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Activity Concentrations of Natural Radionuclides and Ingestion Radiological Risk in Common Medicinal Plants from Iraq

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ABSTRACT

The increasing use of medicinal plants as natural alternatives to pharmaceutical drugs has raised concerns about contamination by naturally occurring radioactive materials and the potential health risks associated with their consumption. This study aimed to determine the activity concentrations of U-238, Th-232, and K-40 in commonly consumed medicinal plants and to assess the associated radiological risks resulting from their ingestion. Twenty medicinal plant samples were collected from four herbal shops in Al-Diwaniyah City, Iraq, and analyzed using gamma-ray spectrometry with a NaI(Tl) detector on a dry-weight basis. The mean activity concentrations were 3.90 ± 0.39 $Bq.kg^{-1}$ for U-238, 13.03 ± 1.16 $Bq.kg^{-1}$ for Th-232, and 548.99 ± 12.65 $Bq.kg^{-1}$ for K-40. The results showed that the activity concentrations of U-238 and Th-232 were below the global average values reported by UNSCEAR, whereas the activity concentration of K-40 exceeded these values in most samples because of natural uptake and agricultural practices. All calculated radiological hazard indices, including radium equivalent activity and excess lifetime cancer risk, were within the recommended safety limits. Overall, the findings confirm that the investigated medicinal plants are radiologically safe for consumption under normal conditions of use while emphasizing the need for regular monitoring to support long-term public health protection.

1. INTRODUCTION

Treatment with medicinal plants is among the oldest therapeutic practices known to humankind (Kırıs 2020). Since ancient times, various plant parts, including leaves, seeds, stems, bark, and roots, have been used to treat diseases and promote general health (Shuaibu et al. 2023). In recent decades, interest in medicinal herbs has grown considerably because of their reported benefits in reducing inflammation and the risk of cardiovascular disease, aging, cancer, and obesity (Shuaibu et al. 2023). Current statistics indicate that approximately 25% of the active ingredients in prescribed medicines are of plant origin (Kırıs 2020), highlighting their importance in the pharmaceutical industry and the increasing interest in enhancing their bioactive compounds to improve therapeutic outcomes (Khanal et al. 2024). The widespread use of medicinal plants is further attributed to their accessibility, low cost, favorable therapeutic properties, and fewer side effects than synthetic drugs (Güven et al. 2023).

With the increasing reliance on alternative medicine (Biira et al. 2021), there is a growing need to evaluate environmental pollutants that may compromise the safety of medicinal herbs, including naturally occurring radionuclides that can be transferred from the soil to different plant parts (Güven et al. 2023, Bal et al. 2023). These radionuclides may enter plants through direct deposition onto the soil and subsequent uptake by the roots (Desideri et al. 2010), ultimately accumulating in the human body through the food chain (Ali et al. 2024). Internal radiation exposure occurs primarily through the ingestion of terrestrial radionuclides, particularly members of the U-238 and Th-232 decay series and K-40, via food and drinking water, whereas inhalation exposure may occur through airborne dust particles (IAEA 1999). Numerous studies have shown that ionizing radiation emitted by these radionuclides can cause DNA damage, embryonic mutations, and an increased lifetime risk of cancer (Sweaf & Oudah 2024). Given these concerns, the radiological risks associated with the consumption of medicinal herbs are of particular importance in Iraq, where cancer incidence has been increasing, as reported in the annual cancer registry (Ministry of Health, Iraqi Cancer Board 2022).

Several studies conducted in Iraq have investigated the activity concentrations of natural radionuclides in medicinal plants, herbs, and spices and have generally reported that these products are radiologically safe for consumption despite occasional observations of elevated K-40 activity. Most Iraqi studies concluded that the measured radionuclide activities were within internationally accepted limits and did not pose significant radiological health risks (Kadhim et al. 2021, Jassim et al. 2024, Obaid 2022). However, some studies reported relatively high K-40 activity in certain herbal products, particularly chamomile and other plant-derived materials, although the associated ingestion doses and excess lifetime cancer risk indicators remained below internationally accepted safety thresholds (Najam et al. 2015, Hamza et al. 2020, UNSCEAR 2000, ICRP 2012). Similar findings were reported in subsequent Iraqi studies, in which internal hazard indices and ingestion doses consistently remained within permissible limits, confirming that medicinal plant consumption generally represents a low radiological risk under normal dietary patterns (Hamza et al. 2020). Similar radiological behavior has also been reported for other foodstuffs commonly consumed in Iraq. Abbas et al. (2023) found that, despite elevated K-40 activity, the calculated ingestion doses and excess lifetime cancer risk (ELCR) values remained within internationally accepted limits. These findings support the conclusion that food-chain products, including medicinal plants, generally pose low radiological health risks when consumed under normal dietary patterns, even when K-40 activity exceeds the global average (Abbas et al. 2023). A related study conducted in Al-Diwaniyah measured radon concentrations in imported tea and found them to be within the safety limits recommended by the ICRP, emphasizing the importance of monitoring other herbal products (Sweaf & Oudah 2024). Moreover, Rajih & Oudah (2025) investigated the concentrations of toxic elements in the same plant samples examined in the present study. They concluded that the samples were safe with respect to non-carcinogenic health risks, although prolonged consumption may pose potential carcinogenic risks, thereby providing a more comprehensive dataset for the plants investigated.

For these reasons, international organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP) have established international guidelines for acceptable radionuclide levels in foodstuffs (UNSCEAR 2000, ICRP 2012).

Against this background, the present study investigates the activity concentrations of naturally occurring radionuclides (U-238, Th-232, and K-40) in twenty commonly consumed medicinal plants obtained from herbal shops in Al-Diwaniyah City, Iraq. The study does not claim methodological novelty; rather, it addresses a local exposure assessment by providing the first comprehensive radiological evaluation of medicinal plants sold in this region. Al-Diwaniyah is characterized by a high reliance on herbal medicine, a diverse mixture of locally sourced and imported plant products, and traditional market handling and storage practices that differ from those reported in other regions of Iraq. These local characteristics may influence both radionuclide concentrations and realistic ingestion patterns. Accordingly, the novelty of this study lies in its site-specific, consumer-oriented radiological risk assessment, supported by locally derived consumption data, rather than in the development of new analytical methodologies.

Radiological health risks were evaluated using ingestion-based parameters, including the ingestion effective dose (IED) and excess lifetime cancer risk (ELCR), and the results were compared with internationally recognized safety standards. This approach provides a scientific basis for assessing compliance with radiation protection guidelines and contributes to public health protection and the safe regulation of medicinal plant consumption in Iraq.

2. MATERIALS AND METHODS

2.1. Area of Study

The study was conducted in Al-Diwaniyah Governorate, located in south-central Iraq. The governorate extends between latitudes 31°45' and 31°52' N and longitudes 44°30' and 45°45' E, covering a total area of approximately 8,521 km². According to the Commission of Statistics and GIS (Commission of Statistics and GIS 2023), the population of Al-Diwaniyah reached 1,430,714 inhabitants.

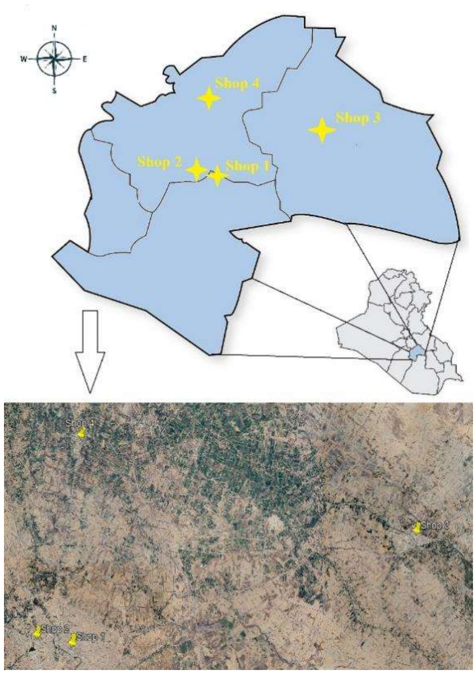

Fig :1 The geographic location of the Shops from which the samples were taken within Al-Diwaniyah, Iraq (Rajih & Oudah 2025).

Herb sampling sites were concentrated in densely populated urban districts characterized by intense commercial activity and traffic congestion, as highlighted in yellow in Fig. 1. The raw medicinal plant materials available in local markets were imported from several countries, including Iraq, Egypt, Iran, China, India, Pakistan, Syria, and the Maghreb region.

