ZANCO Journal of Pure and Applied Sciences

TYPE: Origin article
DOI http://dx.doi.org/10.21271/ZJPAS.38.1.7

OPEN ACCESS

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RECEIVED :06 /05/2025
ACCEPTED :06/08/ 2025
PUBLISHED :28/ 02/ 2026

KEYWORDS:

Rice,
Scintillation Detector NaI (TI),
Natural Radioactivity,
Erbil City,
Effective dose.

Assessment of Natural Radioactivity Level in Rice Available in Erbil City, Iraq, and Its Radiological Indices

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ABSTRACT

Natural radioactivity is present in all food types, including rice, and gradually enters the body through the digestive tract. An important metric for estimating population exposure from natural radionuclide intake during regular food consumption is the amount of natural radioactivity present in food. This study used a gamma-ray spectrometer to evaluate the radioactivity levels of naturally occurring radioactive elements in rice samples available in Erbil markets. The ^{226}Ra, ^{232}Th, and ^{40}K activity concentration values in rice samples were within the range (0.212 ± 0.023 to 0.671 ± 0.160) Bq kg^{-1}, (0.104 ± 0.018 to 0.289 ± 0.025) Bq kg^{-1}, and (48.677 ± 3.534 to 153.876 ± 3.885) Bq kg^{-1}, respectively. The activity concentration of the primordial radionuclides was used to determine the annual effective radiation doses from eating rice samples. The total annual effective dosage (IAED) resulting from taking radioactive nuclear in rice varied from (16.600 ± 2.511 to 44.873 ± 2.688) μSv y^{-1}, with the average value of (27.407 ± 7.862) μSv y^{-1}, and was below the UNSCEAR reference limit of 290 μSv y^{-1}. Additionally, the parameters for radiological hazards in rice grains were computed and compared to the international dose safety limit for rice crops.

1.Introduction

Primordial radionuclides were naturally formed during nucleosynthesis and increased their concentrations by human intervention through military, medical, and other activities. Our bodies contain naturally occurring radioactive materials, and every human environment contains naturally occurring radioactive nuclides, such as air, soil, food, water, and plants (Aswood et al., 2013). Animals can acquire these radioactive nuclides by consuming plants, while plants can acquire them through their roots or leaves. Eating plants as food and drinking water can directly or indirectly expose humans to radionuclides, as can consuming animal products, such as milk or meat (Alharbi and El-Taher, 2013).

Thorium-232, Potassium-40, and Uranium-238 are the primary sources of external radiation exposure for the general population. Long-term exposure to high radiation levels can cause cancer and other health problems. The half-lives of radionuclides ^{232}Th, ^{238}U, and ^{40}K are 1.40 × 10^{10} years, 4.47 × 10^{9} years, and 1.23 × 10^{9} years, respectively (Al-Hassan et al., 2014). It has been determined that uranium and the byproducts of its radioactive decay are carcinogenic, which causes cancer to grow in situations in which human exposure exceeds defined safety thresholds. Additionally, these compounds present increased dangers related to radiation exposure from the environment (Chen et al., 2021). Radionuclides, both natural and man-made, enter plants through the roots and then pass straight through the leaves (James et al., 2011).

Environmental gamma radiation and charged particles have all been present during the evolution of life on Earth. Ionizing radiation, however, is known to be hazardous to biological processes and life. Naturally occurring radionuclides are mainly derived from the soil, which impacts the chain of food. Therefore, as different plant types have variable rates of radionuclide uptake, high radionuclide concentrations in soils can be a primary cause of food contamination by radioactivity (Arije et al., 2022). There has been some improvement in the levels of the natural radionuclides ^{232}Th, ^{238}U, and ^{40}K in soil and plants, according to radiometric surveys conducted around the globe (Alrefae and Nageswaran, 2013). Physiological and biological processes, climate, agricultural techniques, and the chemical characteristics of the soil and plants all influence the occurrence of radionuclides in different plant components (Samad et al., 2024). Our daily lives use more and more radioactive sources, which could raise the risk of radiation exposure and pollution (Al-Gazaly et al., 2014).

