Assessment of radionuclide concentrations and radiological safety for seeds and roots parts of selected medicinal plants from Iraq markets

S. T. Kadhem

Department of Physics, College of Science, University of Al Mustansiriyah, Baghdad, Iraq.
Department of Physiology and Medical Physics, College of Medicine, University of Thi Qar, Thi Qar, 64001, Iraq.

M. Alrakabi

Department of Physics, College of Science, University of Al Mustansiriyah, Baghdad, Iraq.

J. M. Rashid

Department of Physics, College of Science, University of Thi-Qar, Thi-Qar, Iraq.

Received 21 June 2025; accepted 3 October 2025

The present study was conducted to determine the natural radioactivity levels and evaluate the health impact of 25 samples of seeds and roots of some medicinal plants widely used in Iraq. A 3×3 $\mathrm{NaI(Tl)}$ gamma-ray spectroscopy system was utilized to measure and analyze the specific activities of $^{238}\mathrm{U}$, $^{232}\mathrm{Th}$, $^{226}\mathrm{Ra}$, $^{228}\mathrm{Ra}$, and $^{40}\mathrm{K}$ in the selected samples. The specific activities (Bq/kg) varied from 5.86 to 1.39 Bq/kg, 4.36 to 1.62 Bq/kg, 2.28 to 0.99 Bq/kg, 7.61 to 1.34 Bq/kg, and 232.92 to 102.96 Bq/kg for $^{238}\mathrm{U}$, $^{232}\mathrm{Th}$, $^{226}\mathrm{Ra}$, $^{228}\mathrm{Ra}$, and $^{40}\mathrm{K}$, respectively. The average values obtained were 16.7 Bq/kg for radium equivalent activity (Ra_{eq}), 11.866 Bq/kg for thorium equivalent activity (Th_{eq}), 217.2 Bq/kg for potassium equivalent activity (K_{eq}), 8.79 nGy/h for absorbed dose (D_{ICRP}), 9.068 nGy/h for absorbed dose (D_{Beck}), 10.98 nGy/h for absorbed dose (D_{UNSCEAR}), 0.049 for internal hazard index (H_{in}), 0.045 for external hazard index (H_{ex}), 0.136 Bq/kg for gamma representative level index ($I_{\gamma r}$), 0.0539 mSv/y for total annual effective dose equivalent ($AEDE_{\text{total}}$), and 0.189×10^{-3} for total excess lifetime cancer risk ($ELCR$).The specific concentration and all the hazard indices associated with it were lower than the maximum permissible limits recommended for safety therefore, there was no threat to the health of the consumer.

Keywords: NORM; Medicinal plants; Radiation hazard; Activity concentration; gamma ray spectroscopy.

DOI: https://doi.org/10.31349/RevMexFis.72.021102

1. Introduction

Medicinal plants have historically played a significant role in traditional medicine as a reservoir for novel pharmaceuticals. Their use spans many cultures and has long contributed to public health, often serving as preventive or complementary treatments within various societies. The therapeutic potential of plants is largely attributed to the presence of biologically active organic substances that possess diverse molecular structures and healing properties [1]. Plants are living chemical factories that produce a wide variety of secondary metabolites [2]. As a result, alkaloids, polyphenols, tannins, and terpenoids are the bioactive molecules that give medicinal plants their medical and curative capabilities [3].

Despite their critical significance in national healthcare systems, medicinal plants' chemical purity has frequently been damaged by environmental contaminants such as biological toxins, radioactive and heavy metals, fumigants, and pesticide residues. Primordial radionuclides, in particular, are a major pollutant that can reduce the quality of medicinal plants [4].

Throughout their lives, humans are continually subjected to ionizing radiation from both natural and artificial origins [5]. The radiological assessment of ionizing radiation exposure to the human body provides essential information about the potential negative effects of radiation on human health [6,7,8]. Understanding the levels and distribution of radionuclides in the environment is therefore crucial in determining whether radiation exposure remains within safe limits. Natural sources account for approximately 80% of the total radiation exposure experienced by the global population [9]. Naturally occurring radioactive series such as $^{238}\mathrm{U}$ and $^{232}\mathrm{Th}$, along with independent radionuclides like $^{40}\mathrm{K}$, are found in varying concentrations in the Earth's crust and atmosphere [10]. Exposure to terrestrial radiation represents the primary form of external irradiation affecting the human body [5]. Regardless of whether they originate naturally or through human activity, radionuclides can be absorbed by plants and animals, subsequently entering the human system via the food chain [11]. In some cases, certain radioactive elements may directly enter the human body [10]. Plants typically act as the first medium through which radionuclides are taken up from the soil, moving alongside essential minerals and accumulating in various plant tissues, sometimes reaching edible portions [12]. The extent of uptake of natural radionuclides depends on both the intake of food and water and the existing environmental concentrations of these elements [10,13]. Natural radiation can harm living cells and produce various alterations in chromosomes owing to DNA damage. As a result, the evaluation of several radiological indicators has become critical in the current nuclear age [14,15]. Once ingested, radionuclides may accumulate in specific organs; for