2.2. Sample Collection and Preparation

To accurately represent local market conditions, medicinal plant samples were collected from four different herbal shops across Al-Diwaniyah City and its surrounding districts (Table 1). Two shops located in the city center (coded as Shop 1 and Shop 2) were selected to represent areas characterized by intense commercial activity and high population density. The remaining two shops, located in the Afak and Al-Daghara districts (Shop 3 and Shop 4), represented semi-urban or rural environments characterized by agricultural surroundings and varying storage conditions.

A total of 20 medicinal plant samples (five from each location) were obtained to reduce sampling bias and ensure balanced representation. Sample selection was based on the frequency of use in traditional medicine and the range of diseases the plants are commonly used to treat. Interviews

Table 1: List of medicinal plants reported in the present study.

Sample Code	Shop Number	The herb	Part used	Dosage amount*	I [kg.y^{-1}]	Country
P1	1	Green tea *(Camellia sinensis)*	Leaves	15 g.day^{-1}	1.35	Iran
P2		Lemon Balm *(Melissa officinalis)*	Leaves	2 g.day^{-1}	0.18	Syria
P3		Basil *(Ocimum basilicum)*	Leaves	15 g.day^{-1}	1.35	Iraq
P4		Black Seed *(Nigella sativa)*	Seeds	6 g.day^{-1}	0.54	India
P5		Fenugreek *(Trigonella foenum-graecum)*	Seeds	30 g.day^{-1}	2.7	Egypt
P6	2	Moringa *(Moringa oleifera)*	Leaves	5 g.day^{-1}	0.45	Iraq
P7		Gorgeous roses *(Rosa damascena)*	Flowers	10 g.day^{-1}	0.9	Iraq
P8		Purslane seeds *(Portulaca oleracea)*	Seeds	10 g.day^{-1}	0.9	Syria
P9		Chia seeds *(Salvia hispanica)*	Seeds	20 g.day^{-1}	1.8	India
P10		Mahaleb *(Prunus mahaleb)*	Seeds	10 g.day^{-1}	0.9	Syria
P11	3	Sage *(Salvia fruticosa)*	Leaves	10 g.day^{-1}	0.9	Egypt
P12		Ginger *(Zingiber officinale)*	Roots	3 g.day^{-1}	0.27	China
P13		Bee pollen	Seeds	5 g.day^{-1}	0.45	Iran
P14		Chamomile *(Matricaria chamomilla)*	Flowers	15 g.day^{-1}	1.35	Egypt
P15		Licorice *(Glycyrrhiza glabra)*	Roots	10 g.day^{-1}	0.9	Syria
P16	4	Senna *(Senna alexandrina)*	Leaves	10 g.week^{-1}	0.9	Pakistan
P17		Lady’s mantle *Alchemilla vulgaris*	Leaves	15 g.day^{-1}	1.35	Maghreb
P18		Roselle *(Hibiscus sabdariffa)*	Flowers	15 g.day^{-1}	1.35	Iraq
P19		Clover *(Medicago sativa)*	Leaves	5 g.day^{-1}	0.45	Iraq
P20		Neem *(Azadirachta)*	Leaves	20 g.Week^{-1}	1.8	Iraq

*The consumed dose was estimated based on a questionnaire conducted among practitioners of alternative medicine and herbal specialists, as well as local consumers who regularly use these medicinal herbs.

with local herbal vendors and consumers supported plant identification and selection.

All samples were purchased in their commercially dried form, as sold in herbal shops, either as whole dried plant material or dried powdered samples, according to traditional use. The collected samples consisted of dried whole plant parts or ground preparations typically marketed for their therapeutic properties, including benefits for cardiovascular health, cancer prevention, weight control, blood purification, wound healing, muscle relaxation, diuretic effects, immune enhancement, and the treatment of skin conditions such as eczema (Shuaibu et al. 2023, Güven et al. 2023). Shop names were coded to preserve confidentiality and maintain objectivity.

Each sample was processed under a strict chain-of-custody protocol to ensure the traceability and reliability of the results. The procedure involved: (i) assigning a unique identification code to each sample at the time of collection, (ii) documenting all preparation steps, including drying, grinding, sieving, and weighing, (iii) storing the samples securely in sealed containers to prevent cross-contamination or material loss, (iv) transferring the sealed containers to the measurement laboratory under controlled conditions, and (v) recording sample receipt and measurement parameters in laboratory records.

A mass of 1 kg of each medicinal plant was collected and stored in polyethylene bags, with the assigned code, plant name, and country of origin clearly labeled (Hady & Mashkor 2022, Obaid 2022). Both dried whole and ground samples were homogenized into a fine powder by grinding (Obaid 2022) and then passed through a sieve with an approximate mesh size of 0.8 mm (Obaid 2022). Subsequently, each sample was oven-dried at 120 °C for six consecutive hours (Obaid 2022). This step was essential because the determination of specific activity depends on the dry weight of the material (Hady & Mashkor 2022). After drying, 0.5 kg of each powdered sample was weighed using a high-precision digital balance with an accuracy of 0.001%. The prepared samples were then sealed in airtight plastic containers, each labeled with its unique identification code. To allow secular equilibrium to be established between radionuclides in the decay series, the samples were stored for four weeks before measurement (Garba et al. 2024).

2.3. Experimental Procedure

Gamma-ray spectroscopy measurements were performed using a NaI(Tl) scintillation detector with a 3 × 3 inch crystal (Alpha Spectra, Inc., Model 12I12/3), coupled to an ORTEC DigiBase multichannel analyzer (4096 channels). Data acquisition and spectral analysis were carried out using MAESTRO-32 software connected directly to the laboratory computer (Dawal & Oudah 2025). To minimize background radiation, the detector was mounted vertically inside an ORTEC cylindrical shielding chamber. The shielding consisted of two components: an upper cylindrical cover (5 cm thick and 22 cm in diameter) enclosing the detector crystal and a lower base designed to reduce scattered radiation. The detector was positioned at the geometric center of the shielding system (Obaid 2022).

2.4. Energy Calibration of the NaI(Tl) Detector

The energy calibration of the NaI(Tl) detector was performed using standard gamma-ray sources with well-known emission lines: Na-22 (511 and 1274.5 keV), Cs-137 (661 keV), and Co-60 (1173 and 1332.5 keV) (Jassim et al. 2024, Dawal & Oudah 2025). The full-energy peaks of these sources were identified, and their corresponding channel numbers were recorded. A linear relationship was then established between channel number and gamma-ray energy, with a high correlation coefficient ($R^2 \approx 0.99$), confirming the accuracy of the calibration (Dawal & Oudah 2025). The uncertainties associated with the reference energies were negligible compared with the resolution of the NaI(Tl) detector (Dawal & Oudah 2025).

In addition to energy calibration, efficiency calibration was performed using the same standard sources, following procedures reported in the literature (Hady & Mashkor 2022). This calibration is essential for converting the measured net counts under each photopeak into activity concentrations. The efficiency curve was fitted as a function of gamma-ray energy, allowing correction for the energy dependence of the detector response (Dawal & Oudah 2025).

Background (blank) measurements were also performed using the same counting geometry and counting time as those used for the samples to subtract natural background contributions, primarily from K-40, U-238, and Th-232 present in the laboratory environment (Garba et al. 2024). This procedure ensured that the reported net peak areas represented only the activity of the measured samples.

The calibrated system was then used to quantify naturally occurring radionuclides. U-238 activity was determined from the 1764 keV gamma-ray emission of Bi-214, Th-232 activity was determined from the 2614 keV emission of Tl-208, and K-40 activity was evaluated using its 1460 keV gamma-ray emission (Garba et al. 2024, Dawal & Oudah 2025). These gamma-ray emission lines are widely recommended because of their relatively high emission intensities and minimal spectral interference (Hady & Mashkor 2022).

3. CALCULATIONS

3.1. Specific Activity

The specific activity concentrations of the radionuclides were calculated using Eq. 1(Garba et al. 2024).

$$A= \frac{N - N_o}{I_\gamma \varepsilon m t} \quad ...(1)$$

where : A the specific activity of the radioactivity in the dry sample, N : the net number of a specific peak for the sample, N_o: the background count for the specific peak of the sample, γ the number of photons per gamma ray for each decay, ε the efficiency of the detector to measure the specific gamma ray energy, m the measured mass of the dry sample of medicinal plants, : t the measurement time 10,800 s (Garba et al. 2024).

3.2. Hazard Indicators

3.2.1. Radium Equivalent

Radium equivalent activity (Bq/kg) was calculated from the following Eq. 2 (Muhammad et al. 2024):

$$Ra_{eq} = AU + 1.43\ ATh + 0.077AK \quad ...(2)$$

Where: Ra_{eq} is an important index for accurately assessing the activity levels of radionuclides present in samples. leads to a uniform dose rate for gamma rays, with a maximum permissible value of 370 $Bq.kg^{-1}$ (UNSCEAR 2000), (Muhammad et al. 2024), (AU, ATh, AK): is the radioactivity concentration of each radionuclide.