The transfer factor (TF) measures the movement of radionuclides from soil to plant systems. Transfer factor is a frequently used assessment model in soil-plant activity concentration ratios. Fertilizers contain radionuclides from the decay series of Potassium, Uranium, and Thorium. It indicates the degree of bioaccumulation of particular radionuclides in materials like crops (Ehlken and Kirchner, 2002). In addition, the amount of radionuclides in fertilizers varies by nation and where the constituents are sourced. The immediate impact of natural radioactivity on human safety necessitates measurement and evaluation. The majority of the world's nations have conducted studies on ambient radioactivity and naturally occurring radiation (Tufail, 2012).

Radionuclides can be inhaled or consumed when they are released, and they can build up in varying concentrations in soil, water, and plant surfaces. Following that, these components are moved and recycled by natural processes. Therefore, there are significant radiological dangers to human health since radionuclides can enter the human system through the food chain (Hassan et al., 2017). Several international organizations, including the World Health Organization (WHO), have expressed the importance of conducting a study on radioactive contamination of food worldwide (Organization, 1988).

This study's primary goals are to measure the levels of naturally occurring radionuclides ^{232}Th, ^{40}K, and ^{226}Ra in imported and locally produced rice in the Iraqi Kurdistan region, as well as to compute the related radiological parameters, such as the annual effective dosage associated with ingesting these radionuclides. Regarding the radioactivity of rice in Erbil, the results might also

serve as a starting point for future comparisons.

2. Materials and Methods

2.1 Rice Sampling and Preparation

Twelve samples of rice commonly consumed in Erbil City, the variable brands imported from various countries and locally produced, were collected from major supermarkets located in Erbil City within the Kurdistan region of Iraq. After collecting, all rice samples were ground into a powder form using the milling machine. From each rice sample, a 1000 g amount is taken and kept in Marinelli beakers for 30 days to achieve radioactivity equilibrium between radium and its decay products.

2.2 Measurement and Analysis System

Figure 1 shows a gamma-ray spectrometry used to quantitatively analyze. The majority of radioactive sources emit gamma rays with various levels of intensity and energy. When these emissions are detected, a gamma-ray energy spectrum is produced and examined using an energy-calibrated gamma spectroscopy apparatus.

An instrument used for gamma spectrometry is a 3" x 3" NaI (Tl) detector (CRYDET Kft-model S76S/UA76) consisting of a 7.6 cm × 7.6 cm NaI(Tl) crystal that has a resolution of 7.4% for Cs-137 at an energy line of 661.7 keV. The detector is insulated by a 10 cm thick layer of lead to reduce background interference, and a 0.2 cm layer of copper to block any possible X-ray emissions from the lead. A multichannel analyzer with sensor-CASSY (made by Leybold GmbH company) connects the detector to a spectrum analyzer. A Marinelli beaker containing the samples was set on top of the detector, and the counting duration was 7 hours for each sample to reduce counting error.

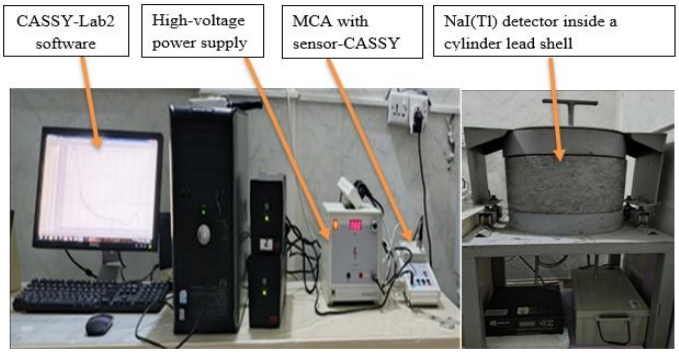

Figure 1: The system of gamma-ray spectrometry was employed in the present study.