instance, ^{238}U tends to concentrate in the kidneys and lungs, ^{232}Th in the liver, bones, and lungs, and ^{40}K in muscle tissue [16]. The deposition of such radionuclides within body organs can lead to adverse health effects, including illness, immune system suppression, and potentially increased mortality rates [17]. Continuous exposure to natural background radiation is an unavoidable aspect of human life. Therefore, evaluating gamma radiation doses from naturally occurring radionuclides is essential, given that natural radiation constitutes the largest share of external exposure for people worldwide [18]. Recently, numerous studies on the identification and assessment of natural radioactivity in medicinal plants and the attendant health risks have been conducted in different regions of the world, including South India [19], Bangladesh [20], Turkey [21], Jordan [22], Serbia [23], South Africa [24], Nigeria [25], Egypt [26], Malaysia [27], Nepal [28], and Uganda [29].

In Iraq, however, rigorous research on the distribution and enrichment of radionuclides in medicinal plants is limited. Kareem *et al.* assessed primordial radionuclide concentrations in selected Iraqi medicinal plant samples and determined the activity concentration, radium equivalent, and internal hazard index of the naturally occurring radionuclides ^{238}U, ^{232}Th, and ^{40}K [30]. Additionally, Hamza *et al.* employed gamma-ray spectroscopy to determine the radioactivity concentration of naturally occurring radionuclides, as well as their associated radiological hazard indices, in ten samples of commonly used medicinal plants. Furthermore, they measured the risk factor to be 1.4325×10^{-5} [31]. Despite the growing global interest in studying radiation levels in medicinal plants, it is worth emphasizing that a comprehensive database on the radioactivity of medicinal plants in Iraq is still lacking. Therefore, the current study investigates the presence of natural radionuclides in 25 samples of the most commonly used medicinal plants in Iraqi traditional medicine. It determines the activity concentrations of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K, calculates the corresponding radiological hazard indices due to the consumption of these natural radionuclides, and compares the results with the standards recommended by the World Health Organization (WHO) to evaluate the safety of these plants.

TABLE I. Samples of seeds and roots of medicinal plants used in present study.

No.	Sample ID	Scientific name	Common name	Used part
1	S1	*Foeniculum vulgare*	Fennel	Seed
2	S2	*Trigonella foenum-graecum*	Fenugreek	Seed
3	S3	*Ammi visnaga*	Toothpick	Seed
4	S4	*Anethum graveolens*	Dill	Seed
5	S5	*Coriandrum sativum*	Coriander	Seed
6	S6	*Carum carvi*	Caraway	Seed
7	S7	*Cuminum cyminum*	Cumin	Seed
8	S8	*Pimpinella anisum*	Anise	Seed
9	S9	*Peganum harmala*	Harmal	Seed
10	S10	*Eruca sativa*	Roca	Seed
11	S11	*Sinapis alba*	Mustard	Seed
12	S12	*Nigella sativa*	Black cumin	Seed
13	S13	*Petroselinum crispum*	Parsley	Seed
14	S14	*Allium ampeloprasum*	Leek	Seed
15	S15	*Lepidium sativum*	Peppergrass	Seed
16	S16	*Daucus carota*	Carrot	Seed
17	S17	*Ferula hermonis*	Church zallouh	Root
18	S18	*Glycyrrhiza glabra*	Licorice root	Root
19	S19	*Curcuma longa*	Turmeric	Root
20	S20	*Linum usitatissimum*	Flax	Seed
21	S21	*Elettaria cardamomum*	Cardamom	Seed
22	S22	*Descurainia sophia*	Flixweed	Seed
23	S23	*Apium graveolens*	Celery	Seed
24	S24	*Raphanus sativus*	Radish	Seed
25	S25	*Astragalus tragacantha L.*	Gum tragacanth	Seed

2. Methodology

2.1. Collection of sample

The sampling site was an important factor therefore a total of 25 common medicinal plant samples were obtained from various markets throughout Iraq. The plants used were chosen based on their popularity among the general public and broad treatment of various diseases or as complementary medicine. Polythene bags were used to transport the samples to the lab. Medicinal plants were identified at Thi - Qar University, College of Science, Environmental and Radioactive Pollution Research Unit (ERPRU). Table I summarizes the medicinal plants and parts used in this study.