3.2.2. Dose Rate (DR)

The dose rate for gamma radiation was calculated according to Eq. 3 (Muhammad et al. 2024):

$$D(nGy.h^{-1}) = 0.462\ AU + 0.604\ ATh + 0.0417\ AK \quad ...(3)$$

Where: (0.462, 0.604, 0.0417) ($nGy.h^{-1}$) for each ($Bq.kg^{-1}$) are the dose conversion factors for U-238, Th-232 and K-40, respectively (Dawal & Oudah 2025).

3.2.3. Internal Hazard Index (H_{in})

The Internal hazard index is calculated for the gamma radiation activity concentration of the naturally occurring radioactivity of U-238, Th-232 and K-40, as it is calculated from Eq. 4 (Kadhim et al. 2021, Dawal & Oudah 2025):

$$H_{in} = AU/185 + ATh/259 + AK/4810 \leq 1 \quad ...(4)$$

Where: (AU, ATh, AK) are the activity concentrations ($Bq.kg^{-1}$) for each of the radionuclides (U-238, Th-232 and K-40), respectively.

3.2.4. Gamma Activity Index (lγ)

This index is used to assess the risk of gamma rays. It is also called the representative level index. It is calculated from Eq. 5 (Kırıs2020 , Dawal & Oudah 2025):

$$l\gamma = AU/150 + ATh/100 + AK/1500 \quad ...(5)$$

3.2.5. Annual Gonadal Dose Equivalent (AGDE)

The amount of AGDE is calculated from Eq. 6 (Saudi et al. 2022):

$$AGDE(\mu Sv/y) = 309/100\ AU + 418/100\ Th + 314/1000\ AK \quad ...(6)$$

3.2.6. Annual Effective Dose for Internal Exposure (AEDEin)

This is called the annual effective dose equivalent and is calculated using Eq. 7 (Abdelfadeel et al. 2023):

$$AEDEin\ (mSv.y-1) = DR \times 8760\ (h.y-1) \times 0.8 \times 0.7(Sv.Gy-1) \times 10^{-6} \quad ...(7)$$

8760: number of h per year (Saudi et al. 2022), 0.8: duration of indoor exposure (UNSCEAR 2000), and 0.7: consensus has been applied to the updated process in air (UNSCEAR 2010).

The limit recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000), which is equivalent to (1 $mSv.y^{-1}$), is the maximum permissible effective dose proposed by the International Commission on Radiological Protection (ICRP) (ICRP 2012) (Hassan 2025).

The average global radiation dose received from natural sources due to drinking water and food consumption is (280 $\mu Sv.y^{-1}$), which ranges from (200 to 800) $\mu Sv.y^{-1}$ (Sundström et al. 2025, Kinahan et al. 2025).

Although $AEDE_{in}$ is calculated for comparison with international screening benchmarks, the ingestion effective dose (IED) is considered the primary exposure pathway for risk assessment in this study, as it reflects actual consumption patterns of medicinal plants.

3.2.7. Ingestion Effective Dose (IED)

The dose resulting from ingesting U-238, Th-232, and K-40 was determined for medicinal plants using Eq. 8:

$$IED = A \times I \times DCF \quad ...(8)$$

Where A is the activity concentration of the radionuclide in the medicinal plant sample ($Bq.kg^{-1}$), I: Consumption rate of medicinal plants ($kg.y^{-1}$) Assuming that the number of days consumption per year (90 $day.y^{-1}$) (Luo et al. 2021), DCF: the dose conversion factor for consuming each radioactive nuclide (4.5×10^{-5}, 2.3×10^{-4}, 6.2×10^{-6} $mSv.Bq^{-1}$ for U-238, Th-232, K-40 respectively for adults) (UNSCEAR 2017), Consumption rates of the studied medicinal plants were obtained through 280 consumer questionnaires, distributed as 70 forms for each of the four surveyed herbal shops, in addition to 4 questionnaires completed by the herbal sellers who prescribe and recommend dosages of these plants. Although no standardized or agreed-upon dosage exists for the use of medicinal plants, local practitioners typically provide dose recommendations to consumers. Table 1 presents the average consumption of medicinal plants for therapeutic purposes (g.day^{-1}). However, it is important to note that an increased rate of regular consumption by patients for the treatment of specific diseases can significantly elevate the average annual effective dose resulting from their intake.

In the present study, a uniform consumption period of 90 days per year was adopted as a conservative and standardized exposure scenario. This approach was selected due to the absence of reliable plant-specific quantitative intake data and the wide inter-individual variability in herbal usage patterns. Therefore, the applied consumption rate represents an averaged exposure scenario suitable for screening-level radiological risk assessment rather than individual dose estimation.

3.2.8. Excess Lifetime Cancer Risk (ELCR)

It can be estimated using the effective dose for ingestion that we obtained by the methodology for the evaluation of the specific cancer risks (ICRP) using Eq. 9 (Kırıs 2020, ICRP 2007):

$$ELCR = IED \times DL \times RF \quad \ldots(9)$$

Where DL is the average adult life expectancy of 70 years, RF is the risk factor (1/Sv) for the random effects, and ICRP a value of 0.05 for the population is used as the risk factor (ICRP 1990).

4. RESULTS AND DISCUSSION

The radioactivity levels of naturally occurring radioactive materials (NORMs) were measured in 20 different medicinal plant samples using a gamma-ray spectrometer. The activity concentrations were calculated using Eq. (1). Table 2 presents the average dry-weight activity concentrations. The activity concentration of U-238 ranged from ND to 10.23 ± 0.87 Bq.kg^{-1}, with a mean value of 3.90 ± 0.39 Bq.kg^{-1}. The highest U-238 activity concentration was observed in chia seed (P9). The activity concentration of Th-232 ranged from 3.30 ± 0.67 to 25.74 ± 1.88 Bq.kg^{-1}, with a mean value of 13.03 ± 1.16 Bq.kg^{-1}. The highest Th-232 activity concentration was found in black seed (P4). The activity concentration of K-40 ranged from 65.01 ± 4.14 Bq.kg^{-1} in bee pollen to 1322.11 ± 18.65 Bq.kg^{-1} in lion's foot herb, with a mean value of 548.99 ± 12.65 Bq.kg^{-1}.

In contrast, the activity concentrations of K-40 exceeded the recommended limit of 400 Bq.kg^{-1} in 15 of the 20 samples (75%), which may be attributed to the natural heterogeneity in the distribution of radionuclides in the environment (Olagbaju et al. 2021). Because some of the medicinal plant samples analyzed were imported from different geographic regions, the measured radionuclide activity concentrations were likely influenced by variations in soil radioactivity and environmental conditions among the countries of origin. This observation reflects the well-established geographic variability in the distribution of natural radionuclides, which largely depends on local geological and geochemical characteristics (Olagbaju et al. 2021, UNSCEAR 2000). Despite this variation, the activity concentrations of U-238 and Th-232 in all the studied samples remained within the internationally accepted limits of 33 and 45 Bq.kg^{-1}, respectively (UNSCEAR 2000).

Table 2: Specific activities (Bq.kg^{-1}) of U-238, Th-232, andK-40 inthe medicinal plants measured using gamma spectroscopy.

Sample Code	U-238	Th-232	K-40
P1	ND	16.65±1.51	569.59±12.24
P2	2.84±0.45	14.45±1.41	688.04±13.46
P3	0.51±0.19	15.97±1.48	376.66±9.96
P4	4.59±0.58	25.74±1.88	291.64±8.76
P5	2.19±0.4	16.52±1.51	591.17±12.47
P6	2.19±0.4	11.42±1.25	300.32±8.89
P7	ND	3.3±0.67	422.98±10.55
P8	0.44±0.18	18.86±1.61	602.49±12.59
P9	10.23±0.87	17.2±1.54	503.26±11.51
P10	6.99±0.71	17.34±1.54	135.03±5.96
P11	ND	7.57±1.02	442.99±10.8
P12	8.16±0.77	8.26±1.07	569.59±12.24
P13	0.95±0.26	7.02±0.98	65.01±4.14
P14	2.11±0.39	22.16±1.75	488.1±11.32
P15	9.62±0.84	8.67±1.09	495.36±11.42
P16	6.56±0.69	11.01±1.23	1007.05±16.28
P17	0.29±0.15	11.15±1.24	1322.11±18.65
P18	3.64±0.52	10.87±1.22	751.73±14.07
P19	3.5±0.5	11.84±1.28	709.36±13.66
P20	1.46±0.33	4.68±0.8	647.24±13.05
MIN	ND	3.3±0.67	65.01±4.14
MAX	10.23±0.87	25.74±1.88	1322.11±18.65
AVE	3.90 ±0.39	13.03±1.16	548.99±12.65
World (UNSCEAR 2000)	35	30	400

ND: Not Detected

Table 3: Comparison of mean activity concentrations ($Bq.kg^{-1}$) in medicinal plants with previous local and international studies.