The weighted average of the ^{226}Ra activity concentration was calculated using the gamma-ray lines at 351.9 (35.8%) keV from ^{214}Pb decay and 609.3 (44.8%) keV from ^{214}Bi decay. By calculating the weighted average of the activity using the gamma-ray lines at 238.6 keV (43%), from ^{212}Pb decay, and 583 keV (84.5%), from ^{208}Tl decay, the ^{232}Th activity concentration was calculated. Additionally, the 1461 keV (10.7%) gamma-ray line was used to assess the ^{40}K activity concentration directly.

2.3 Energy Calibration

The detector is often energy-calibrated using certain energy peaks from a standard reference sample to assign a specific energy value to each channel in the gamma-ray spectrum. The gamma spectrometer energy calibration was performed using standard cobalt-60 (with gamma emitted energies 1174 and 1333 keV) and cesium-137 (with gamma emitted energies 661 keV) radioactive sources, and a one-liter Marinelli flask containing potassium chloride KCl with a gamma energy emission (1461 keV). Table 1 shows the energy of gamma rays for radioactive substances versus the channel number.

Table 1: Gamma-ray energy of radioactive elements versus Channel number data for Calibration energy.

Elements	Energy of the gamma-ray (keV)	Channel number.
^{137}Cs	661	215
^{60}Co	1174	349
	1333	395
^{40}K	1461	433

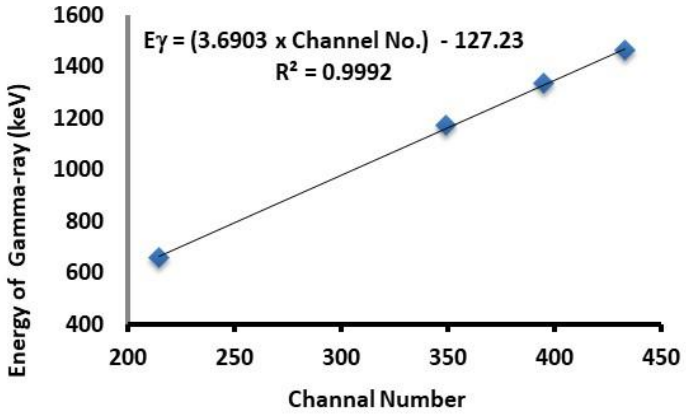

Figure 2: Graph for gamma-ray spectrometry energy calibration system.

2.4 Efficiency Calibration

Efficiency calibration was performed using standard sources ^{226}Ra, ^{152}Eu, and two radioactive powder samples: Potassium Chloride (KCl) (PO-01990500 from Scharlau company), and Thorium Nitrate Hydrate (Th $(NO_3)_4 \cdot 5H_2O$) (31686 from Seelze-Hanover company). These calibrations were conducted to meet the engineering requirements for sample assays. The combined results were synthesized to determine the following forces:

$$\varepsilon = 1.6026\, xE_{\gamma}^{-0.703} \quad (1)$$

Here, ε represents the detector's maximum efficiency, while E_γ refers to the energy of the gamma-ray. Figure 3 illustrates the relationship between absolute full peak efficiency and gamma-ray energy.

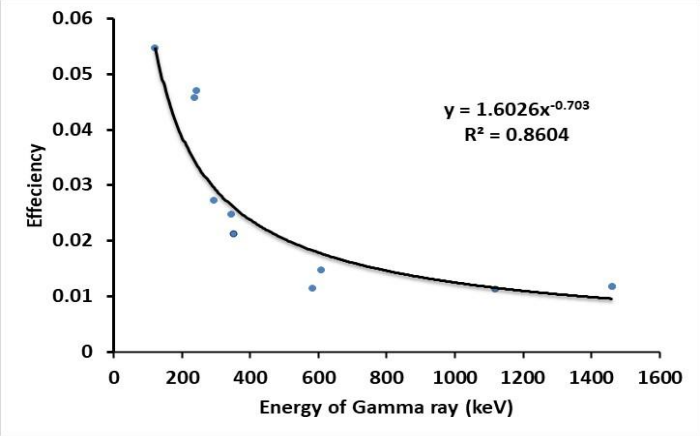

Figure 3: Describes the absolute efficiency of the NaI (Tl) detector as a function of gamma-ray energy.