2.2. Sample preparation

The samples were open air dried on trays for one week at room temperature in a dust-free environment, then oven dried for 6 hours at $110\,^{\circ}\mathrm{C}$ to remove moisture and maintain the actual weight in the laboratory. Figure 1 shows the collected samples. After complete drying, the plant samples were crushed into fine particles using a TAISITE brand mechanical grinder to ensure uniformity in texture. The ground material was then passed through a fine sieve to obtain a homogeneous powder suitable for accurate radiometric analysis. Each powdered sample was placed into a pre-weighed one-liter Marinelli plastic beaker, which was then tightly sealed to prevent any contamination or loss of material. Following this, the beaker was reweighed using a precision analytical balance with a readability of 0.01% to ensure high accuracy in sample mass determination. All prepared samples were stored in sealed containers for approximately 30 days before measurement. This waiting period allows for the establishment of secular equilibrium between long-lived parent radionuclides and their short-lived radioactive decay products, ensuring more reliable and stable gamma-ray emissions during subsequent spectrometric analysis.

FIGURE 1. Collected and prepared samples of medicinal plants used in the current study.

2.3. Samples measurement

Measurements were carried out by adopting a gamma spectrometry system of American origin (Teledyne Isotope type) equipped with a high-efficiency scintillation detector, NaI(Tl), with a crystal dimension of 3×3 inches and an energy resolution of 7.5% for $^{137}\mathrm{Cs}$ (661.7 keV), which is one of the characteristic gamma-ray energies of the standard radionuclide source $^{137}\mathrm{Cs}$. The crystal was coupled to a photomultiplier tube with high efficiency in order to convert the light flashes into electrical signals proportional to the energy of the incident gamma-ray photons. A lead shield was placed around the detector to reduce background radiation and attenuate the emitted X-rays. Before performing the measurements, an empty plastic sample container was counted in the same manner as the samples to determine background effects. The two spectra were collected and analyzed to specify all variables that could affect the spectral shape before and after using the Marinelli beaker. This process was repeated to determine the radiation background of the detection system, thereby achieving greater accuracy and reliability. The background spectrum was then subtracted from all measured sample spectra. Figure 2 shows a diagram of the gamma spectroscopy system.The detection system was used to measure and analyze different medicinal plant samples in order to identify naturally occurring radioactive elements, including uranium ($^{238}\mathrm{U}$), thorium ($^{232}\mathrm{Th}$), radium ($^{226}\mathrm{Ra}$ and $^{228}\mathrm{Ra}$), and potassium ($^{40}\mathrm{K}$). All operating parameters of the system were kept constant for all samples and background measurements. The measurement time was 64,800 s, and the operating voltage of the system was 730 V. Figure 3 illustrates the NaI(Tl) gamma spectroscopy system used in the present study.Based on the measured γ-ray peaks emitted by daughter radionuclides in the $^{238}\mathrm{U}$ and $^{232}\mathrm{Th}$ decay series and by $^{40}\mathrm{K}$, the activity concentration was expressed as

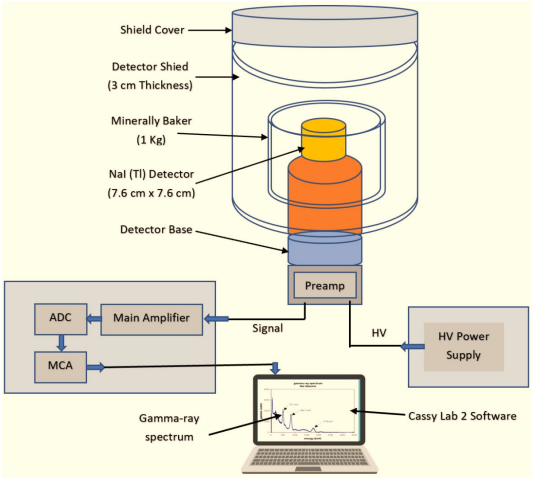

FIGURE 2. Diagram of NaI(Tl) gamma spectrometer used in present study.

FIGURE 3. NaI (Tl) gamma spectroscopy system used in present study.

TABLE II. Natural radionuclides and their characteristic γ-ray energies used to calculate the radioactivity concentrations of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K.

