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The radioactivity assessment of local and imported rice in Erbil city

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ABSTRACT

This study involved collecting samples of 27 different rice varieties from local markets in Erbil, Kurdistan region, Iraq. Measurements were performed using the NaI (Tl) scintillation detector system. The specific activity of ^{232}Th, ^{226}Ra, and ^{40}K radionuclides in the rice samples ranged (0.13-1.79) Bq kg^{-1}, (0.16-8.3) Bq kg^{-1}, and (77.1-180) Bq kg^{-1}, respectively. The total annual effective dose (A_E) in the rice samples ranged from 32.37 μSv y^{-1} to 116.42 μSv y^{-1}, which obtained due to an ingestion of radionuclides via rice consumption, the values of A_E were lower than the global value of 290 μSv y^{-1}, as reported by UNSCEAR 2008. The excess lifetime cancer risk (ELCR) ranged from 0.113 to 0.407×10^{-4}, below the acceptable value of 2.9×10^{-4}, as reported by UNSCEAR 2000. In addition, the internal hazard index (H_{in}) ranged from 0.33 to 0.70 and the external hazard index (H_{ex}) ranged from 0.025 to 0.046. Estimated radiological indices were below the overall limit value of 1. The study used multivariate statistical techniques including descriptive statistics, histogram and Pearson correlation analysis to investigate the relationship between specific natural radioactivity and associated radiological parameters. The study utilized multivariate statistical analysis techniques, including descriptive statistics, histograms, and Pearson correlation analyses, to investigate the relationship between the specific activity of natural radionuclides and the associated radiological parameters. Thus, the studied rice brands are radiologically safe as an essential foodstuff in Erbil Governorate.

1.Introduction

Accumulation of radioactive materials in our environment has been happening since the formation of the Earth. The concentrations of these substances are not homogeneous and vary from place to place, and are affected by different terrain characteristics (Kessaratikoon et al., 2023). Life on Earth developed in parallel with the environmental, gamma and charged particle processes. However, it is recognized that ionizing radiation may pose a risk to life and biological processes. The food chain is mainly affected by natural radionuclides from soil. Therefore, the presence of high concentrations of radionuclides in soils may be a major cause of radioactive contamination of foodstuffs, as different plant species exhibit different levels of radionuclide uptake (Arije et al., 2022). The earth's crust has been home to long-lived, naturally occurring radionuclides such as ^{232}Th, ^{238}U and ^{40}K since its formation. The presence of radionuclides in various plant parts relies on the chemical properties of the soil and plants, along with the physiological and biological processes, climate, and agricultural practices (Samad et al., 2024). Technological progress has increased the amount of naturally occurring radioactive elements that may be released into the environment by agricultural practices such as the use of fertilisers and pesticides (Hassan et al., 2017). The release of radionuclides can lead to their ingestion or inhalation, resulting in their accumulation on the surfaces of plants, as well as in water and soil. As a result, radionuclides may enter the human body via the food chain and pose a serious radiological risk to human health in many regions of the world (Ibikunle et al., 2019; Samad et al., 2024). Rice is a basic diet for almost half of the world's population of more than three billion people, particularly those living in poverty (Custodio et al., 2016; Kiple and Ornelas, 2000).

Several previous studies of natural radioactivity in rice samples have been carried out (Sithong et al., 2024), (Alrefae and Nageswaran, 2013), (Al-Zahrani, 2016), (Hussein, 2019), (Leiphrakpam and Maisnam, 2023), (Mgbeokwere et al., 2023), and (Huang et al., 2023). The main objectives of this study are to assess the specific activity of natural radionuclides ^{232}Th, ^{226}Ra, and ^{40}K in rice imported for consumption by the population of Iraq and Kurdistan and to calculate related radiological parameters, including the annual effective dose and the Excess lifetime cancer risk associated with the consumption of these radionuclides. The results of this study can be used to provide basic data on radioactivity levels in rice for future research in Erbil.

2. Materials and methods

2.1 Sample collection

A total of twenty-seven (27) rice samples commonly consumed in Erbil city: two local and the available brands imported from various countries, were purchased from major supermarkets located in Erbil city, the city is situated in the southern region of Kurdistan, Iraq, sharing its western border with Syria, its eastern border with Iran, and its northern border with Turkey (Figure 1). The samples collected are immediately brought to the laboratory. Each sample is labelled with a label to identify the brand name and date of the sample.