No.	Country	U-238	Th-232	K-40	Methodology	REF
1	Iraq			263.7 ± 4.6	(NaI(Tl)(HPGe)	Najam et al. 2015
2	Iraq (Najaf)	4.86 ± 0.68	2.91 ± 0.12	219.13 ± 2.24	(NaI(Tl)	Kareem et al. 2016
3	Iraq (Najaf)	38.12 ± 1.619	12.95 ± 0.896	570.70 ± 31.453	(NaI(Tl)	Hamza et al. 2020
4	Iraq (Karbala)	12.052±1.247	8.760±0.650	256.924±5.966	(NaI(Tl)	Obaid 2022
5	Iraq (Kurdistan)		0.65 ± 0.10	400.17 ± 17.95	(HPGe)	Sabr et al. 2023
6	Iraq		0.370.16 ±	102.93 ± 58.5	(NaI(Tl)	Kadhim et al. 2021
7	Turkey (Rize province)		1.83 ± 0.09	259.2 ± 12.1	(HPGe)	Kırıs 2020
8	Jordan (Irbid)		1.44 ± 0.18	593.97 ± 63.47	(HPGe)	Abu-Qatouseh et al. 2019
9	Egypt (Egyptian markets)	7.25 ± 0.54	7.78 ± 0.63	471.4 ±11.33	(HPGe)	Saudi et al. 2022
10	Egypt	25.09	20.61	1191.35	(HPGe)	Abdelfadeel et al. 2023
11	Malaysia			340 ± 13	(HPGe)	Shuaibu et al. 2023
12	Bangladesh (Chattogram district)		15.73 ± 3.90	157.93 ± 59.84	(HPGe)	Hossen et al. 2024
13	Northwest Nigeria (duanao international grain market)		37 ± 4	5883 ± 23	(HPGe)	Shuaibu et al. 2025
14	Thailand (various local markets and pharmacies)			420.33±3.77	(HPGe)	Kranrod et al. 2017
15	Nigeria (Ewu, Edo State)	4.73± 0.15	8.00 ± 0.40	209.43 ± 5.14	(NaI(Tl)	Popoola et al. 2024
16	India (the Kollam district of Kerala state)		15 ± 36	46 ± 230	(NaI(Tl)	Monica et al. 2020
17	Average activity from previous studies [$Bq.Kg^{-1}$]	13.71	11.14	689.25		
18	World	35	30	400		UNSCEAR 2000
19	This study Iraq Diwaniyah	3.90 ±0.39	13.03±1.16	548.99±12.65	(NaI(Tl)	

The elevated K-40 activity observed in leaf and flower samples, compared with other plant parts, can be attributed to the essential role of potassium in plant physiology and its efficient uptake through root ion carriers and ion channels (Desideri & Roselli 2010). Consequently, elevated K-40 activity is frequently observed in medicinal plants, particularly in leaves and flowers, which have a greater physiological capacity for potassium uptake than other plant tissues (Saudi et al. 2022). In addition to biological factors, soil chemistry and agricultural practices play a significant role in influencing K-40 accumulation, as the intensive use of potassium-based fertilizers and related by-products can substantially increase K-40 levels in agricultural soils (John et al. 2025). Therefore, the relatively high K-40 activity detected in these plant components likely reflects the combined effects of efficient biological uptake and agricultural growing conditions rather than abnormal radiological contamination.

Table 3 compares the average activity concentrations measured in this study with those reported in previous local and international investigations. The mean U-238 activity concentration (3.90 ± 0.39 $Bq.kg^{-1}$) in the medicinal plants from Al-Diwaniyah was lower than those reported in most Iraqi studies, including Karbala (12.05 $Bq.kg^{-1}$) (Obaid 2022) and Najaf (38.12 $Bq.kg^{-1}$) (Hamza et al. 2020), as well as in Egypt (25.09 $Bq.kg^{-1}$) (Abdelfadeel et al. 2023). However, it was comparable to the value reported in Nigeria (4.73 $Bq.kg^{-1}$) (Popoola et al. 2024).

The mean Th-232 activity concentration (13.03 ± 1.16 $Bq.kg^{-1}$) was within the range reported in regional studies. It was slightly higher than the value reported in one Iraqi study (12.95 $Bq.kg^{-1}$) (Hamza et al. 2020) but lower than those reported in Egypt (20.61 $Bq.kg^{-1}$) (Abdelfadeel et al. 2023), Bangladesh (15.73 $Bq.kg^{-1}$) (Hossen et al. 2024), and Nigerian markets (37.00 $Bq.kg^{-1}$) (Shuaibu et al. 2025). Importantly, it remained below

Table 4: Comparison of the activity concentrations of natural radionuclides in medicinal plants from Al-Diwaniyah with average values from previous studies.

Radionuclide	Difference %	Interpretation
U-238	−71.6%	Significantly lower
Th-232	+17.0%	Slightly higher
K-40	−20.3%	Moderately lower

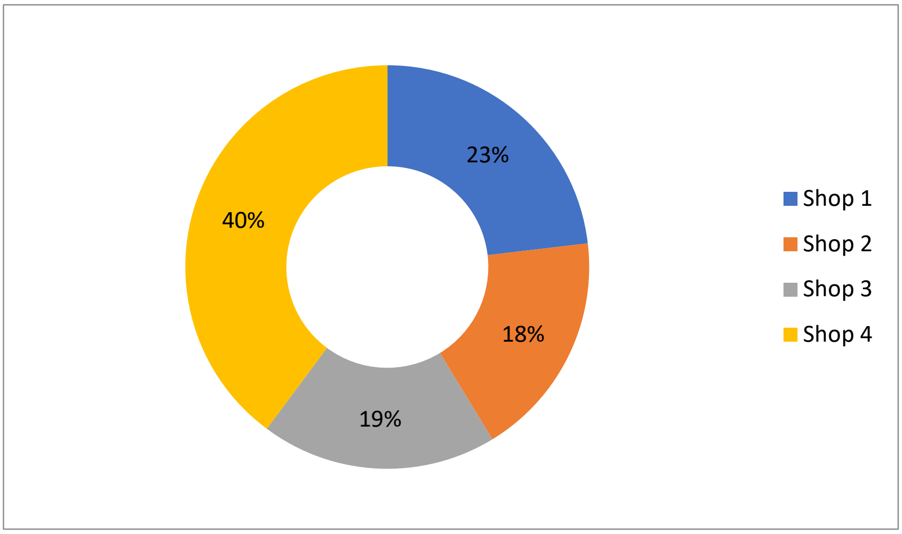

Fig. 2: Contribution of each herbal shop to the total activity of U-238, Th-232, and K-40 in the analyzed medicinal plant samples.

the UNSCEAR (2000) global reference value of 30 Bq.kg^{-1}.

In contrast, the mean K-40 activity concentration (548.99 ± 12.65 Bq.kg^{-1}) exceeded the UNSCEAR (2000) global average of 400 Bq.kg^{-1}, consistent with values reported in Najaf (570.70 Bq.kg^{-1}) (Hamza et al. 2020), Jordan (593.97 Bq.kg^{-1}) (Abu-Qatouseh & Mansour 2019), and Egypt (471.40–1191.35 Bq.kg^{-1}) (Saudi et al. 2022, Abdelfadeel et al. 2023). This elevated activity may be attributed to the widespread use of potassium-based fertilizers, which increase K-40 levels in soil and consequently enhance its uptake by plants (Szaciłowski 2024).

Overall, the radiological profile of medicinal plants from Al-Diwaniyah indicates that the activity concentrations of U-238 and Th-232 are within internationally accepted safety limits, whereas K-40 exhibits moderately elevated activity concentrations consistent with agricultural and environmental influences.

To better understand the relative levels of natural radionuclides in the studied medicinal plants, the measured activity concentrations were compared with the average values reported in previous regional and international studies. This comparison helps determine whether the present findings indicate elevated or reduced radioactivity levels relative to those reported elsewhere. The results are summarized in Table 4.

The percentage contribution of each of the four sampling sites (Shops 1–4) to the total measured activity of the three radionuclides was calculated based on their combined activity concentrations and is presented in Fig. 2. Shop 4 showed the highest contribution (40%), followed by Shop 1 (23%), Shop 3 (19%), and Shop 2 (18%). The observed order (Shop 4 > Shop 1 > Shop 3 > Shop 2) suggests that Shop 4 may represent the largest source of radionuclide contamination, possibly because of the origin of the medicinal plants sold at that location. These percentage contributions are descriptive indicators based on cumulative activity concentrations and are intended to illustrate distribution patterns rather than statistically significant differences among the shops.