Parent nuclide	Daughter nuclide	Energy (keV)	Abundance (%)
^{40}K	Natural	1460.8	10.66
^{238}U	^{214}Bi	1120.3	14.7
^{226}Ra	^{214}Bi	609.3	45.49
^{232}Th	^{208}Tl	583.0	85.0
^{228}Ra	^{228}Ac	911.0	25.8

$\mathrm{Bq\,kg^{-1}}$ (dry weight), depending on the sample type. The quantitative analysis of the spectra obtained from gamma-ray spectrometry was performed using the *Gamma-ray Spectrum Analysis Software Cassy Lab*. The analysis at specific energies, measured from characteristic gamma-lines, allowed the determination of the specific activity concentrations of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K in the medicinal plant samples. The γ-ray line of ^{214}Bi (1120.3 keV) was used to determine ^{238}U, and that of ^{214}Bi (609.3 keV) for ^{226}Ra. The γ-ray line of ^{208}Tl (583.0 keV) was used to determine ^{232}Th, and that of ^{228}Ac (911.0 keV) for ^{228}Ra. The single transition at 1460.8 keV was used to determine the activity concentration of ^{40}K. Table II summarizes the natural radionuclides used to calculate the radioactivity concentrations of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K.

3. Assessment of radiation hazards

3.1. Minimum detectable activity

Detection of low-concentration radioactive elements including naturally occurring radioactive material (NORM) depends heavily on Minimum Detectable Activity (MDA). A detector typically registers no difference between sample and background counts rates. The investigator should measure radiation background with identical measurement setups and ideally during the same time period as when they measure the sample.

The Minimum Detectable Activity (MDA) emerges from the combination of detection system efficiency and detection limit level (DLL) [32]. The detector system determines its detection limit level through the following mathematical formula:

$$\mathrm{DLL} = 4.66 \times \sigma_b + 3. \tag{1}$$

The minimum level at which MDA can be reliably detected, often referred to as the detection limit, may be determined using the following equation:

$$\mathrm{MDA} = \frac{\mathrm{DLL}}{k \cdot t}, \tag{2}$$

$$\mathrm{MDA} = \frac{4.66 \times \sigma_b + 3}{k \cdot t}. \tag{3}$$

The duration of the radiation background measurement and sample counting plays a crucial role in determining the accuracy and reliability of radiological analysis. This measurement time directly affects the standard deviation of the background radiation, σ_b, which is an essential statistical parameter for evaluating detection limits. Furthermore, the calculation of the constant k depends on several key factors, including the efficiency of the detection system ε, the abundance or concentration of the radionuclide in the sample C, and the mass or weight of the sample W.

The relationship between these variables can be mathematically expressed using the following formula:

$$k = \varepsilon E_\gamma \cdot I_\gamma E_\gamma \cdot W. \tag{4}$$

For clarity and ease of application, Eq. (3) can be rewritten or expressed in the following alternative form:

$$\mathrm{MDA} = \frac{(4.66 \times \sigma_b) + 3}{\varepsilon(E_\gamma) \cdot I_\gamma(E_\gamma) \cdot W \cdot t}. \tag{5}$$

Equations (1) and (3) are applicable only under the condition that the measurement times for both the sample and the radiation background are equal. If the counting durations differ, it becomes necessary to use the more general forms of these equations, which account for the variation in measurement times and ensure accurate results.

$$\mathrm{LLD} = 3.29\sqrt{n_b t_s \left(1 + \frac{t_s}{t_b}\right)} + 3, \tag{6}$$

$$\mathrm{MDA} = \frac{3.29\sqrt{n_b t_s \left(1 + \frac{t_s}{t_b}\right)} + 3}{\varepsilon(E_\gamma) \cdot I_\gamma(E_\gamma) \cdot W \cdot t}. \tag{7}$$

In the current investigation, the quantity n_b represents the radiation background count rate recorded over a defined measurement interval t_b. Meanwhile, t_s indicates the total counting duration associated with the sample measurement, as outlined in Ref. [32]. Using these fundamental parameters, the Minimum Detectable Activity (MDA) was computed by applying Eq. (5). The calculated MDA values under various experimental conditions are summarized in Table III.

TABLE III. Minimum detection activity (MDA) of measurement system for targeted radionuclide in present.