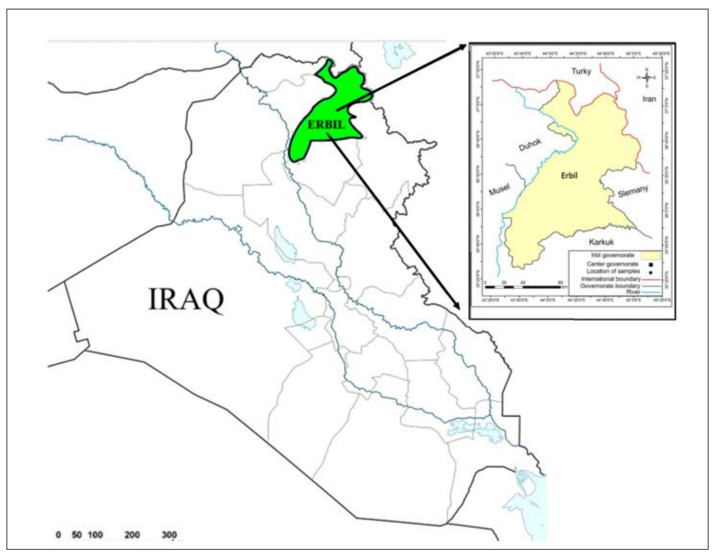

Figure 1: Map of Erbil of the Kurdistan Region in Iraq (Samad et al., 2024)

2.2 Sample preparation

The samples were dried at 85 oC for 5 to 6 hours, to prevent moisture (Kessaratikoon et al., 2023). The dried samples were then pulverized and processed using a sieve to create particles of uniform size (Alhiall and Alsalihi, 2019). Equal portions (0.65 kg) were taken from each rice sample using a highly sensitive digital weighing balance with a percentage of ± 0.02%. Next the samples were sealed in Marinelli beakers for a month to achieve equilibrium between the isotopes of the natural decay series of ^{226}Ra and ^{232}Th (Nahar et al., 2018).

2.3 Gamma ray spectrometry analysis

Measurements were made using a high-efficiency gamma spectrometry system. The system includes a NaI (Tl) scintillation detector (SILENA-model-3S3), with a resolution of 7.4% for ^{137}Cs at an energy line of 661.7 keV. To reduce background interference, the detector is shielded with a 10 cm thick layer of lead, along with an additional 0.2 cm layer of copper (Samad et al., 2024). The detector energy calibration with a range of 186 to 1273 keV was achieved utilizing gamma-ray point sources (^{137}Cs, ^{22}Na, and ^{226}Ra). However, ^{152}Eu, ^{60}Co, and ^{137}Cs standard sources were utilized to calibrate the systems' efficiency. To minimize counting error, samples were placed in a Marnelli beaker, set atop the detector, and the counting time was established at 216000 seconds for each sample. The specific activity of ^{232}Th, ^{226}Ra, and ^{40}K in Bq kg^{-1} was measured from the photo peak energy line of (583 keV at ^{208}Ti, 911 keV at ^{228}Ac) for ^{232}Th, (352 keV at ^{214}Pb, 609.3 keV at ^{214}Bi) for ^{226}Ra, and 1460 keV for ^{40}K.

3. Radiological Parameters

3.1. Specific activities

The specific activity (A_s) of natural radionuclides in the studied samples is calculated by using equation 1 (Gilmore, 2008, Samad et al., 2023):

$$A_s = C/(\rho \times m \times t \times \varepsilon) \quad (1)$$

In which ρ is the probability of emitting gamma ray, m in Kg is the mass of sample, C in count sec^{-1} is the net peak area at energy of radionuclides, t in sec is the counting time, and ε is the efficiency of detector for a particular energy of gamma ray.

3.2. Annual effective dose (A_E)

The annual effective dose (A_E) due to an ingestion of radionuclides via rice consumption, A_E is calculated by using equation 2 (Asaduzzaman et al., 2015):

$$A_E = D \times A_s \times I \quad (2)$$

The dose conversion factor D = 230 nSv Bq^{-1}, 280 nSv Bq^{-1} and 6.2 nSv Bq^{-1} for ^{232}Th, ^{226}Ra, and ^{40}K, respectively, A_s is the specific activity of natural radionuclides and the annual rice intake I= 36 kg y^{-1} (Abojassim et al., 2016).

