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Original Research

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 with naturally occurring radioactive materials and possible health risks. 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 from 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 (dry-weight basis). The mean activity concentrations were 3.90 ± 0.39 Bq/kg for U-238, 13.03 ± 1.16 Bq/kg for Th-232, and 548.99 ± 12.65 Bq/kg for K-40. The results showed that U-238 and Th-232 activities were below global average values (UNSCEAR), while K-40 exceeded these levels in most samples due to natural uptake and agricultural practices. All calculated radiological hazard indices, including radium equivalent activity and excess lifetime cancer risk, were within recommended safety limits. Overall, the findings confirm that the investigated medicinal plants are radiologically safe for consumption under normal 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, different plant parts such as 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 due to their reported benefits in reducing inflammation, 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 both their importance in the pharmaceutical industry and the increasing attention to enhancing their bioactive compounds for improved therapeutic outcomes (Khanal et al. 2024). The widespread use of medicinal plants is further attributed to their accessibility, low cost, favorable therapeutic properties, and reduced side effects compared with synthetic drugs (Güven et al. 2023).

With the expanding reliance on alternative medicine (Biira et al. 2021), the need has emerged to evaluate environmental pollutants that can compromise the safety of medicinal herbs, including radioactive nuclides that may be transferred from the soil to different plant parts (Güven et al. 2023; Bal et al. 2023), through direct deposition in the soil and absorption by the roots (Desideri & Roselli 2010), leading to their accumulation in the human body through the food chain (Ali et al. 2024). Internal exposure arises primarily through ingestion of terrestrial radionuclides, particularly those belonging to the U-238, Th-232 and K-40 decay series, via food and drink, while inhalation exposure may occur through dust particles suspended in the atmosphere (IAEA 1999). Numerous studies have confirmed that ionizing radiation emitted by these radionuclides may cause DNA damage, embryonic mutations, and an increased lifetime risk of cancer (Sweaf & Oudah 2024). Given these concerns, the radiation risks associated with herbal consumption are especially significant in Iraq, where the incidence of cancer has been increasing, as reported in the annual cancer registry (Cancer registry of Iraq 2022).

Several studies conducted in Iraq have investigated the activity concentrations of natural radionuclides in medicinal plants, herbs, and spices, and generally reported that these products are radiologically safe for consumption, despite occasional observations of elevated K-40 levels. Most Iraqi investigations concluded that the measured radionuclide activities remained 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 higher K-40 activity in certain herbal products, particularly in chamomile and other plant-based materials, although the associated ingestion doses and cancer risk indicators remained below global safety thresholds (Najam & Kitah 2015; Hamza et al. 2020; UNSCEAR 2000; ICRP 2012). Similar findings were reported in subsequent Iraqi assessments, where internal hazard indices and ingestion doses were consistently within permissible limits, confirming that medicinal plant consumption generally represents a low radiological risk under normal dietary patterns (Hamza et al. 2020). Similar radiation behavior has been reported for other foodstuffs commonly consumed in Iraq. (Abbas et al. 2023) found that despite high K-40 activity, calculated ingestion doses and lifetime cancer risk (ELCR) values remained within internationally accepted limits. This supports findings that food chain products, including medicinal plants, generally pose low radiation health risks when consumed under normal dietary patterns, even when activity exceeds K-40 global averages (Abbas et al. 2023). A related study in Al-Diwaniyah measured radon in imported tea and found concentrations within safe ICRP limits, emphasizing the need to monitor other herbal products (Sweaf & Oudah 2024). Moreover, Zainab and Osamah (Rajih & Oudah 2025) investigated the toxic element concentrations in the same plant samples examined in the present study, finding them safe from the perspective of non-carcinogenic risk, while noting potential carcinogenic risks with prolonged consumption, thereby providing a more comprehensive dataset for the plants under study.