3. Radiological Parameters

3.1. Radioactivity Calculations

The relationship given was utilized to determine the radionuclide activity concentration in the samples after background counts were deducted from the measured net counts (Khandaker et al., 2012; Azeez et al., 2018):

$$Activity\ concentration(A) = \frac{N_{net\ area}}{\varepsilon \times T \times I_\gamma \times M} \pm \frac{SD}{\varepsilon \times T \times I_\gamma \times M} \quad (2)$$

Where A is the radioactivity concentration of samples expressed in Bq kg^{-1}, $N_{net\ area}$ is net counts under the corresponding full energy peak, ε is the detection efficiency corresponding to the specific gamma-ray, Iγ is an absolute probability of the shift from a particular gamma-ray, T is the counting time in seconds, and M is the sample's mass in grams.

3.2 Radium equivalent activity (Raeq)

Radium equivalent activity (Ra_{eq}), expressed in Bq kg^{-1}, was used to calculate the total amount of radiation these naturally occurring radioactive nuclides emit. Evaluate the risks of gamma-ray radiation from the designated radionuclides ^{40}K, ^{232}Th, and ^{226}Ra for each sample. The value is computed using the formula below, which was suggested by UNSCEAR (Yasir et al., 2007).

$$Ra_{eq} = (A_{Ra}) + (A_{Th} \times 1.43) + (A_K \times 0.077) \quad (3)$$

where A_K, A_{Th}, and A_{Ra} indicate the corresponding activity concentrations of ^{40}K, ^{232}Th, and ^{226}Ra in a unit (Bq kg^{-1}). The OECD (1979) states that any naturally occurring radioactive material has a safe Ra_{eq} value of less than 370 Bq kg^{-1} (OECD, 1979).

3.3 Representative Level Index of Gamma Index (Iγ) and Alpha Index (Iα)

This coefficient is determined using the formula and serves as a typical measure of the gamma-radioactivity level (Najam et al., 2015):

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \leq 1 \quad (4)$$

where activity concentrations of the radionuclides ^{232}Th, ^{226}Ra, and ^{40}K are denoted by the letters A_{Th}, A_{Ra}, and A_K, respectively. Iγ < 1 values indicate an effective dosage of less than or equal to 1 mSv per year.

The alpha index (*Iα)* is calculated as shown in the equation below (Samaila et al., 2023):

$$I_\alpha = \frac{A_{Ra}}{200Bq/Kg} \quad (5)$$

3.4 Ingestion Annual Effective Dose Equivalent (IAEDE) Assessment

Measurements of natural radionuclide concentration levels in rice samples are used to estimate the annual effective dose from human rice consumption (IAED) using the following formula (Ahmed et al., 2021):

$$A_E = D \times A_S \times I \quad (6)$$

Were A_S is the activity concentration of radioactive elements in the sample. Adults' dose conversion factor (D) was taken from the ICRP 2012 report, which are 280,230 and 6.2 nSv Bq^{-1} for ^{226}Ra,^{232}Th, and ^{40}K, respectively (ICRP, 2012). The yearly per capita consumption rate of rice in the Iraqi Kurdistan Region (I)= 38.5 kg y^{-1}. (KRSO, 2023).

3.5 Excess Lifetime Cancer Risk

Estimating the lifetime risk of cancer development in an exposed population is the reason for the excess cancer risk effects. The cancer risk as determined by the International Commission of Radiological Protection (ICRP) concept was applied to estimate the carcinogenic hazards associated with consuming the examined food, as shown in Equation 7:

$$ELCR = AID \times RF \times DL \quad (7)$$

ELCR stands for excess life cancer risk. AID is the annual ingestion dose resulting from food consumption, DL is the life duration of 70 years, and RF is the risk factor (Sv^{-1}) 0.05, which was selected as a risk factor for stochastic impacts by the ICRP (ICRP, 1990).