Analysis of the radionuclide distribution by shop (Table 5) revealed distinct patterns among the sampling locations. Shop 3 contributed the highest proportion of U-238 activity (32%), Shop 1 exhibited the highest Th-232 activity (34%), and Shop 4 showed the greatest K-40 activity (40%). These differences may be attributed to several environmental and operational factors, including proximity to heavy traffic and fuel combustion emissions, which may result in the deposition of K-40 and other radionuclides on exposed herbal materials. Additional contributing factors may include proximity to medical or industrial sources, suboptimal storage practices, such as displaying products outdoors near busy streets, and inadequate ventilation or packaging that permits dust accumulation. The observed variability among the shops may also reflect differences in soil composition and the radionuclide uptake capacity of the plants. Collectively,

Table 5: Contribution of each shop to radioactive nuclide contamination by element (%). Each row shows how the contamination is distributed for a certain nuclide between four stores.

Radionuclide	Shop 1	Shop 2	Shop 3	Shop 4
U-238	15%	30%	32%	23%
Th-232	34%	26%	21%	19%
K-40	23%	18%	19%	40%

these findings suggest the presence of localized sources influencing radionuclide activity and highlight the importance of appropriate environmental monitoring and storage practices, particularly for Shops 1 and 4.

Overall, the results indicate that the radiological profile of the studied medicinal plants is governed primarily by natural environmental and botanical factors rather than by market-specific practices. The consistently low activity concentrations of U-238 and Th-232 across all samples, together with the moderately elevated K-40 activity, reflect the natural uptake behavior of plants and the influence of soil composition and agricultural inputs. Importantly, although K-40 activity exceeded the UNSCEAR global average in several samples, this elevation did not translate into an increased radiological risk, as confirmed by the hazard indices and dose assessments discussed below. These findings emphasize that elevated activity concentrations alone are insufficient indicators of health risk without considering realistic exposure pathways and corresponding dose assessments.

4.1. Multivariate Statistical Analysis

4.1.1. Principal Component Analysis (PCA) of Radionuclide Concentrations in Medicinal Plants

Principal Component Analysis (PCA) was performed to examine the relationships and variability among the activity concentrations of three naturally occurring radionuclides (U-238, Th-232, and K-40) in twenty medicinal plant samples collected from four herbal shops across Al-Diwaniyah City. The first two principal components (PC1 and PC2) together explained approximately 72.8% of the total variance, indicating that they effectively captured the primary structure of variation within the dataset.

PC1 accounted for 38.7% of the total variance and exhibited a strong positive loading for K-40 (0.729), with negative loadings for Th-232 (−0.543) and U-238 (−0.417), indicating that this component was driven primarily by variability in K-40 activity. PC2 explained 34.1% of the total variance and showed a strong positive loading for U-238 (0.776) and a negative loading for Th-232 (−0.631), reflecting the relationship between U-238 and Th-232 independent of K-40 activity.

The PCA biplot (Fig. 3) illustrates both the distribution of the samples and the loadings of the radionuclides. The red arrows indicate the direction and magnitude of each radionuclide's contribution to the principal components. The K-40 vector is strongly aligned with PC1, confirming its dominant contribution to the total variance. Samples from Shop 4 (diamonds) cluster toward the positive side of the PC1 axis, consistent with their higher K-40 activity. In contrast, the U-238 vector is aligned primarily with PC2,

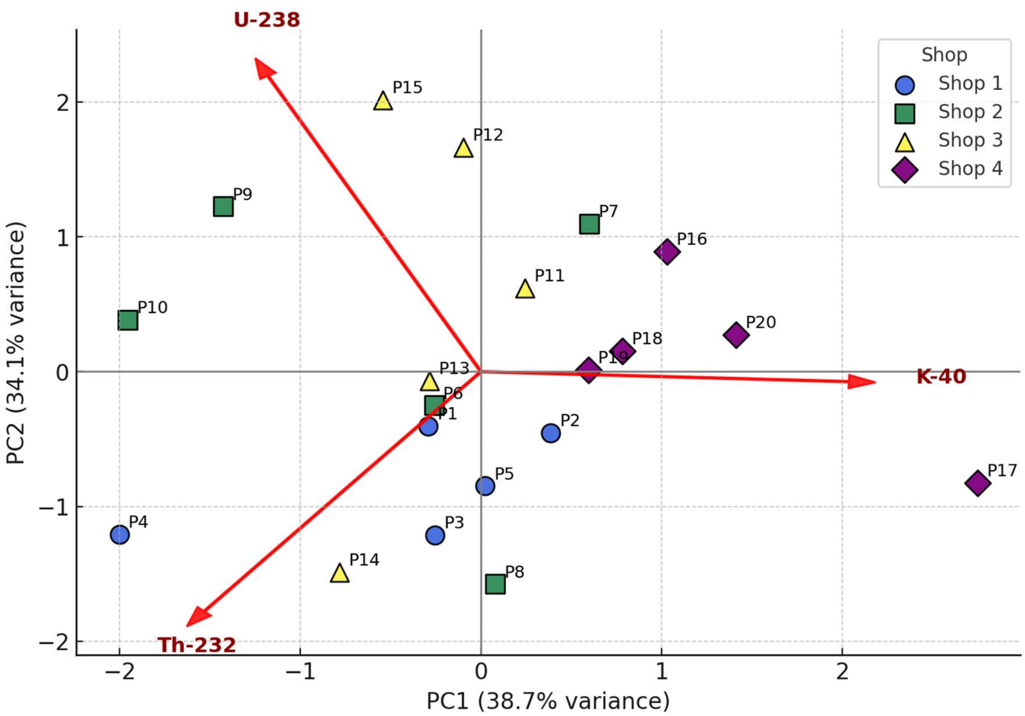

Fig. 3: PCA biplot showing the distribution of medicinal plant samples by herbal shop (Shop 1–4) and the loading vectors of U-238, Th-232, and K-40, illustrating the contribution of each radionuclide to the principal components (PC1 and PC2).

indicating samples with elevated U-238 activity, whereas the Th-232 vector points in the opposite direction, suggesting an inverse relationship between Th-232 and the other radionuclides.

Overall, the PCA results indicate that K-40 is the primary driver of variation among the samples, followed by U-238 and Th-232. Moderate clustering by shop origin, particularly for Shops 1 and 4, suggests a partial site-specific influence, likely associated with plant type, soil composition, and handling practices rather than market location alone. The alignment between the radionuclide vectors and the sample distribution further underscores the influence of environmental and botanical factors in shaping the observed radiological profiles of the medicinal plants.

4.1.2. Hierarchical Cluster Analysis (CA) of Medicinal Plant Samples

The hierarchical cluster analysis (HCA) grouped the twenty medicinal plant samples based on similarities in radionuclide concentrations (U-238, Th-232, and K-40; Fig. 4). The dendrogram revealed three major clusters, reflecting differences in activity patterns among the samples. Samples within the same cluster share comparable radionuclide profiles, indicating similar environmental exposure or plant origin.

Cluster I mainly comprised samples with relatively high K-40 activity, consistent with those located on the positive side of PC1 in the PCA plot. Cluster II included samples characterized by higher U-238 activity but moderate Th-232 activity, whereas Cluster III consisted of samples with generally lower radionuclide activity concentrations. Although environmental and botanical factors primarily govern the overall radiological profile, minor differences among the shops may be attributed to local environmental and operational conditions, such as proximity to traffic, dust deposition, and storage practices.

The close correspondence between the PCA grouping patterns and the HCA dendrogram confirms the reliability of the multivariate classification. Together, these analyses demonstrate that variations in radionuclide activity among medicinal plants are influenced more by botanical and environmental factors than by market location. However, these findings contrast with those reported by Rajih and Oudah (2025), who investigated toxic element concentrations in the same plant samples and found that the distribution of toxic elements was strongly influenced by market location and individual shop conditions.

The PCA and HCA results consistently demonstrate that variations in U-238, Th-232, and K-40 activity concentrations are governed primarily by geological and botanical factors, indicating that the observed radioactivity originates from the plants' natural environmental sources rather than from herbal shop practices. This finding confirms the value of multivariate analysis in distinguishing between market-related contamination and naturally occurring radioactivity.