Parent Nuclide	Daughter Nuclide	Energy (KeV)	Abundance (%)	$\varepsilon(E_\gamma)$	MDA (Bq/Kg)
$^{40}_{19}$K	Natural	1460.8	10.66	0.01762	10.93
$^{238}_{92}$U	$^{214}_{83}$Bi	1120.3	14.7	0.02701	0.166
$^{226}_{88}$Ra	$^{214}_{83}$Bi	609.3	45.49	0.07128	0.110
$^{232}_{90}$Th	$^{208}_{81}$Tl	583.0	85.00	0.07643	0.121
$^{228}_{88}$Ra	$^{228}_{89}$Ac	911.0	25.8	0.03745	0.130

3.2. Radioactivity concentration

The specific activity of a radioactive substance is expressed as the activity per unit mass, typically quantified in units of curies per gram (Ci/g) or becquerels per kilogram (Bq/kg). To determine the activity concentration A (in Bq/kg) for individual radionuclides, Eq. (8) was applied in this study [33]:

$$A\ (\mathrm{Bq/kg}) = \frac{N}{t\, I_\gamma(E_\gamma)\, \varepsilon(E_\gamma)\, m}. \tag{8}$$

In this context, N represents the net counts under the gamma-ray photopeak obtained from the spectrum after subtracting the radiation background contribution. The parameter t denotes the total measurement time in seconds. The term $I_\gamma(E_\gamma)$ refers to the emission intensity of the gamma-ray at a specific energy E_γ, while $\varepsilon(E_\gamma)$ indicates the detector efficiency at that particular gamma-ray energy. Finally, m corresponds to the mass of the analyzed sample expressed in kilograms.

3.3. Radium equivalent activity (Ra_{eq})

The equivalent radium concentration, denoted as Ra_{eq}, is a radiological index employed to assess the potential health hazards arising from materials containing naturally occurring radioactive nuclides, specifically radium-226 (^{226}Ra), thorium-232 (^{232}Th), and potassium-40 (^{40}K). This parameter provides a means of expressing the combined gamma radiation exposure from these radionuclides in terms of an equivalent activity of radium-226.

The value of Ra_{eq} is determined under the assumption that a concentration of 370 Bq/kg of ^{226}Ra produces the same gamma dose rate as 260 Bq/kg of ^{232}Th or 4810 Bq/kg of ^{40}K. Therefore, it serves as a useful tool for comparing the radiological impact of different materials in a standardized manner. The equivalent radium concentration can be calculated using the following expression [34]:

$$\mathrm{Ra_{eq}}\ (\mathrm{Bq/kg}) = A_{\mathrm{Ra}} + 1.43\, A_{\mathrm{Th}} + 0.077\, A_{\mathrm{K}}, \tag{9}$$

In this context, A_{Ra}, A_{Th}, and A_{K} denote the specific activity concentrations of radium, thorium, and potassium, respectively, and are expressed in units of becquerels per kilogram (Bq/kg). These values are commonly used to characterize the radiological content of natural materials.

To account for the combined gamma radiation contribution from thorium and potassium in terms equivalent to radium, this indicator can be adjusted and expressed using the following relations:

$$\mathrm{Th_{eq}}\ (\mathrm{Bq/kg}) = A_{\mathrm{Th}} + 0.7\, A_{\mathrm{Ra}} + 0.055\, A_{\mathrm{K}}, \tag{10}$$

$$K_{\mathrm{eq}}\ (\mathrm{Bq/kg}) = A_{\mathrm{K}} + 18.46\, A_{\mathrm{Th}} + 13.24\, A_{\mathrm{Ra}}. \tag{11}$$

3.4. External hazard index (H_{ex})

This term is primarily used to evaluate the potential external exposure risk associated with gamma radiation. It helps in estimating the likely absorbed gamma dose that individuals may encounter due to external exposure when handling or being in proximity to gamma-emitting materials. The main purpose of introducing this factor is to provide a safety benchmark, ensuring that the resulting effective dose remains within internationally accepted safety limits. The external hazard index can be determined through the following mathematical expression:

$$H_{\mathrm{ex}} = \frac{A_{\mathrm{Ra}}}{370} + \frac{A_{\mathrm{Th}}}{259} + \frac{A_{\mathrm{K}}}{4810} \leq 1, \tag{12}$$

where H_{ex} denotes the external hazard index, which is used to assess the potential radiological risk from external gamma radiation exposure [35].