4. Results and discussion

The specific activities of the radionuclides ^{232}Th, ^{226}Ra, and ^{40}K were measured in imported and locally produced rice in Erbil city, and are listed in Table 2. The range of ^{232}Th specific activity was (0.104 ± 0.018 to 0.289 ± 0.025) Bq kg^{-1}. The China rice sample had the highest ^{232}Th specific activity. In contrast, the rice sample from Argentina had the least amount of specific activity of ^{232}Th. The range of ^{226}Ra specific activity was (0.212 ± 0.023 to 0.671 ± 0.160) Bq kg^{-1}. The Iraq (Erbil 3) rice sample (cultivated in Erbil city) had the highest ^{226}Ra specific activity. The Indian rice sample had the lowest specific activity of ^{226}Ra. Also, the ^{40}K specific activity range was (48.677 ± 3.534 to 153.876 ± 3.885) Bq kg^{-1}. The Iraq (Erbil 1) rice sample (cultivated in Erbil city) has the highest specific activity of ^{40}K. The rice sample from Thailand had the lowest specific activity of ^{40}K. The variance in the radioactivity of radioactive nuclei in rice samples is due to changes in the concentration of those nuclei in the soil in which they are planted, the quality of the soil, and the use of fertilizer in agriculture.

Table 2: Activity concentration (Bq kg^{-1}) of ^{232}Th, ^{226}Ra, and ^{40}K in some imported rice samples in Erbil city.

Country of production	Code of sample	Radioactivity concentration (Bq kg^{-1})		
		^{226}Ra	^{232}Th	^{40}K
Argentina	R1	0.477 ± 0.192	0.104 ± 0.018	76.101 ± 3.667
India	R2	0.212 ± 0.023	0.160 ± 0.022	98.546 ± 3.773
Thailand	R3	0.338 ± 0.144	0.151 ± 0.013	48.677 ± 3.534
China	R4	0.533 ± 0.105	0.289 ± 0.025	61.617 ± 3.597
Iran	R5	0.498 ± 0.162	0.160 ± 0.013	57.199 ± 3.576
Iraq (Najaf)	R6	0.281 ± 0.036	0.235 ± 0.016	59.513 ± 3.587
Iraq (Akre)	R7	0.455 ± 0.058	0.175 ± 0.018	87.955 ± 3.723
Iraq (Ranya)	R8	0.371 ± 0.151	0.155 ± 0.012	91.567 ± 3.740
Iraq (Erbil 1)	R9	0.596 ± 0.151	0.194 ± 0.015	153.876± 3.885
Iraq (Erbil 2)	R10	0.276 ± 0.025	0.194 ± 0.025	103.200 ± 3.650
Iraq (Erbil 3)	R11	0.671± 0.160	0.150 ± 0.014	117.263 ± 3.717
Iraq (Erbil 4)	R12	0.414 ± 0.120	0.223 ± 0.020	109.723 ± 3.681

Figure 4 displays the radioactivity concentration of radioactive nuclides in rice samples. As shown in this figure, the ^{40}K radioactivity concentration was greater than comparatively of ^{226}Ra and ^{232}Th activity concentration, because globally, potassium is more abundant in the crust of the Earth than ^{226}Ra and ^{232}Th, and the solubility of potassium was greater than that of ^{226}Ra and ^{232}Th.

The values obtained for ^{226}Ra, ^{232}Th, and ^{40}K specific radioactivity in rice. Results of this study are contrasted with those of other nations worldwide in Table 3. The data for radium and thorium in the rice studied are consistent with the survey conducted in rice in Bangladesh, Egypt, Saudi Arabia, and Brazil, but lower than those concluded by research conducted in Italy, Ghana, and Nigeria. Meanwhile, the data for potassium concentration are consistent with all the studies mentioned in Table 3.