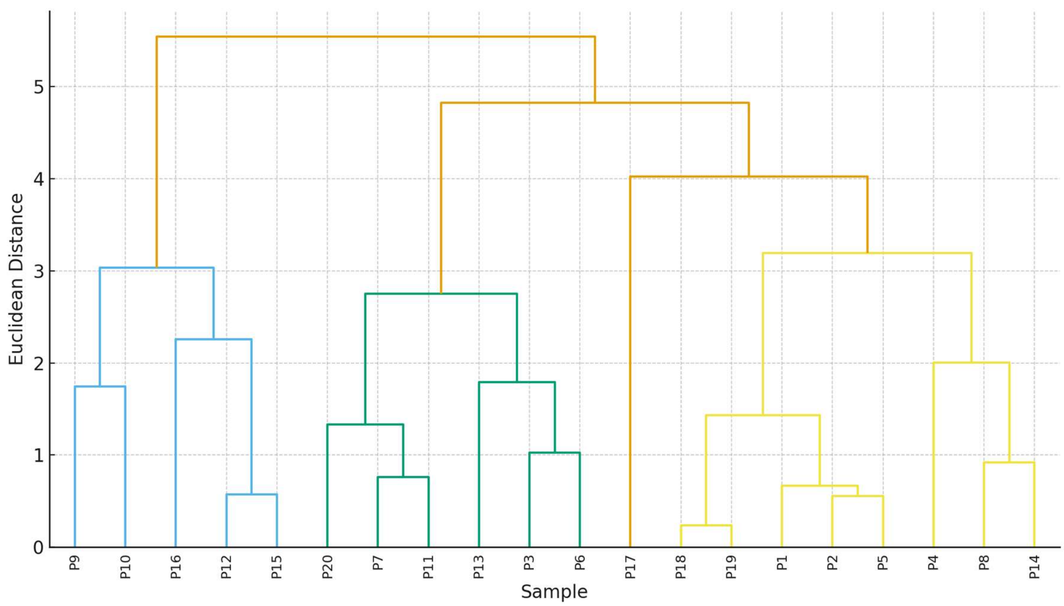

Fig. 4: Hierarchical cluster analysis (HCA) dendrogram of medicinal plant samples based on the activity concentrations of U-238, Th-232, and K-40, illustrating the grouping of samples according to their radiological similarity.

4.2. Radiation Risks

Table 6 presents the calculated radiological hazard parameters, including radium equivalent activity (Raeq), absorbed gamma dose rate (DR), internal hazard index (Hin), gamma activity index (Iγ), annual gonadal dose equivalent (AGDE), and annual effective dose for indoor exposure (AEDEin), for the analyzed medicinal plants.

All Raeq values were below the recommended safety limit of 370 Bq/kg (UNSCEAR 2000), indicating that the samples pose no significant external radiation hazard. The absorbed gamma dose rate (DR) ranged from 7.39 to 62.00 $nGy.h^{-1}$. The highest DR value was observed in the lion's foot sample (P17), whereas most samples exhibited values below the global average of 59 $nGy.h^{-1}$ reported by UNSCEAR (2000).

The internal hazard index (Hin) values for all samples were below unity, confirming a minimal risk of internal radiation exposure. Similarly, the gamma activity index (Iγ) ranged from 0.12 to 0.99, remaining within the permissible range for all medicinal plants (UNSCEAR 2000). The highest Iγ value was also observed in the lion's foot sample (P17).

The calculated annual gonadal dose equivalent (AGDE) ranged from 52.69 to 462.65 $\mu Sv.y^{-1}$. Only the lion's foot sample (P17) slightly exceeded the global reference level of 300 $\mu Sv.y^{-1}$ (UNSCEAR 2000). The annual effective dose for indoor exposure (AEDEin) ranged from 0.04 to 0.30 $mSv.y^{-1}$, with bee pollen (P13) recording the lowest value and lion's foot (P17) the highest.

Overall, the results indicate that the radiological hazard parameters for all samples were generally within internationally accepted safety limits, with only a few individual medicinal plants, particularly lion's foot, approaching the upper reference levels. These findings suggest that the studied medicinal plants are radiologically safe for consumption under normal usage patterns.

Table 7 presents the ingestion effective dose (IED) for each radionuclide, as well as the total ingestion effective dose and the corresponding excess lifetime cancer risk

Table 6: Radium activity equivalent (Ra_{eq}), gamma dose rate (DR), internal hazard index (H_{in}), gamma activity index (I_γ), annual gonadal dose equivalent (AGDE), annual effective dose for indoor exposure ($AEDE_{in}$) for various medicinal plants.

Sample Code	Ra_{eq} [$Bq.kg^{-1}$]	DR	H_{in}	I_γ	AGDE [$\mu Sv.y^{-1}$]	$AEDE_{in}$ [$mSv.y^{-1}$]
P1	67.67	34.27	0.18	0.55	251.54	0.17
P2	76.48	38.73	0.22	0.62	285.22	0.19
P3	52.35	25.59	0.14	0.41	186.60	0.13
P4	63.85	29.83	0.18	0.48	213.35	0.15
P5	71.33	35.64	0.19	0.57	261.45	0.17
P6	41.65	20.43	0.11	0.32	148.80	0.10
P7	37.29	20.09	0.10	0.31	149.70	0.10
P8	73.80	36.72	0.20	0.59	269.38	0.18
P9	73.58	36.10	0.23	0.58	261.53	0.18
P10	42.18	19.33	0.14	0.31	136.48	0.09
P11	44.94	23.51	0.12	0.38	173.83	0.12
P12	63.83	32.51	0.19	0.51	238.59	0.16
P13	15.99	7.39	0.05	0.12	52.69	0.04
P14	71.38	34.71	0.20	0.56	252.41	0.17
P15	60.16	30.34	0.18	0.49	221.51	0.15
P16	99.85	51.67	0.09	0.82	382.51	0.25
P17	118.04	62.00	0.31	0.99	462.65	0.30
P18	77.07	39.59	0.22	0.63	292.73	0.19
P19	75.05	38.35	0.22	0.61	283.05	0.19
P20	57.99	30.49	0.16	0.50	227.31	0.15
MIN	15.99	7.39	0.05	0.12	52.69	0.04
MaX	118.04	62.00	0.31	0.99	462.65	0.30
AVE	64.22	32.37	0.17	0.52	237.57	0.16
Safety limits (UNSCEAR 2000).	≤ 370	≤ 59	≤ 1	≤ 1	≤ 300	≤ 0.3 (UNSCEAR 2017)

Table 7: Ingestion effective dose (IED), Excess lifetime cancer risk (ELCR) for various medicinal plants.

Sample Code	IED $mSv.y^{-1}$			Total $mSv.y^{-1}$	ELCR $\times 10^{-3}$
	U-238	Th-232	K-40		
P1	6.08×10^{-05}	5.17×10^{-03}	4.77×10^{-03}	1.00×10^{-02}	0.03
P2	2.30×10^{-05}	1.18×10^{-04}	3.13×10^{-03}	3.27×10^{-03}	0.01
P3	3.10×10^{-05}	1.71×10^{-02}	1.29×10^{-02}	3.00×10^{-02}	0.10
P4	1.12×10^{-04}	1.10×10^{-02}	9.96×10^{-03}	2.11×10^{-02}	0.07
P5	2.66×10^{-04}	3.53×10^{-02}	4.04×10^{-02}	7.59×10^{-02}	0.27
P6	4.71×10^{-04}	4.07×10^{-03}	3.42×10^{-03}	7.96×10^{-03}	0.03
P7	1.64×10^{-04}	2.35×10^{-03}	9.63×10^{-03}	1.21×10^{-02}	0.04
P8	1.87×10^{-04}	1.34×10^{-02}	1.37×10^{-02}	2.73×10^{-02}	0.10
P9	8.91×10^{-03}	2.45×10^{-02}	2.29×10^{-02}	5.63×10^{-02}	0.20
P10	3.01×10^{-03}	1.24×10^{-02}	3.07×10^{-03}	1.85×10^{-02}	0.06
P11	1.64×10^{-04}	5.40×10^{-03}	1.01×10^{-02}	1.56×10^{-02}	0.05
P12	$1.05\times^{03-}10$	1.77×10^{-03}	3.89×10^{-03}	6.71×10^{-03}	0.02
P13	2.04×10^{-04}	2.50×10^{-03}	7.40×10^{-04}	3.45×10^{-03}	0.01
P14	1.36×10^{-03}	2.37×10^{-02}	1.66×10^{-02}	4.17×10^{-02}	0.15
P15	4.14×10^{-03}	6.18×10^{-03}	1.13×10^{-02}	2.16×10^{-02}	0.08
P16	2.82×10^{-03}	$7.85\times^{03-}10$	2.29×10^{-02}	3.36×10^{-02}	0.12
P17	1.87×10^{-04}	1.19×10^{-02}	3.21×10^{-04}	1.24×10^{-02}	0.04
P18	2.35×10^{-03}	1.16×10^{-02}	2.57×10^{-02}	3.96×10^{-02}	0.14
P19	7.53×10^{-04}	4.22×10^{-03}	8.07×10^{-03}	1.30×10^{-02}	0.05
P20	1.25×10^{-03}	6.67×10^{-03}	2.95×10^{-02}	3.74×10^{-02}	0.13
MIN	2.30×10^{-05}	1.18×10^{-04}	3.21×10^{-04}	3.27×10^{-03}	0.01
MAX	8.91×10^{-03}	3.53×10^{-02}	4.04×10^{-02}	7.59×10^{-02}	0.27
AVE	1.38×10^{-03}	1.04×10^{-02}	1.26×10^{-02}	2.44×10^{-02}	0.09
W.AVE (UNSCEAR 2000).				0.3	$\leq$ (0.29)