3.3. Excess lifetime cancer risk ($ELCR$)

The excess lifetime cancer risk is calculated using equation 3 (Jafir et al., 2022, Arije et al., 2022):

$$ELCR = A_E \times D_L \times R \quad (3)$$

where, A_E is the annual effective dose, R is the risk factor = 0.05 Sv^{-1}, and D_L is the average human life span taken as (70) years.

3.4. Hazard Indices

It was established that the samples' external gamma radiation might be limited by the internal hazard index (H_{in}) and external hazard index (H_{ex}). The formula (4 and 5) is used to compute the H_{in} and H_{ex} (Sayyed et al., 2024) :

$$H_{in} = \frac{A_{sRa}}{185} + \frac{A_{sTh}}{259} + \frac{A_{sK}}{4810} \leq 1 \quad (4)$$

$$H_{ex} = \frac{A_{sRa}}{370} + \frac{A_{sTh}}{259} + \frac{A_{sK}}{4810} \leq 1 \quad (5)$$

where $A_{s_{Ra}}$, $A_{s_{Th}}$, and A_{s_K} represent the specific activity of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides, respectively.

4. Results and Discussion

The specific activity of the radionuclides ^{232}Th, ^{226}Ra, and ^{40}K measured in the collected 27 rice samples are detailed in Table 1 and illustrated in Figures 2 and 3. According to Table 1, the specific activity of Thorium (^{232}Th) ranged from 0.13 Bq kg^{-1} in RC8 (Sheefa) to 1.79 Bq kg^{-1} in RC10 (Sorgul), with a mean value of 0.69 Bq kg^{-1}. The comparisons presented in Table 2 indicate that the mean specific activity of ^{232}Th in this study exceeds that found in Taiwan (0.62Bq kg^{-1}), Kuwait (0.48 Bq kg^{-1}), and Bangladesh (0.17 Bq kg^{-1}), while being significantly lower than the levels reported in Saudi Arabia (1.19 Bq kg^{-1}), Iraq (39.11 Bq kg^{-1}). Thailand (2.76 Bq kg^{-1}), Nigeria (7.08 Bq kg^{-1}), Malaysia (1.03 Bq kg^{-1}), India (8.78 Bq kg^{-1}), and Iraq (2.46 Bq kg^{-1}). The specific activity of ^{226}Ra ranged from 0.16 Bq kg^{-1} in RC3 (Hana) to 8.3 Bq kg^{-1} in RC18 (Arroz), with a mean of 2.65 Bq kg^{-1}, below that recorded in Thailand (3.01 Bq kg^{-1}), Nigeria (5.86 Bq kg^{-1}), Iraq (84.12 Bq kg^{-1}) and India (6.86 Bq kg^{-1}), but higher than that observed in Iraq (2.59 Bq kg^{-1}), Saudi Arabia (1.08 Bq kg^{-1}), Kuwait (0.62Bq kg^{-1}), Bangladesh (1.09 Bq kg^{-1}), and Malaysia (1.42 Bq kg^{-1}). The specific activity of ^{40}K ranged from 77.1 Bq kg^{-1} in RC19 (Bilbaak) to 180 Bq kg^{-1} in RC12 (Shahana), with a mean of 123.96 Bq kg^{-1}, which is higher than Thailand (29.46 Bq kg^{-1}), Nigeria (113.8 Bq kg^{-1}), Iraq (17.76 Bq kg^{-1}), India (29.71 Bq kg^{-1}), Malaysia (72.15 Bq kg^{-1}), Taiwan (24.05 Bq kg^{-1}), Saudi Arabia (83.09 Bq kg^{-1}), Kuwait (48.6 Bq kg^{-1}), Bangladesh (4.70 Bq kg^{-1}), with the exception of Iraq (435 Bq kg^{-1}), as shown in Table 2. The results indicate that ^{40}K exhibited the highest activity concentration rice among the radionuclides, followed by ^{226}Ra and ^{232}Th.This phenomenon can be attributed to the smaller mass of ^{40}K when compared to ^{232}Th and ^{226}Ra, which results in its more effective transfer to crops than that of heavier isotopes (Ahmed and Samad, 2014).