3.5. Internal Hazard Index (H_{in})

The internal hazard index is used to assess the radiation exposure risk that workers may face in environments with naturally occurring radioactive materials (NORM). This type of exposure typically occurs through ingestion or inhalation of radioactive particles present in the working environment. The internal hazard index serves as an important indicator for monitoring and controlling occupational radiation doses, ensuring they remain within safe levels. It can be calculated using the following expression:

$$H_{\mathrm{in}} = \frac{A_{\mathrm{Ra}}}{185} + \frac{A_{\mathrm{Th}}}{259} + \frac{A_{\mathrm{K}}}{4810} \leq 1. \tag{13}$$

Ideally, this index should remain below unity in safe working environments to minimize potential harm to the respiratory system. This is particularly important because radioactive particles, when inhaled, can deposit in the lungs and other respiratory tissues, leading to long-term health risks such as lung damage or increased cancer risk. Maintaining a value less than one ensures that the exposure levels are within acceptable safety limits, providing adequate protection for workers who may be regularly exposed to airborne radioactive material [36].

3.6. Absorbed gamma ray dose (D_γ)

The absorbed dose refers to the amount of radiation energy deposited per unit mass of a material or tissue exposed to ionizing radiation. This concept applies universally to all types of radiation, energy levels, and various materials, including biological tissues. In the context of naturally occurring radionuclides, the absorbed dose rates resulting from gamma-ray emissions are particularly important for assessing radiation exposure and its potential health impacts on humans and the environment (^{226}Ra, ^{232}Th, and ^{40}K) and were calculated based on the recommendations of the International Commission on Radiation Protection (ICRP) [nGy/h] using the following equation [37]:

$$D_{\gamma(\mathrm{ICRP})} = 0.427\, A_{\mathrm{Ra}} + 0.662\, A_{\mathrm{Th}} + 0.043\, A_{\mathrm{K}}. \quad (14)$$

For each radioactivity concentration (1 Bq/kg), the conversion factors used to calculate the absorption rate of gamma rays are radium-226 (0.462 nGy/h), thorium-232 (0.604 nGy/h), and potassium-40 (0.0417 nGy/h). Additionally, the absorbed dose can be calculated using Beck's [38] relationship:

$$D_{\gamma(\mathrm{Beck})} = 0.042\, A_{\mathrm{K}} + 0.429\, , A_{\mathrm{Ra}} + 0.666\, A_{\mathrm{Th}}, \quad (15)$$

and according to the formula adopted by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [9],

$$D_{\gamma(\mathrm{UNSCEAR})} = 0.533\, A_{\mathrm{Ra}} + 0.827\, A_{\mathrm{Th}} + 0.0537\, A_{\mathrm{K}}. \quad (16)$$

3.7. Gamma representative level index (I_γ)

This factor is employed to assess the potential radiological risk posed by gamma-ray emissions originating from natural radionuclides present in the analyzed samples. This indicator helps in evaluating the overall radiological safety of the environment or material under study. The gamma representative level index can be determined using the following equation, which has been developed and recommended by the Organization for Economic Co-operation and Development (OECD) for such assessments [39]:

$$I_\gamma = \frac{A_{\mathrm{Ra}}}{150} + \frac{A_{\mathrm{Th}}}{100} + \frac{A_{\mathrm{K}}}{1500}. \quad (17)$$

3.8. Annual effective dose equivalent

In order to estimate the effective dose resulting from gamma-emitting radionuclides, it is necessary to convert the absorbed dose in air into an effective dose received by humans. According to the guidelines provided by UNSCEAR 2000[9], a conversion factor of 0.7 Sv/Gy is applied to transform the absorbed dose in air into the annual effective dose equivalent for adults. This calculation incorporates an important behavioral assumption regarding human exposure: it is considered that approximately 80% of an individual's time is spent indoors, where exposure to terrestrial radiation is typically higher, while the remaining 20% is spent outdoors, where exposure levels are relatively lower. Taking these factors into account, the annual effective dose equivalent was calculated using the following expressions:

$$\mathrm{AEDE_{out}} = D\ (\mathrm{nGy/h}) \times 0.2 \times 0.7\ (\mathrm{Sv/Gy}) \times 8760 \times 10^{-6}, \quad (18)$$

$$\mathrm{AEDE_{in}} = D\ (\mathrm{nGy/h}) \times 0.8 \times 0.7\ (\mathrm{Sv/Gy}) \times 8760 \times 10^{-6}, \quad (19)$$

$$\mathrm{AEDE_{tot}} = \mathrm{AEDE_{out}} + \mathrm{AEDE_{in}}, \quad (20)$$

where $\mathrm{AEDE_{out}}$, $\mathrm{AEDE_{in}}$, and $\mathrm{AEDE_{tot}}$ are the outdoor, indoor, and total annual effective doses equivalent, respectively, D is the total absorbed dose rate in air in (nGy/h), 8760 h is the total number of hours in one year, and 10^{-6} is the conversion factor between nano- and milli-measurements.