(ELCR) for the studied medicinal plants. The combined annual effective dose from all radionuclides was below the UNSCEAR (2000) recommended limit of 0.3 $mSv.y^{-1}$. Similarly, the calculated ELCR values ranged from 0.01×10^{-3} to 0.27×10^{-3}, with a mean value of 0.09×10^{-3}, which is below the permissible limit of 0.29×10^{-3} established by the International Commission on Radiological Protection (ICRP 2007). The lowest and highest ELCR values were observed for bee pollen (P13) and lion's foot (P17), respectively. These findings indicate that, under normal consumption conditions, the ingestion of these medicinal plants does not pose a significant radiological health risk.

It is noteworthy that, in comparative analyses, the annual effective dose for indoor exposure (AEDEin) generally yielded slightly higher excess lifetime cancer risk (ELCR) values than those derived from the ingestion effective dose (IED). This difference arises because AEDEin assumes continuous annual exposure based on the absorbed dose rate (DR) and occupancy factor, rather than exposure through the realistic ingestion pathway, which depends on actual consumption frequency. However, because the IED-based approach incorporates local consumption data and measured radionuclide activity concentrations, it provides a more realistic estimate of internal exposure resulting from medicinal plant consumption. Therefore, the ELCR values calculated in this study from the ingestion pathway are considered to represent the actual radiological risk associated with medicinal plant consumption in Al-Diwaniyah.

Although the AEDEin-based ELCR values (not presented here) indicated slightly higher risk levels, they remained below the international benchmark of 0.29×10^{-3} (UNSCEAR 2000, ICRP 1990), confirming that even under continuous exposure assumptions, the radiological impact of these medicinal plants would not exceed internationally accepted safety limits.

It should be noted that the ingestion doses estimated in this study are based on an average consumption scenario and are intended for screening-level risk assessment. Actual exposure may vary depending on plant-specific usage patterns and individual consumption habits, which should be considered in future studies when detailed intake data become available.

4.3. Implications for Radiological Health Risk

From a radiological protection perspective, the combined evaluation of the hazard indices, ingestion effective dose (IED), and excess lifetime cancer risk (ELCR) demonstrates that consumption of the investigated medicinal plants does not pose a significant health risk under normal usage patterns. Even in samples with relatively high K-40 activity, the calculated dose and ELCR values remained well below internationally recommended limits. This finding highlights the importance of dose-based risk assessment rather than relying solely on activity concentration thresholds. Consequently, the results provide a scientifically sound basis for considering these medicinal plants radiologically safe for consumption while supporting the need for periodic monitoring to ensure long-term public health protection.

5. CONCLUSIONS

The results revealed that the activity concentrations of U-238 and Th-232 were within internationally accepted limits, whereas K-40 activity exceeded the UNSCEAR global average in most samples, reflecting both the natural biological accumulation of K-40 and the influence of local agricultural and environmental conditions.

Multivariate statistical analyses (PCA and HCA) confirmed that the variability in radionuclide activity concentrations among the samples was governed primarily by botanical and environmental factors rather than by market location. All calculated radiological hazard indices (Raeq, DR, Hin, Iγ, AGDE, and AEDEin) were below internationally accepted safety thresholds, indicating no significant external or internal radiation hazard. Similarly, the ingestion-based annual effective dose (IED) and excess lifetime cancer risk (ELCR) values were well below international limits, suggesting that the consumption of these medicinal plants under normal conditions does not pose a radiological health risk.

In conclusion, the studied medicinal plants can be considered radiologically safe for public use. However, the slightly elevated K-40 activity and dose values observed in specific medicinal plants, particularly lion's foot, highlight the need for periodic monitoring of radionuclide activity in herbal products, especially those imported or cultivated under varying soil and environmental conditions.

6. CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest related to the publication of this scientific research. The study was carried out independently, according to the highest standards of academic integrity and scientific impartiality, in the analysis and formulation of the results, without any unjustified bias or external influence.

7. AUTHOR CONTRIBUTIONS

Osamah Oudah designed the study framework and methodology, performed statistical analysis, and critically reviewed the manuscript. Zainab Rajih collected samples, conducted the analytical procedures, drafted the initial manuscript, and verified data accuracy. Both authors approved the final version and take full responsibility for the integrity of the research.

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9. REFERENCES

Abbas, H.H., Kadhim, S.A., Alhous, S.F., Hussein, H.H., Al-Temimei, F.A. and Mraity, H.A.A., 2023. Radiation risk among children due to natural radioactivity in breakfast cereals. *Nature Environment and Pollution Technology*, 22(1), pp.527-533. [DOI]

Abdelfadeel, E.H., El-Halim, E.A., Hegazy, T.M. and Ghany, H.A., 2023. Relationship between radioactivity and toxicity in some medicinal plants. *Scientific Reports*, 13(1), p.10952. [DOI]

Abu-Qatouseh, L., Mallah, E. and Mansour, K., 2019. Evaluation of anti-Propionibacterium acnes and anti-inflammatory effects of polyphenolic extracts of medicinal herbs in Jordan. *Biomedical and Pharmacology Journal*, 12(1), pp.211-217. [DOI]

Ali, S., Baloch, S.B., Bernas, J., Konvalina, P., Onyebuchi, E.F., Naveed, M. and Mustafa, A., 2024. Phytotoxicity of radionuclides: A review of sources, impacts and remediation strategies. *Environmental Research*, 240, p.117479. [DOI]

Bal, S.Ş., Kurşat, M., Kuluöztürk, M.F., Çelik, Ş.K. and Yılmaz, E., 2023. Soil to plant transfer of 226Ra, 232Th and 137Cs to some medicinal and aromatic plants growing in Bitlis (Turkey). *Journal of Environmental Radioactivity*, 257, p.107089. [DOI]

Biira, S., Ochom, P. and Oryema, B., 2021. Evaluation of radionuclide concentrations and average annual committed effective dose due to medicinal plants and soils commonly consumed by pregnant women in Osukuru, Tororo (Uganda). *Journal of Environmental Radioactivity*, 227, p.106460. [DOI]

Commission of Statistics and GIS, 2023. Annual Statistical Abstract 2023. Republic of Iraq. Retrieved August 4, 2026, from https://cosit.gov.iq/documents/AAS2023/2.pdf

Dawal, A.A.A.H. and Oudah, O.N., 2025. Measurement of natural radioactivity and radiation hazards in bricks produced in Babylon brick factories, Iraq. *Radiation Protection Dosimetry*, 201(4), pp.261-269. [DOI]

Desideri, D., Meli, M.A. and Roselli, C., 2010. Natural and artificial radioactivity determination of some medicinal plants. *Journal of Environmental Radioactivity*, 101(9), pp.751-756. [DOI]

Garba, N.N., Aliyu, A.S., Rabiu, N., Kankara, U.M., Vatsa, A.M., Ismaila, A. and Onuh, E., 2024. Investigation of natural radionuclides and radiation shielding potential of some commonly used building materials in Northwestern Nigeria. *Scientific Reports*, 14(1), p.9696. [DOI]

Güven, A., Cengiz, G.B., Çağlar, İ. and Ateş, S., 2023. Evaluation of radioactivity levels and radiological hazards of some endemic plants used as medicine in Ankara, Turkey. *Applied Radiation and Isotopes*, 200, p.110939. [DOI]

Hady, H.N. and Mashkor, Z.M., 2022. The measurement of the total excess lifetime cancer risk in soil samples from Tar Al-Najaf in Al-Najaf Al-Ashraf-Iraq. *Pakistan Journal of Medical & Health Sciences*, 16(11), p.706. [DOI]

Hamza, Z.M., Alshebly, S.A. and Hussain, H.H., 2020. A practical study to determine the percentage of radiation in medicinal herbs used in the Iraqi market. *Journal of Physics: Conference Series*, 1591(1), p.012007. [DOI]

Hassan, H.J., 2025. Radiation hazards and effective dose evaluation: A study of various imported walnut consumed in Kurdistan-Iraq. *Radiation Physics and Chemistry*, p.112899. [DOI]

Hossen, M.J., Haydar, M.A., Rahman, M.A., Ali, M.I., Paul, D., Asaduzzaman, K. and Khandaker, M.U., 2024. Committed effective dose due to the intake of medicinal plants and herbs by the Bangladeshi populace. *International Journal of Environmental Analytical Chemistry*, pp.1-13. [DOI]

IAEA, 2022. Exposure due to radionuclides in food other than during a nuclear or radiological emergency. Part 2: Considerations in implementing requirement 51 of IAEA general safety requirements Part 3. International Atomic Energy Agency, Vienna.