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 global 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 mix of locally sourced and imported plant products, and traditional market-handling and storage practices that differ from those reported in other Iraqi regions. 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°52′ to 31°45′ N and longitudes 44°30′ to 45°45′ E, covering a total area of approximately 8,521 km². According to the Commission of Statistics and GIS (Commission of Statistics 2023), the population of Al-Diwaniyah reached 1,430,714 inhabitants. Herb sampling sites were concentrated in densely populated urban districts characterized by intense commercial activity and traffic congestion, highlighted in yellow (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.

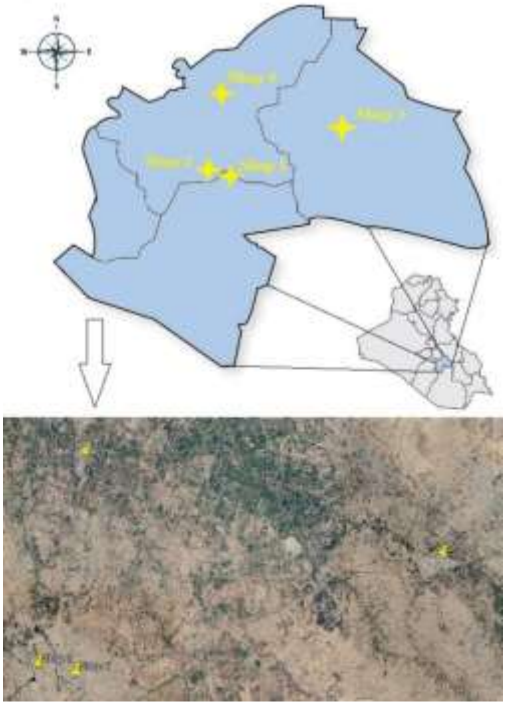

Fig.1 : The geographic location of the Shops from which the samples were taken within Al-Diwaniyah, Iraq (Rajih & Oudah 2025).

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 influenced by intense commercial activity and high population density. The remaining two shops, located in Afak and Al-Daghara districts (Shop 3 and Shop 4), represented semi-urban or rural environments characterized by agricultural surroundings and varied storage conditions.

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

Sample Code	Shop Number	The herb	Part used	Dosage amount*	I (kg/year)	Country
P1	1	*Green tea (Camellia Sinensis)*	Leaves	15 g/day	1.35	Iran
P2		*Lemon Balm (Mellisa officinalis)*	Leaves	2 g/day	0.18	Syria
P3		*Basil (Ocimum Basilicum)*	Leaves	15 g/day	1.35	Iraq
P4		*Black Seed (Nigella Sativa)*	Seeds	6 g/day	0.54	India
P5		*Fenugreek (Trigonella Foenum Graecum)*	Seeds	30 g/day	2.7	Egypt

P6	2	*Moringa (Moringa Oleifera)*	Leaves	5 g/day	0.45	Iraq
P7		*Gorgeous roses (Rosa Damascena)*	Flowers	10 g/day	0.9	Iraq
P8		*Purslane seeds (Portulaca oleracea)*	Seeds	10 g/day	0.9	Syria
P9		*Chia seeds (Salvia hispanica)*	Seeds	20 g/day	1.8	India
P10		*Mahaleb (Prunus mahaleb)*	Seeds	10 g/day	0.9	Syria
P11	3	*Sage (Salvia fruticosa)*	Leaves	10 g/day	0.9	Egypt
P12		*Ginger (Zingiber officinale)*	Roots	3 g/day	0.27	China
P13		*Bee pollen*	Seeds	5 g/day	0.45	Iran
P14		*Chamomile (Matricaria chamomilla)*	Flowers	15 g/day	1.35	Egypt
P15		*Licorice (Glycyrrhiza glabra)*	Roots	10 g/day	0.9	Syria
P16	4	*Senna (Senna alexandrina)*	Leaves	10 g/Week	0.9	Pakistan
P17		*Lady's mantle Alchemilla vulgaris*	Leaves	15 g/day	1.35	Maghreb
P18		*Roselle (Hibiscus sabdariffa)*	Flowers	15 g/day	1.35	Iraq
P19		*Clover (Medicago sativa)*	Leaves	5 g/day	0.45	Iraq
P20		*Neem (Azadirachta)*	Leaves	20 g/Week	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.

