 3.

A10	117.07	0.137	0.402	50.70	25.46	0.031	0.109
A11	115.16	0.138	0.396	50.98	25.30	0.031	0.109
A12	102.86	0.122	0.353	45.19	22.67	0.028	0.097
A13	102.85	0.121	0.353	44.96	22.72	0.028	0.098
A14	63.75	0.076	0.219	28.13	13.97	0.017	0.060
A15	60.27	0.076	0.209	28.05	13.46	0.017	0.058
A16	85.97	0.102	0.296	37.92	18.87	0.023	0.081
A17	73.23	0.091	0.253	33.76	16.41	0.020	0.070
Mean±SD	93.37±16.31	0.11±0.02	0.32±0.06	41.64±6.95	20.56±3.56	0.03±0.004	0.09±0.02

4 Conclusion

This research measured the specific activity of ^{238}U, ^{232}Th, and ^{40}K from soil samples collected from five faculties at the University of Kufa in the Al-Najaf province, Iraq, using the NaI (Tl) system. The specific activity of studied radionuclides is in the order $^{40}K > ^{238}U > ^{232}Th$. All results of ^{238}U, ^{232}Th, and ^{40}K were below the worldwide levels. The determined radioactive hazard factors for the chosen soils indicate that they are radiologically safe because they are less than the global average values. It can be concluded that the natural background radiation from the studied soils collected from five faculties at the University of Kufa is within the normal range and poses no significant radiological risk to the university population. It is advised that the natural radioactivity of soil in this area be measured regularly to avoid exposing the population to unnecessary levels of radiation.

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