3.9. Excess lifetime cancer risk

At a specific exposure level, Excess lifetime cancer risk (ELCR) provides the probability of developing cancer over a lifetime. Equation (23) was used to calculate the total Excess Lifetime Cancer Risk (ELCR), where $\mathrm{ELCR_{out}}$, $\mathrm{ELCR_{in}}$, and $\mathrm{ELCR_{tot}}$ are the outdoor, indoor, and total excess lifetime cancer risks, RF is the risk factor (Sv^{-1}) representing the fatal cancer risk per Sievert, DL is the duration of life (70 years on average), and ICRP 60 uses a value of $RF = 0.05$ for the general public for stochastic effects [40].

$$\mathrm{ELCR_{out}} = \mathrm{AEDE_{out}} \times DL \times RF, \quad (21)$$

$$\mathrm{ELCR_{in}} = \mathrm{AEDE_{in}} \times DL \times RF, \quad (22)$$

$$\mathrm{ELCR_{tot}} = \mathrm{ELCR_{out}} + \mathrm{ELCR_{in}}. \quad (23)$$

4. Results and discussion

Using a gamma ray spectrometer, the current study determined the radioactivity concentrations of naturally occurring radionuclides in a selection of medicinal plants that were gathered from various marketplaces and are commonly utilized in Iraq. Equation (8) was used to calculate the activity concentrations of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K. Several hazard indices were also assessed using Eqs. (9) - (23) to quantify the possible radiation risks associated with consuming these therapeutic plants. The outcomes were then compared to global averages. The following subsections provide a systematic presentation of our findings and comparisons.

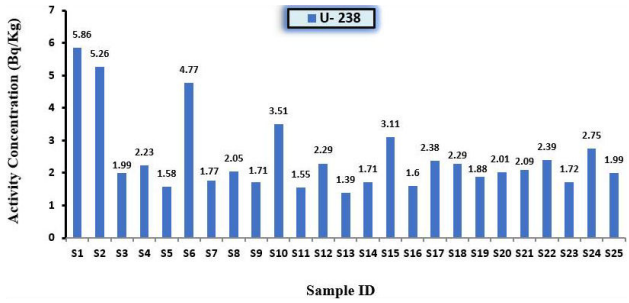

FIGURE 4. The specific activity concentration of ^{238}U.

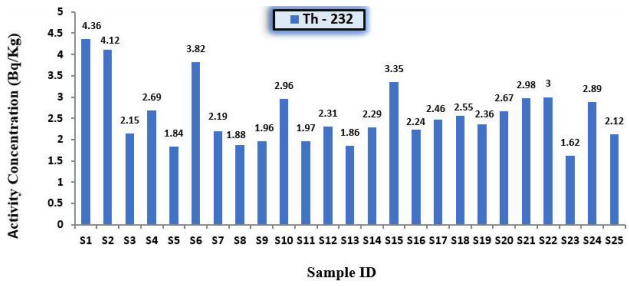

FIGURE 5. The Specific activity concentration of ^{232}Th.

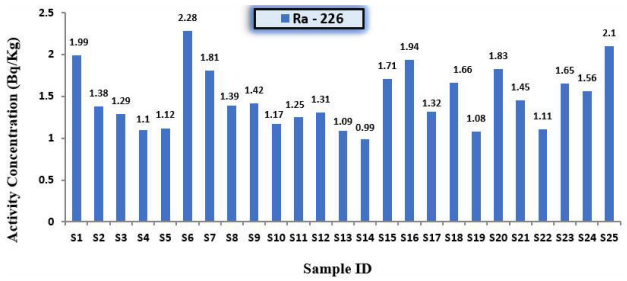

FIGURE 6. The Specific activity concentration of ^{226}Ra.

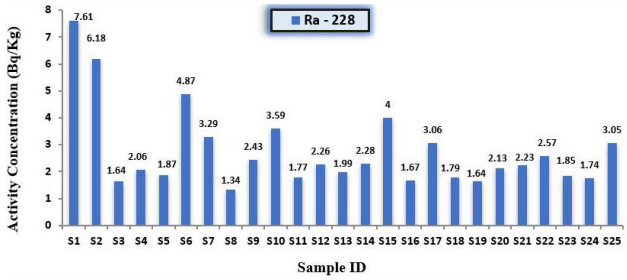

FIGURE 7. The Specific activity concentration of ^{228}Ra.