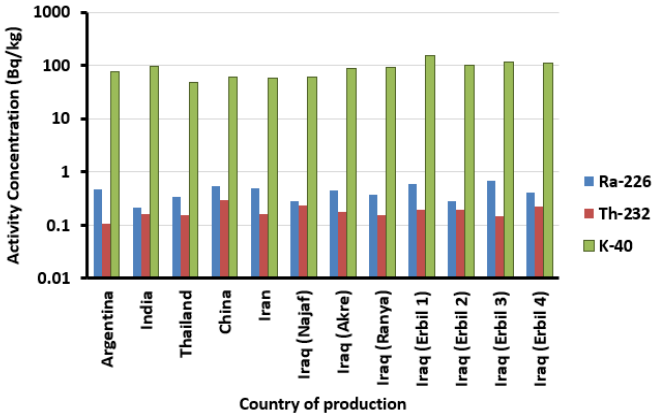

Figure 4: Activity concentration of ^{232}Th, ^{226}Ra, and ^{40}K in rice samples in Erbil city.

Table 3: The specific activity of ^{226}Ra, ^{232}Th, and ^{40}K in rice samples was compared to research results conducted in several nations.

Country	Radioactivity concentration (Bq kg^{-1})			Reference
	^{226}Ra	^{232}Th	^{40}K	
Italy	2.90	2.80	119.30	(Desideri et al., 2019)
Bangladesh	1.9	0.17	4.70	(Nahar et al., 2018)
Egypt	0.80	0.60	36	(Alrefae and Nageswaran, 2013)
Ghana	4.72	4.33	104.36	(Awudu et al., 2012)
Nigeria	5.86	7.08	113.8	(Mgbeokwere et al., 2023)
Saudi Arabia	1.23	0.70	154.83	(Al-Zahrani, 2016)
Brazil	0.10	0.20	14.70	(Venturini and Sordi, 1999)
Iraq	0.636	0.309	72.648	Present study

The total annual effective dose (IAED) in the rice samples is presented in Table 4 from the consumption of rice by Iraqi people. IAED was determined based on the measured specific activity of radioactive nuclei to be in the range of (16.600 to 44.873) μSv y^{-1} with the average value (27.407) μSv y^{-1}. All samples had yearly effective doses below the maximum permissible limit of 290 μSv/y, which has been set by the International Commission on Radiological Protection based on the annual effective dosage from adult rice consumption (Radiation, 2000).

Table 4: Ingestion annual effective dose IAEDE from ^{226}Ra, ^{232}Th, and ^{40}K existing in some imported rice samples in Erbil city.

Country of production	Code of sample	IAED (μSv/y)			(IAEDE) total μSv/y
		^{226}Ra	^{232}Th	^{40}K	
Argentina	R1	5.142	0.921	18.165	24.228
India	R2	2.285	1.417	23.523	27.225
Thailand	R3	3.644	1.337	11.619	16.6
China	R4	5.746	2.559	14.708	23.013
Iran	R5	5.368	1.417	13.653	20.438
Iraq (Najaf)	R6	3.029	2.081	14.206	19.316
Iraq (Akre)	R7	4.905	1.55	20.995	27.45
Iraq (Ranya)	R8	3.999	1.373	21.857	27.229
Iraq (Erbil 1)	R9	6.425	1.718	36.73	44.873
Iraq (Erbil 2)	R10	2.975	1.718	24.634	29.327
Iraq (Erbil 3)	R11	7.233	1.328	27.991	36.552
Iraq (Erbil 4)	R12	4.463	1.975	26.191	32.629
Average		4.601	1.616	21.189	27.407

Table 5 displays the related radiological risk parameters in the rice samples, which were computed as the Radium equivalent activity (Ra_{eq}), the level index of gamma and alpha, and the Excess Lifetime Cancer Risk (ELCR) for rice grain samples to determine the radiological dangers. In samples of rice grains, the computed radium equivalent activity (Ra_{eq}) ranged from 4.302 to 12.723 Bq kg^{-1}, with an average value of 7.524 Bq kg^{-1}. The kind and amount of naturally occurring radioactive nuclides in each soil sample determined variations in the radium equivalent activity and the fertilizer type that is applied chemically in the area under study.