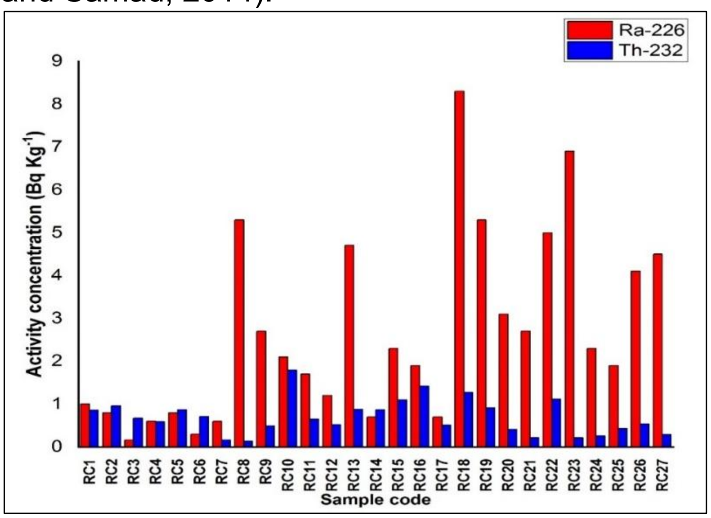

Figure 2: Specific activity of ^{226}Ra and ^{232}Th radionuclides in rice samples

Table 1. Specific activity of ^{232}Th, ^{226}Ra, and ^{40}K radionuclides in rice samples analyzed

Sample code	Brand	Specific activity (Bq kg^{-1})		
		^{232}Th	^{226}R	^{40}K
RC1	Mahmud	0.86	1	92.4
RC2	Smar	0.96	0.8	158
RC3	Hana	0.67	0.16	131
RC4	Ahmed	0.59	0.6	121
RC5	Heva	0.87	0.8	139
RC6	Krmanj	0.71	0.3	160
RC7	Bilal	0.16	0.6	110
RC8	Sheefa	0.13	5.3	126
RC9	Muzhda	0.49	2.7	166
RC10	Sorgul	1.79	2.1	137
RC11	Nawros	0.65	1.7	140
RC12	Shahana	0.52	1.2	180
RC13	Gulabahar	0.88	4.7	140
RC14	Bakhtiari	0.87	0.7	106
RC15	Royal	1.1	2.3	174
RC16	Mihad	1.42	1.9	169
RC17	Khosh	0.51	0.7	124
RC18	Arroz	1.27	8.3	92.5
RC19	Bilbaak	0.91	5.3	77.1
RC20	Friend	0.41	3.1	81
RC21	Kobane	0.21	2.7	102
RC22	Kalar (local)	1.12	5	113
RC23	Bazian (local)	0.21	6.9	91.2
RC24	Loras	0.26	2.3	115
RC25	Nabin	0.43	1.9	101
RC26	Seian	0.54	4.1	108
RC27	Zer	0.29	4.5	92.8
Mean		0.69	2.65	123.96

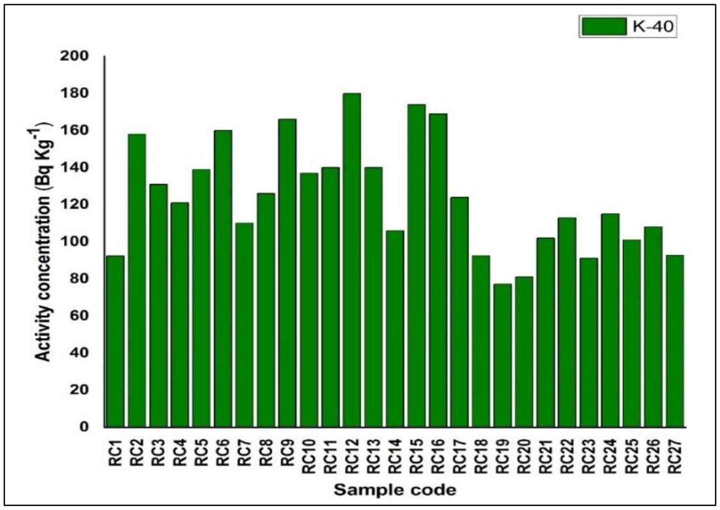

Figure 3: Specific activity of ^{40}K radionuclide in rice samples

Table 2. The specific activity of ^{232}Th, ^{226}Ra and ^{40}K radionuclides in rice samples was measured and compared with results from other countries