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 they are commonly used to treat. Interviews 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. All collected samples consisted of dried whole plant parts or ground preparations, typically marketed for their therapeutic roles, including benefits for blood vessel and heart health, cancer prevention, weight control, blood purification, wound healing, muscle relaxation, diuretic properties, 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 guarantee 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) controlled transfer of the sealed containers to the measurement laboratory, and (v) registering 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 unground and ground samples were homogenized into a fine powder by grinding (Obaid 2022) and then passed through a sieve of approximately 0.8 mm mesh size (Obaid 2022) Subsequently, each sample was oven-dried for six consecutive hours at 120 °C (Obaid 2022), a step 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 code for identification. To allow for secular equilibrium between radionuclides in the decay series, the samples were stored for four weeks prior to 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 with 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, 22 cm 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, namely 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 the channel number and the gamma-ray energy, with a high correlation coefficient ($R^2 \approx 0.99$), confirming the accuracy of the calibration (Dawal & Oudah 2025). The uncertainties of the reference energies are negligible compared to the NaI (Tl) detector resolution (Dawal & Oudah 2025). In addition to energy calibration, efficiency calibration was carried out using the same standard sources, following procedures reported in the literature (Hady & Mashkor 2022). This calibration is essential to convert 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 detector response (Dawal & Oudah 2025).

Background (blank) measurements were also performed under the same geometry and counting time as the samples, in order to subtract natural background contributions (mainly from K-40, U-238, and Th-232 present in the laboratory environment) (Garba et al. 2024). This ensures that the reported net peak areas represent only the activity of the measured samples.

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

3. CALCULATIONS

3.1 Specific Activity

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

$$A= \frac{N - N_{\circ}}{I_{\gamma}\, \varepsilon\, m\, t} \qquad (1)$$

where A: the specific activity of the radioactivity in the dry sample, N: the net number of a specific peak for the sample, $N_{\circ}$: the number of background for the specific peak of the sample, I_{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 10800 sec (Garba et al. 2024).

3.2 Hazard Indicators

3.2.1. Radium equivalent

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

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

Where: Ra_{eq} is 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

(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):

$$D(nGy/h)=0.462\ AU+0.604\ ATh+0.0417\ AK \tag{3}$$

Where: (0.462, 0.604, 0.0417) (nGy/h) for each (Bq/kg) 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):

$$H_{in}=AU/185\ +ATh/259\ +AK/4810\ \leq 1 \tag{4}$$

Where: (AU, ATh, AK) are the activity concentrations (Bq/kg) 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 (Kırıs 2020), (Dawal & Oudah 2025):

$$l\gamma=AU/150+ATh/100+AK/1500 \tag{5}$$

3.2.5. Annual Gonadal Dose Equivalent (AGDE)

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

$$\mathrm{AGDE}(\mu\mathrm{Sv/y}) = 309/100\ \mathrm{AU} + 418/100\ \mathrm{Th} + 314/1000\ \mathrm{AK} \tag{6}$$

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):

$$AEDEin\ (mSv/y) = \mathrm{DR} \times 8760\ (h/y) \times 0.8 \times 0.7 (Sv/Gy) \times 10^{-6} \tag{7}$$