ICRP, 1990. *Recommendations of the International Commission on Radiological Protection*. ICRP Publication 60, Ann. ICRP 21 (1–3). Pergamon Press, Oxford.

ICRP, 2012. Compendium of dose coefficients based on ICRP Publication 60. *ICRP Publication 119, Ann ICRP 41 (Suppl.)*, 40, pp.1-257.

International Atomic Energy Agency, 1999. Assessment of doses to the public from ingested radionuclides. *Safety Reports Series No. 4*. International Atomic Energy Agency, Vienna. Retrieved August 4, 2026, from https://www-pub.iaea.org/MTCD/Publications/PDF/P067_scr.pdf

International Commission on Radiological Protection (ICRP), 2007. Recommendations of the ICRP. *ICRP Publication 103, Ann. ICRP*, 37(2-4). [DOI]

Jassim, A.S., Oraibi, A.H., Abojassim, A.A., Algazali, S.A., Hameed, A.A. and Hussian, H.H., 2024. Determination of long-lived gamma emitters in some vegetarian products in Al-Najaf governorate using NaI (Tl). *IOP Conference Series: Earth and Environmental Science*, 1325(1), p.012008. [DOI]

John, S.O.O., Olukotun, S.F., Radebe, M.M. and Mathuthu, M., 2025. Radiological safety assessment of sugar consumption in South Africa—a study of 226Ra, 228Ra, and 40K levels. *Frontiers in Public Health*, 13, p.1534383. [DOI]

Kadhim, N.F., Khalaf, H.N.B., Hassan, H.A. and Mostafa, M.Y., 2021. Determining the natural radioactivity of spices widely used in Iraq. *International Journal of Environmental Analytical Chemistry*, 103(13), pp.3097-3108. [DOI]

Kareem, A.A., Hady, H.N. and Abojassim, A.A., 2016. Measurement of natural radioactivity in selected samples of medical plants in Iraq. *International Journal of Physical Sciences*, 11(14), pp.178-182. [DOI]

Khanal, M., Acharya, A., Maharjan, R., Upadhyay, D.R., Dhobi, S.H., Shah, B.R. and Lamichhane, H.P., 2024. Investigation of naturally occurring radionuclides in selected medicinal plants and associated soils, and calculation of soil-to-plant transfer factors. *Journal of Environmental Radioactivity*, 280, p.107556. [DOI]

Kinahan, A., Kelleher, K., Vintró, L.L. and Currivan, L., 2025. A duplicate diet survey for the assessment of the annual effective dose to the Irish adult population from the ingestion of natural radionuclides in food. *Food Chemistry*, 474, p.143227. [DOI]

Kırıs, E., 2020. Radioactivity levels and radiation health hazards in medicinal plants used in Rize Province, Turkey. *International Journal of Environmental Analytical Chemistry*, 102(12), pp.2865-2878. [DOI]

Kranrod, C., Chanyotha, S., Kritsananuwat, R., Ploykrathok, T., Pengvanich, P., Tumnoi, Y., Thumvijit, T. and Sriburee, S., 2017. Preliminary survey of radioactivity level in Thai medicinal herb plants. *Journal of Physics: Conference Series*, 860(1), p.012001. [DOI]

Luo, L., Wang, B., Jiang, J., Fitzgerald, M., Huang, Q., Yu, Z. and Chen, S., 2021. Heavy metal contaminations in herbal medicines: Determination, comprehensive risk assessments, and solutions. *Frontiers in Pharmacology*, 11, p.595335. [DOI]

Ministry of Health, Iraqi Cancer Board, 2022. Cancer registry of Iraq annual report. Republic of Iraq. Retrieved August 4, 2026, from https://storage.moh.gov.iq/2024/03/31/2024_03_31_11983087032_3940351786864953.pdf

Monica, S., Jojo, P.J. and Khandaker, M.U., 2020. Radionuclide concentrations in medicinal florae and committed effective dose through Ayurvedic medicines. *International Journal of Radiation Biology*, 96(8), pp.1028–1037. [DOI]

Muhammad, A.N., Ismail, A.F. and Garba, N.N., 2024. Natural radioactivity in food crops and soil and estimation of the concomitant dose from tin mining areas in Nigeria. *Journal of Taibah University for Science*, 18(1), p.2366507. [DOI]

Najam, L.A., Tafiq, N.F. and Kitah, F.H., 2015. Estimation of natural radioactivity of some medicinal or herbal plants used in Iraq. *Detection*, 3(01), p.1. [DOI]

Obaid, A.S., 2022. *Evaluation of the Radiological Risks of Radionuclides in Different Samples of Seasoning in Iraqi Markets*. Master's Thesis, University of Kerbala, College of Science. Retrieved August 4, 2026, from https://uokerbala.edu.iq/wp-content/uploads/2022/10/Rp-Evaluation-of-the-Radiological-Risks-of-Radionuclides-in-Different-Samples-of-Seasoning-in-Iraqi-Markets-.pdf

Olagbaju, P.O., Wojuola, O.B. and Tshivhase, V., 2021. Radionuclides contamination in soil: effects, sources and spatial distribution. *EPJ Web of Conferences*, 253, p.09006. [DOI]

Popoola, F.A., Isola, O.B., Fakeye, O.D., Owolabi, T.A., Sanyaolu, M.E., Owoyemi, S.I. and Elijah, I.O., 2024. Examination of medicinal plants for radionuclide absorption and their health implications. *Pollution*, 10(2), pp.700-711. [DOI]

Rajih, Z.H. and Oudah, O.N., 2025. Assessment of toxic metal contamination and consumer safety of medicinal plants in Al-Diwaniyah herbal shops. *Biological Trace Element Research*, pp.1-19. [DOI]

Sabr, B., Haji, S.O., Azeez, H., Hussein, M.I. and Smail, J.M., 2023. Assessment of natural radioactivity levels in widely used food spices in the Iraqi Kurdistan region and their associated radiological risks. *Zanco Journal of Pure and Applied Sciences*, 35(6), pp.16-27. [DOI]

Saudi, H.A., Abedelkader, H.T., Issa, S., Diab, H.M., Bashter, I.I., Alharshan, G.A., Uosif, M.A.M. and Zakaly, H.M., 2022. An in-depth examination of the natural radiation and radioactive dangers associated with a regularly used medicinal plant in Egypt. *International Journal of Environmental Research and Public Health*, 19(13), p.8124. [DOI]

Shuaibu, H.K., Kankara, U.M., Muhammad, A.N., Gusau, M.B., Garba, N.N., Kolo, M.T. and Khandaker, M.U., 2025. Natural radioactivity and radiological risks in some medicinal plants consumed in northern Nigeria. *Radiation Physics and Chemistry*, 234, p.112785. [DOI]

Shuaibu, H.K., Mohamed, F., Khandaker, M.U., Ismail, A.F. and Omar, R.S., 2023. Radioactivity and concomitant radiation dose from Malaysian herbal plants. *Radiation Physics and Chemistry*, 211, p.111050. [DOI]

Sundström, J., Piñero-García, F., Thomas, R., Forssell-Aronsson, E. and Isaksson, M., 2025. Radiological characterization of commercial baby food in Sweden. *Journal of Food Composition and Analysis*, p.107709. [DOI]

Sweaf, A.A. and Oudah, O.N., 2024. Determination of radon concentration in the imported tea in Al-Diwaniyah Governorate markets, Iraq using nuclear track detector LR-115. *Caspian Journal of Environmental Sciences*, 22(1), pp.53-57.

Szaciłowski, G., 2024. Evaluation of natural radioactivity and assessment of dose increase due to the use of fertilizers produced in Poland. *Journal of Radioanalytical and Nuclear Chemistry*, 333(7), pp.3425-3430. [DOI]

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 2017. *Report Sources, Effects and Risks of Ionizing Radiation, Report to the General Assembly, with Scientific Annexes*. United Nations, New York.

UNSCEAR, 2000. *Sources, Effects and Risk of Ionizing Radiation, Report to the General Assembly*. United Nations, New York.

UNSCEAR, 2010. *Sources and Effects of Ionising Radiation. Report to the General Assembly with Scientific Annexes*. United Nations, New York.