country	Mean specific activity (Bq kg^{-1})			
	^{232}Th	^{226}Ra	^{40}K	Reference
Tailand	2.76	3.01	29.46	(Sithong et al., 2024)
Malaysia	1.03	1.42	72.15	(Alsaffar et al., 2015)
Iraq	39.11	84.12	435	(Najam et al., 2015)
Kuwait	0.48	0.62	48.6	(Alrefae and Nageswaran, 2013)
Bangladesh	0.17	1.09	4.7	(Nahar et al., 2018)
Saudi Arabia	1.19	1.08	83.09	(Al-Zahrani, 2016)
Iraq	2.46	2.59	17.76	(Hussein et al., 2018)
Nigeria	7.08	5.86	113.8	(Mgbeokwere et al., 2023)
India	8.78	6.86	29.71	(Leiphrakpam and Maisnam, 2023)
Taiwan	0.62	_	24.05	(Huang et al., 2023)
Iraq	0.69	2.65	124	present study

Table 3, Figures. 4 and 6, show the estimated values of annual effective dose (A_E) due to an ingestion of radionuclides via rice consumption and excess lifetime cancer risk (ELCR) for rice samples. Table 3 presents the average intake of ^{232}Th, ^{226}Ra, and ^{40}K, along with a range of estimated total annual effective doses. The data indicates that the mean total annual effective doses ranged from 32.37 μSv y^{-1} in RC7 (Bilal) to 116.42 μSv y^{-1} in RC18 (Arroz). It can be concluded that the population under study does not exhibit a significant radiological risk when the calculated dose value is compared to 0.29 mSv y^{-1} (UNSCEAR, 2008). Among the various natural radionuclides, potassium (^{40}K) is the leading contributor to the intake dose, representing 45.76%. Following this, radium (^{226}Ra) contributes 44.87%, while thorium (^{232}Th) accounts for 9.37% of the total dose, as illustrated in Figure 5. Figure 6, shows the excess lifetime cancer risk (ELCR) ranged from 0.113×10^{-4} in RC3 to 0.407×10^{-4} in RC18, with a mean of 0.213×10^{-4}, are all much lower than the worldwide mean of 2.9×10^{-4} (UNSCEAR, 2000). Figure 7, shows the internal hazard index (H_{in}) and external hazard index (H_{ex}) ranged from 0.33 to 0.70 and from 0.025 to 0.046, with mean of 0.49 and 0.035, respectively, and are therefore much below the suggested limit of one.

Table 3. The calculated radiological hazard indices (H_{ex}, H_{in}), excess lifetime cancer risk (ELCR) and Annual effective dose (A_E) for the studied rice samples

Sample Code	H_{ex}	H_{in}	ELCR ×10^{-4}	Annual effective dose (A_E) in (μSv y^{-1})			
				^{232}Th	^{226}Ra	^{40}K	total
RC1	0.025	0.36	0.134	7.22	10.22	20.91	38.35
RC2	0.039	0.61	0.182	8.06	8.18	35.76	51.99
RC3	0.030	0.51	0.129	5.62	1.64	29.65	36.91
RC4	0.029	0.47	0.135	4.95	6.13	27.38	38.47
RC5	0.034	0.54	0.164	7.30	8.18	31.46	46.94
RC6	0.037	0.62	0.158	5.96	3.07	36.21	45.23
RC7	0.025	0.43	0.113	1.34	6.13	24.89	32.37
RC8	0.041	0.52	0.293	1.09	54.17	28.51	83.77
RC9	0.044	0.66	0.242	4.11	27.59	37.57	69.27
RC10	0.041	0.54	0.236	15.03	21.46	31.00	67.49
RC11	0.036	0.55	0.191	5.46	17.37	31.68	54.51
RC12	0.043	0.70	0.201	4.37	12.26	40.73	57.36
RC13	0.045	0.57	0.305	7.39	48.03	31.68	87.10
RC14	0.027	0.41	0.135	7.30	7.15	23.99	38.45
RC15	0.047	0.68	0.252	9.23	23.51	39.38	72.12
RC16	0.046	0.66	0.244	11.92	19.42	38.24	69.58
RC17	0.029	0.48	0.138	4.28	7.15	28.06	39.50
RC18	0.046	0.40	0.407	10.66	84.83	20.93	116.42
RC19	0.034	0.33	0.277	7.64	54.17	17.45	79.25
RC20	0.027	0.33	0.187	3.44	31.68	18.33	53.45
RC21	0.029	0.41	0.184	1.76	27.59	23.08	52.44