8760: number of hours 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 Radiological Protection (UNSCEAR 2000), which is equivalent to (1mSv/y), 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 µSv/y), which ranges from (200 to 800) µSv/y (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 of medicinal plants using Eq. 8 (Kadhim et al. 2021), (*IAEA* 2022):

$$IED = A \times I \times DCF \tag{8}$$

Where A is the activity concentration of the radionuclide in the medicinal plant sample (Bq/kg), I: Consumption rate of medicinal plants (kg/y) Assuming that the number of days consumption per year (90 day/y) (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 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 per 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). 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):

$$\mathrm{ELCR} = \mathrm{IED} \times \mathrm{DL} \times \mathrm{RF} \quad (9)$$

Where DL: 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 NORMs were measured using a gamma ray spectrometer in 20 different medicinal plants. Calculation performed using Eq. 1. Table 2 shows the average dry weight activity concentrations, the concentration levels of U-238 ranged between ND - 10.23±0.87 Bq/kg, with an average of 3.90±0.39 Bq/kg, the shea seed (P9) has the highest concentration of U-238, the concentrations of Th-232 range between 3.3±0.67-25.74±1.88 Bq/kg, with an average of 13.03±1.16 Bq/kg, the black bean seed (P4) contains the highest concentration. For K-40 the range is 1322.11±18.65 Bq/kg for the lion's mane herb and 65.01±4.14 Bq/kg for the bee pollen, with an average value of 548.99±12.65 Bq/kg.

Table 2: Specific activities (Bq/Kg) U-238, Th-232, K-40 in the 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

In contrast, activity concentrations for K-40 exceeded the recommended limit of 400 Bq/kg in 15 out of 20 samples (75%), which may be attributed to the natural irregular distribution of radionuclides at ground level (Olagbaju et al. 2021). Since some of the medicinal plant samples analyzed were imported from different geographic regions, the measured radioactivity levels of the radionuclides were likely affected by the differences in soil radioactivity and environmental conditions between these countries. This reflects the well-established geographic variation in the distribution of natural radionuclides, which largely depends on the local geological and geochemical characteristics (Olagbaju et al. 2021), (UNSCEAR 2000). Despite this, the concentrations of the specific activity of U-238 and ^{232}Th in all the studied samples remained within the internationally accepted limits, which are 33 and 45 Bq/kg respectively (UNSCEAR 2000). The high K-40 activities observed in the parts of the leaves and flowers compared to the other plant components can be linked to it is essential element in plant physiology and is readily absorbed through root ion carriers and ion channels (Desideri & Roselli 2010). Consequently, elevated K-40 activity is frequently observed in medicinal plants, especially in leaves and flowers, which exhibit a higher physiological capacity for potassium uptake compared to other plant parts (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 reflects the combined effects of efficient biological absorption 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 activity of U-238 (3.90 ± 0.39 Bq/kg) in the medicinal plants from Al-Diwaniyah was lower than that reported in most Iraqi studies, such as Karbala (12.05 Bq/kg) (Obaid 2022) and Najaf (38.12 Bq/kg) (Hamza et al. 2020), as well as in Egypt (25.09 Bq/kg) (Abdelfadeel et al. 2023). However, it was comparable to values found in Nigeria (4.73 Bq/kg) (Popoola et al. 2024).

Table 3: Comparison of mean activity concentrations (Bq/kg) 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 & Kitah 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		0.37 ± 0.16	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 & Mansour 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 marketsand 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 stat)		36±15	230 ±46	(NaI(Tl)	(Monica & Khandaker 2020)
	Average activity from previous studies (Bq/Kg)	13.71	11.14	689.25		
	World	35	30	400		(UNSCEAR 2000)
	This study Iraq Diwaniyah	3.90 ±0.39	13.03±1.16	548.99±12.65	(NaI(Tl)	

The average Th-232 concentration (13.03 ± 1.16 Bq/kg) was within the range observed in regional studies, slightly higher than some Iraqi reports (12.95 Bq/kg) (Hamza et al. 2020) but lower than values from Egypt (20.61 Bq/kg) (Abdelfadeel et al. 2023), Bangladesh (15.73 Bq/kg) (Hossen et al. 2024), and Nigerian markets (37 Bq/kg) (Shuaibu et al. 2025). Importantly, it remained below the UNSCEAR (2000) global reference value of 30 Bq/kg (UNSCEAR 2000).