Also, the level index of gamma (I_γ) varied from 0.0362 (in the Thailand rice sample) to 0.1085 (in Iraq (Erbil 2) rice sample), with a mean value of 0.0638. The level index of alpha (I_α) varied from 0.0010 (in India rice sample) to 0.0033 (in Iraq (Erbil 3) rice sample) with a mean value of 0.0021. The rice grain's computed excess lifetime cancer risk (ELCR) ranges between (58.132 x 10^{-6} and 157.092 x 10^{-6}), with an average value of (95.961 x 10^{-6}). The Iraq (Erbil 2) rice sample had the highest ELCR values. Also, the excess lifetime cancer risk can differ

significantly based on the local geology, which includes minerals rich in potassium, uranium, and thorium, as well as the composition of the soil. These results are less than one, indicating that the internal radiation hazards associated with consuming the examined rice samples are within allowable bounds.

Table 5: The Level Index of Gamma Index (Iγ) and Alpha Index (Iα), Radium Equivalent Activity Raeq, and the Excess Lifetime Cancer Risk of the Rice Grain Samples.

Country of production	Code of sample	Ra_{eq} (Bq kg^{-1})	Iγ	Iα	ELCR x 10^{-6}
Argentina	R1	6.4868	0.0549	0.0023	84.841
India	R2	8.0302	0.0687	0.0010	95.326
Thailand	R3	4.3029	0.0362	0.0016	58.132
China	R4	5.6915	0.0475	0.0026	80.563
Iran	R5	5.1313	0.0430	0.0024	71.542
Iraq (Najaf)	R6	5.2008	0.0439	0.0014	67.646
Iraq (Akre)	R7	7.4790	0.0634	0.0022	96.099
Iraq (Ranya)	R8	7.6448	0.0650	0.0018	95.342
Iraq (Erbil 1)	R9	8.5016	0.0725	0.0013	102.687
Iraq (Erbil 2)	R10	12.7232	0.1085	0.0029	157.092
Iraq (Erbil 3)	R11	9.9171	0.0841	0.0033	127.998
Iraq (Erbil 4)	R12	9.1836	0.0781	0.0020	114.259
Average		7.524	0.0638	0.0021	95.960
Global limit		370	≤ 1	≤ 1	1000

5. Conclusions

Assessing natural radionuclides in selected imported and locally produced rice samples in Erbil City provides crucial insights into potential radiation exposure risks. The study analyzed concentrations of radionuclides potassium-40, thorium-232, and radium-226 in rice grains. The results indicate that radionuclide contamination depends on the environment in which rice is grown. The calculation shows that compared to ^{226}Ra and ^{232}Th, the specific activity of ^{40}K is higher. Also, the annual ingestion dose rate was calculated to estimate the potential radiological risk to consumers.

In most cases, the values were found to be below the internationally recommended limits set by the UNSCEAR. Overall, the studied rice samples are generally safe for consumption. However, variations in radionuclide levels between rice brands highlight the need for continuous monitoring and regulatory control to ensure food safety.

Acknowledgment:

The authors acknowledge the center of scientific research and the Laboratory of Nuclear Radioactivity Testing and Monitoring staff in the Physics Department, College of Education, Salahaddin University-Erbil, for their help in conducting this research.

Financial support:

Thanks to Salahaddin University-Erbil for the funding for this research.

Potential conflicts of interest:

The authors declared no potential conflicts of interest concerning the research and authorship of this paper. No potential conflict of interest was reported by the author(s).

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