RC22	0.041	0.46	0.301	9.40	51.10	25.57	86.07
RC23	0.038	0.39	0.325	1.76	70.52	20.64	92.92
RC24	0.031	0.46	0.181	2.18	23.51	26.02	51.71
RC25	0.028	0.40	0.161	3.61	19.42	22.86	45.88
RC26	0.036	0.44	0.248	4.53	41.90	24.44	70.88
RC27	0.032	0.38	0.243	2.43	45.99	21.00	69.43
Mean	0.035	0.49	0.213	5.85	27.12	28.05	61.03

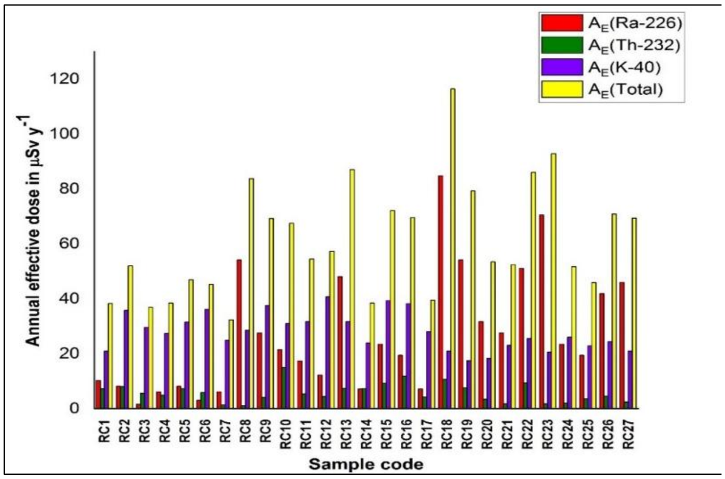

Figure 4: The annual effective dose (AE) of each radionuclide (^{226}Ra, ^{232}Th, ^{40}K) present in rice samples

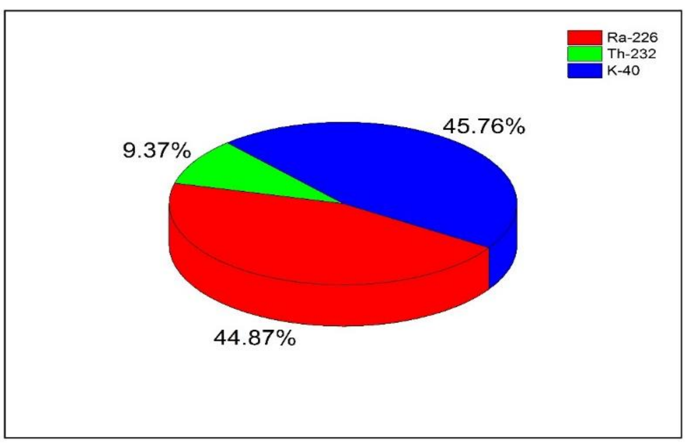

Figure 5: Cumulative annual effective dose distribution for ^{232}Th, ^{226}Ra and ^{40}K in rice samples studied