In contrast, the K-40 activity concentration (548.99 ± 12.65 Bq/kg) exceeded the UNSCEAR global average of 400 Bq/kg (UNSCEAR 2000), aligning with the results of Najaf (570.70 Bq/kg) (Hamza et al. 2020). Jordan (593.97 Bq/kg) (Abu-Qatouseh & Mansour 2019), and Egypt (471.4-1191.35 Bq/kg) (Saudi et al. 2022), (Abdelfadeel et al. 2023). This elevation may result from the widespread use of potassium-based fertilizers that enrich soil K-40 levels, enhancing its uptake by plants (Szaciłowski 2024).

Overall, the radiological profile of Al-Diwaniyah medicinal plants shows U-238 and Th-232 within safe limits, while K-40 exhibits moderately elevated 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 to identify whether the current findings indicate elevated or reduced radioactivity levels relative to global norms. The results are summarized in Table 4.

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

The percentage of the contribution of the four sites from which the studied herbs were collected (Shops 1 to 4) in the total triad of radioactive nuclides was calculated based on the combined concentrations of the three radioactive nuclides, and is shown in Figure 2. Shop 4 had the highest total contribution to pollutant contamination by (40%), followed by Shop 1 (%23), Shop 3 (%19), and Shop 2 (%18) The following order (Shop 4 > Shop 1 > Shop 3 > Shop 2) indicates that shop 4 is probably the main source of contamination, perhaps due to the nature of the origin of these medicinal plants. These percentage contributions are descriptive indicators based on cumulative activity concentrations and are intended to illustrate distribution patterns rather than statistically significant differences between shops.

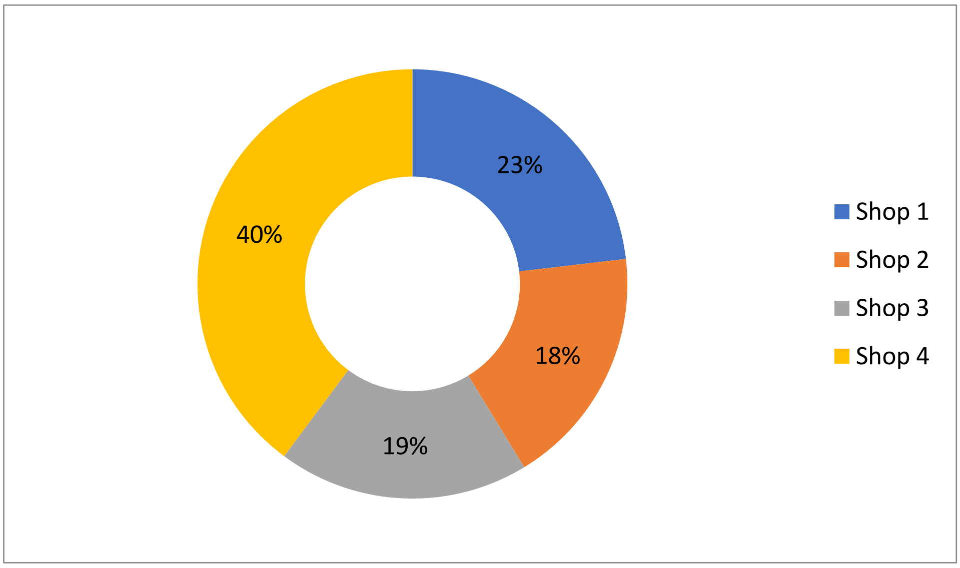

Fig.2: Contribution of each herbal shop to the total activity of U-238, Th-232, and K-40 in the analyzed medicinal plant samples.

Analysis of the radionuclide distribution by shop (Table 5) revealed distinct patterns among locations. Shop 3 contributed the highest proportion of U-238 (32%), Shop 1 showed elevated Th-232 (34%), and Shop 4 exhibited 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 can deposit K-40 and other radionuclides on exposed herbal materials. Additional influences may include closeness to medical or industrial sources, non-ideal storage practices such as outdoor display near streets, and inadequate ventilation or packaging that allows dust accumulation. The variability among sites also reflects differences in soil composition and plant uptake capacity. Collectively, these findings highlight the presence of diverse, localized sources of radioactive contamination and underscore the need for targeted environmental control measures, particularly in Shops 1 and 4.