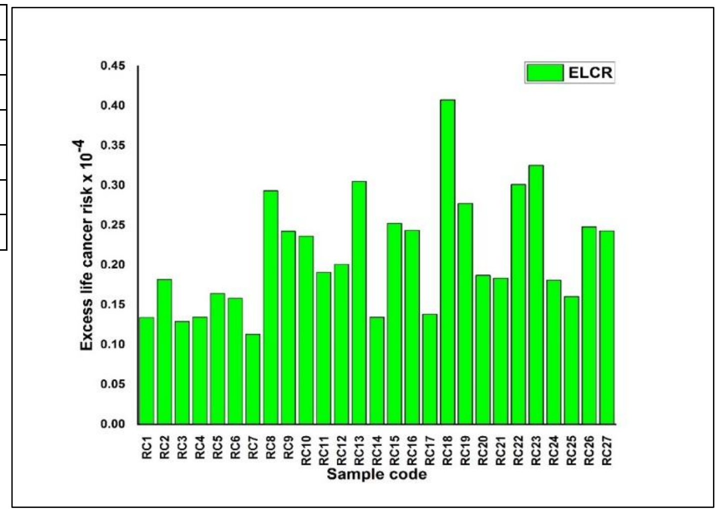

Figure 6: Excess lifetime cancer risk (ELCR) for the studied rice samples

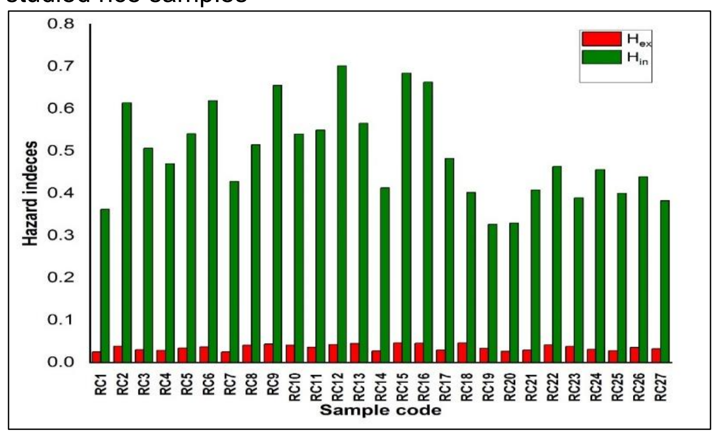

Figure 7: External hazard index (Hex) and internal hazard index (Hin) for the studied rice samples

The statistical properties of the data were assessed using the SPSS-21 software. Key measured variables, such as the mean, median, skewness, kurtosis, and standard deviation, are presented in Table 4. Kurtosis, which indicates the shape of the probability distribution for a random variable, provides insight into the distribution's relative peak or flatness. When compared to a normal distribution, a distribution with positive kurtosis indicates a higher peak and heavier tails. This could indicate that there are more outliers in the data or a higher level of variability. In contrast to a normal distribution, a distribution with negative kurtosis suggests a relatively flat peak and lighter tails. This implies that the data may have less variability or fewer outliers. The shape of the distributions for the corresponding parameters can be evaluated by looking at the kurtosis values in Table 4.

Distributions with higher variance would be indicated by positive kurtosis, whereas distributions with lower variance or a more uniform distribution of values would be suggested by negative kurtosis values, even distribution of values.

Table 4. Descriptive statistics of rice sample

Radio - nuclides	Maximum	Minimum	S.D.	Mean	Skewness	Variance	Kurtosis
^{226}Ra	8.30	0.16	2.16	2.65	0.99	4.67	0.34
^{232}Th	1.79	0.13	0.41	0.69	0.77	0.168	0.50
^{40}K	180.00	77.1	29.69	123.96	0.35	881.71	-0.91

A thorough analysis of all radionuclides' frequency distributions was performed to generate the histograms depicted in Figures 8, 9, and 10. The histogram for ^{40}K indicates a normal distribution, which is typically bell-shaped. In contrast, the distributions for ^{226}Ra and ^{232}Th revealed some multimodal features. The occurrence of multimodal distributions among radioactive elements serves to illustrate the range of minerals found within the rice samples.