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%

Overall, the results indicate that the radiological profile of the studied medicinal plants is primarily governed by natural environmental and botanical factors rather than market-specific practices. The consistently low activity concentrations of U-238 and Th-232 across all samples, combined with the moderate elevation of K-40, 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 does not translate into 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 dose calculations.

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 capture the main structure of variation within the dataset.

PC1 accounted for 38.7% of the variance and exhibited a strong positive loading for K-40 (0.729), with negative contributions from Th-232 (-0.543) and U-238 (−0.417), representing the variability primarily driven by K-40 activity. PC2, explaining 34.1% of the variance, showed a strong positive association with U-238 (0.776) and a negative association with Th-232 (−0.631), reflecting the U-238- Th-232 relationship independent of K-40 levels.

The PCA biplot (Fig. 4) integrates both sample distribution and radionuclide loadings. Red arrows denote the direction and magnitude of each radionuclide's contribution to the principal components. The K-40 vector is aligned strongly with PC1, confirming its dominant role in total variance. Samples from Shop 4 (diamonds) cluster toward the positive PC1 axis, consistent with higher K-40 activity. In contrast, the U-238 vector aligns mainly with PC2, indicating samples with elevated U-238 levels, while the Th-232 vector points in the opposite direction, suggesting an inverse relationship between Th-232 and the other radionuclides.