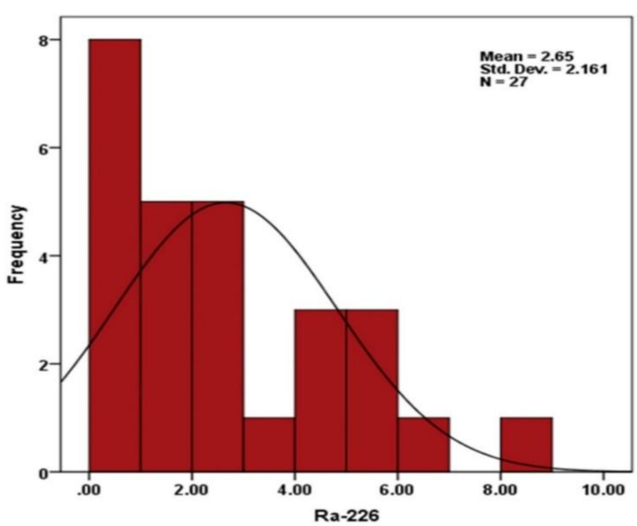

Figure 8: Frequency distribution of ^{226}Ra radionuclide

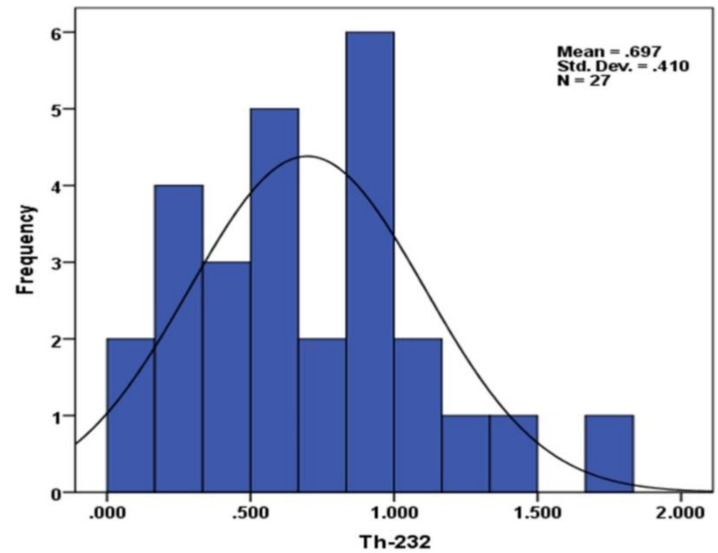

Figure 9: Frequency distribution of ^{232}Th radionuclide

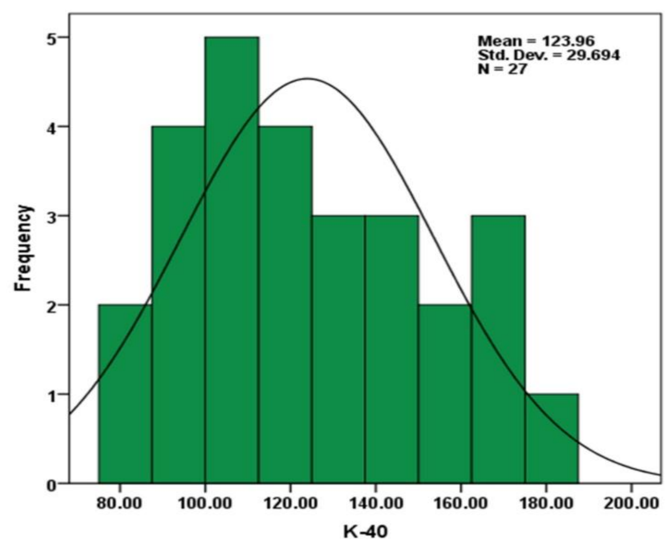

Figure 10: Frequency distribution of 40K radionuclide

Correlation coefficient methodology quantifies the linear relationship between any two continuous variables. Significant correlations are marked in bold (* or **) in Table 5, representing strong correlations that fall between 0.4 and 1. The table indicates high positive correlations, with a perfect monotonic relationship coefficient of 1 as the correlation between annual effective dose (AE) and excess lifetime cancer risk (ELCR). Potassium (40K) shows a high correlation with Hin, and Hex parameters, while 40K has a weak correlation with ^{232}Th and a negative correlation with other parameters. Thorium (^{232}Th) shows a high correlation with the Hex parameter, while it has a weak correlation with other parameters. Radium (^{226}Ra) shows a high correlation with Hex, AE, and ELCR parameters, while it has a weak correlation with other parameters. All samples exhibited three radionuclides that contribute to gamma ray emissions. This observation could be linked to significant concentrations of ^{226}Ra, which play a crucial role in determining the annual effective dose (AE) and the excess lifetime cancer risk (ELCR).

Table 5. Pearson correlation coefficients between natural radionuclide and radiological parameters determined

	^{40}K	^{232}Th	^{226}Ra	H_{ex}	H_{in}	A_E	ELCR
^{40}K	1						
^{232}Th	0.32	1					
^{226}Ra	-0.49	0.02	1				
H_{ex}	**0.56****	**0.54****	**0.43***	1			
H_{in}	**0.99****	0.33	-0.40	**0.63****	1		
A_E	-0.15	0.29	**0.93****	**0.73****	-0.06	1	
ELCR	-0.15	0.29	**0.93****	**0.73****	-0.06	**1.00****	1

5. Conclusions

The analysis of natural radioactivity in 27 rice samples is typically conducted to obtain information about the levels of radioactivity risk from natural radionuclides in the consumed rice in Erbil. The total effective dose received by an adult from rice intake each year is considerably less than the worldwide average value of 290 µSv y^{-1}. Additionally, the risk of cancer linked to rice consumption is found to be beneath the permissible limit of (2.9×10^{-4}) for radiological risk. The radiological hazard effects obtained from this study are within the values related to recommended safety limits internationally accepted, so consequently, there is no radiation risk associated with eating these rice types. Future research can make use of the present findings as fundamental radiological data.

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