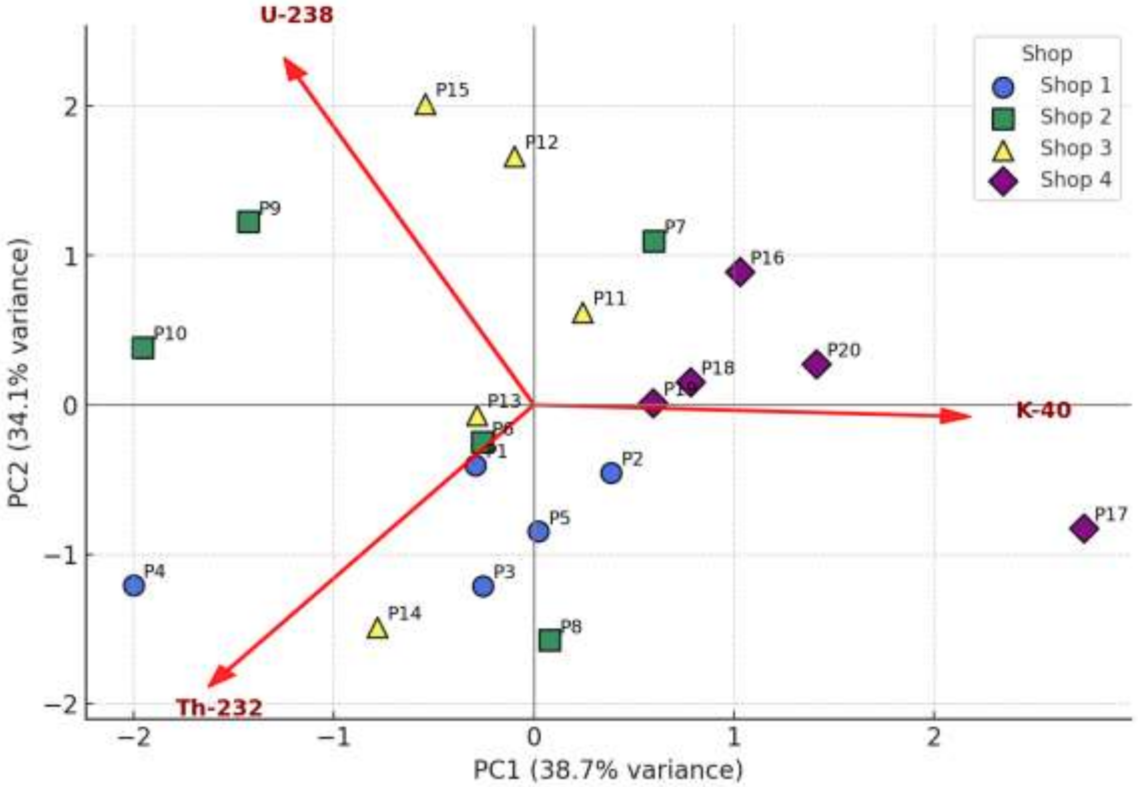

Fig.4: PCA biplot showing the distribution of medicinal plant samples by herbal shop (Shop 1–4) and the loading vectors of U-238, Th-232, and K-40, illustrating the contribution of each radionuclide to the principal components (PC1 and PC2).

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

4.1.1. 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. 5. 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.

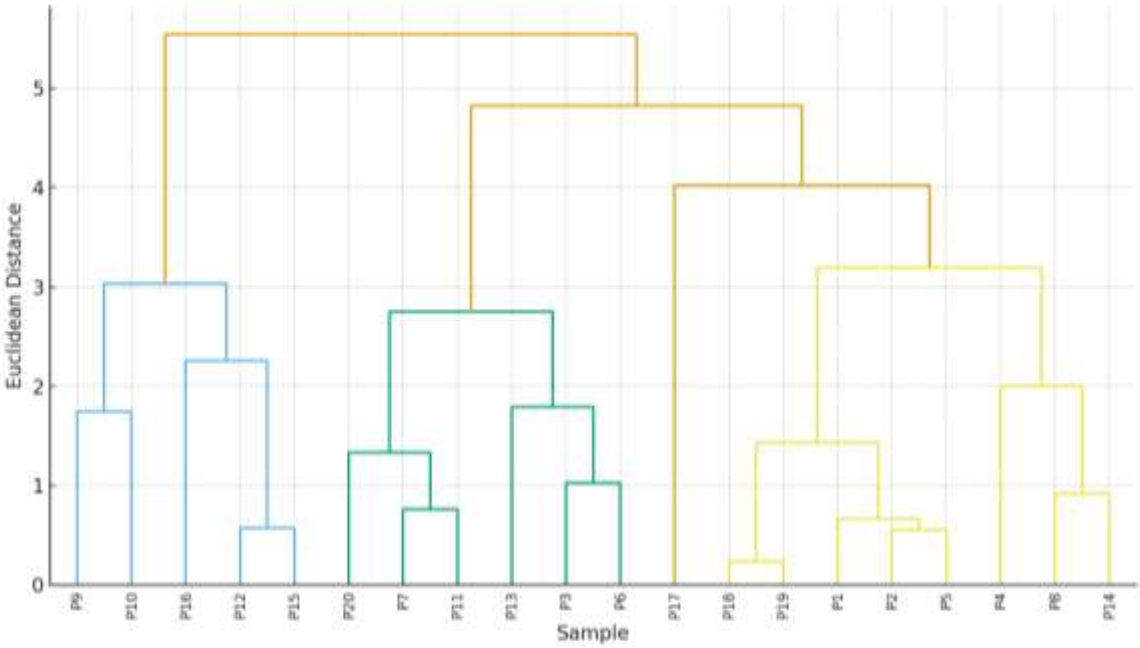

Fig.5: Hierarchical cluster analysis (HCA) dendrogram of medicinal plant samples based on the activity concentrations of U-238, Th-232, and K-40, illustrating the grouping of samples according to their radiological similarity.

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

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 content among medicinal plants are influenced more by botanical and environmental factors than by market location. These results, however, contrast with the findings of this study (Rajih & Oudah 2025), which investigated toxic element concentrations in the same plant samples and reported that the distribution of toxic metals was strongly affected by market location and individual shop conditions.

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

4.2. Radiation risks

Table 6 presents the calculated values of the radiological hazard parameters, including the radium equivalent activity (Ra_{eq}), absorbed gamma dose rate (DR), internal hazard index (H_{in}), gamma activity index (I_γ), annual gonadal dose equivalent (AGDE), and annual effective dose for indoor exposure ($AEDE_{in}$) for the analyzed medicinal plants.

All Ra_{eq} 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. The highest DR value was observed in the lion's mane sample (P17), while most samples exhibited lower values than the global average of 59 nGy/h reported by UNSCEAR (2000) (UNSCEAR 2000).

The internal hazard index (H_{in}) values for all samples were below unity, confirming minimal internal exposure risk. Similarly, the gamma activity index (I_γ) ranged between 0.12 and 0.99, which is within the permissible range for all herbs (UNSCEAR 2000), with the highest value also observed in lion's mane (P17).

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

Sample Code	Ra_{eq} (Bq/ kg)	DR	H_{in}	I_γ	AGDE (µSv/y)	$AEDE_{in}$ (mSv/y)
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)

The calculated annual gonadal dose equivalent (AGDE) varied from 52.69 to 462.65 µSv/y, where only the lion's mane herb (P17) slightly exceeded the global safety threshold of 300 µSv/y (UNSCEAR 2000). The annual effective dose for indoor exposure ($AEDE_{in}$) ranged from 0.04 to 0.30 mSv/y, with bee pollen (P13) recording the lowest and lion's mane (P17) the highest value.

Overall, the results show that the radiological parameters of all samples are generally within international safety limits, with only a few individual herbs-particularly lion's mane-approaching the upper global reference levels. This suggests that the studied medicinal plants are radiologically safe for consumption under normal usage patterns.

Table 7 presents the Ingestion Effective dose (IED) for each of the radionuclides, as well as the total Ingestion Effective dose and the corresponding excess lifetime cancer risk (ELCR) for the studied medicinal plants. The combined annual effective dose values for all radionuclides were below the UNSCEAR (2000) recommended limit of 0.3 mSv/y (UNSCEAR 2000). Similarly, the calculated ELCR values ranged between 0.01×10^{-3} and 0.27×10^{-3}, with an average value of 0.09×10^{-3}, which is lower than the permissible limit of 0.29×10^{-3} established by the International Commission on Radiological Protection (ICRP) (ICRP 2007). The lowest and highest ELCR values were observed for bee pollen (P13) and lion's mane (P17), respectively. These findings indicate that, under normal consumption conditions, the ingestion of these medicinal plants does not pose any significant radiological health risk.

Table 7: Ingestion Effective dose (IED), Lifetime Incremental Cancer Risk (ELCR) for various medicinal plants.

Sampe Code	**IED mSv/y**			**Total IED mSv/y**	**ELCR × 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	1.05×10^{-03}	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}	7.85×10^{-03}	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	≤ (0.29)

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

Although the $AEDE_{in}$-based ELCR values (not presented here) showed slightly higher risk levels, they still 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 herbs would not exceed global safety limits.

It should be noted that the ingestion doses estimated in this study are based on an averaged 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 addressed 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 hazard indices, ingestion effective dose (IED), and excess lifetime cancer risk (ELCR) demonstrates that the consumption of the investigated medicinal plants does not pose a significant health risk under normal usage patterns. Even in samples with relatively higher K-40 activity, the calculated doses and ELCR values remained well below internationally recommended limits. This highlights the importance of dose-based assessment rather than reliance on activity concentration thresholds alone. 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 U-238 and Th-232 activity concentrations were within internationally accepted limits, while K-40 levels exceeded the UNSCEAR global average in most samples, reflecting both the 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 content among samples was mainly governed by botanical and environmental factors rather than market location. All calculated hazard indices (Ra_{eq}, DR, H_{in}, I_{γ}, AGDE, $AEDE_{in}$) were below the global 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 consumption of these herbs under normal conditions does not pose a radiological health concern.

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

Conflict 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.

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Contributions of researchers

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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