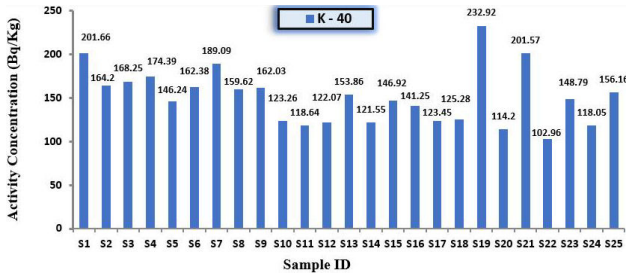

FIGURE 8. The Specific activity concentration of ^{40}K.

4.1. Activity concentration in the medicinal plants

The specific activity concentrations of natural radionuclides, uranium-238 (^{238}U), thorium-232 (^{232}Th), radium-226 (^{226}Ra), radium-228 (^{228}Ra), and potassium-40 (^{40}K) in medicinal plant samples with seeds and roots parts were calculated from Eq. (8). The results indicated that the range of specific activity concentration for ^{238}U in all samples varied from 5.86 to 1.39 Bq/kg with an average of 2.48 Bq/kg and a standard deviation of 1.18. The range of specific activity for ^{232}Th was between 4.36 and 1.62 Bq/kg with an average of 2.59 Bq/kg and a standard deviation of 0.72; that of ^{226}Ra varied from 2.28 to 0.99 Bq/kg with an average of 1.48 Bq/kg and a standard deviation of 0.36; that of ^{228}Ra varied from 7.61 to 1.34 Bq/kg with an average of 2.76 Bq/kg and a standard deviation of 1.51.

Finally, the range of specific activity concentration for ^{40}K was between 232.92 and 102.96 Bq/kg with an average of 151.2 Bq/kg and a standard deviation of 31.95. Figures 4, 5, 6, 7, and 8 show the activity concentrations of the natural radionuclides ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K for all samples of medicinal plants with seeds and roots parts. In Figs. 4 and 5, the highest specific activity concentration levels for ^{238}U and ^{232}Th were found in sample S1, while the lowest activity concentrations were observed in sample S13 for ^{238}U and sample S23 for ^{232}Th. In Fig. 6, the highest specific activity concentration level for ^{226}Ra was found in sample S6, and the lowest in sample S14. In Fig. 7, the highest specific activity concentration level for ^{228}Ra was found in sample S1, and the lowest in sample S8. In Fig. 8, the highest specific activity concentration level for ^{40}K was found in sample S19, and the lowest in sample S22.

In all the figures, a variation in the levels of radionuclides found in plant samples is clearly observed, with ^{40}K showing the highest average total specific activity across all tested samples. As a result, this radionuclide contributes the most to the internal radiation dose received by consumers. It is also considered the most significant due to its essential role in maintaining several physiological processes such as digestion, heart function, and cellular hydration. The differences in activity concentrations among the various sample types may be attributed to the varying capacities of different plants to absorb and retain certain radionuclides more than others.

Additionally, the activity concentration is related to the soil and the geographic region in which the plants are cultivated. Based on UNSCEAR 2000 and ICRP 1990 reports, the average specific activities of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K are 35 Bq/kg, 30 Bq/kg, 35 Bq/kg, 30 Bq/kg, and 400 Bq/kg, respectively. All our obtained values are within the international radioactivity levels and below the maximum permissible limits.

TABLE IV. Radium, thorium, and potassium equivalent activities (Ra_{eq}, Th_{eq}, K_{eq}) in medicinal plant samples (Bq/kg).

Sample ID	Ra_{eq}	Th_{eq}	K_{eq}
S1	19.9	14.12	258.5
S2	23.7	16.84	308.4
S3	17.3	12.31	225.2
S4	16.0	11.36	207.7
S5	15.0	10.66	195.0
S6	20.3	14.35	263.1
S7	19.5	13.86	253.5
S8	16.4	11.63	212.8
S9	16.7	11.86	217.0
S10	14.9	10.56	193.4
S11	13.2	9.37	171.5
S12	14.0	9.94	182.1
S13	15.6	11.09	202.7
S14	13.6	9.67	177.0
S15	17.8	12.63	231.5
S16	16.0	11.36	208.3
S17	14.3	10.17	186.3
S18	15.0	10.60	194.3
S19	22.4	15.93	290.9
S20	14.4	10.23	187.7
S21	21.2	15.08	275.8
S22	13.2	9.44	173.1
S23	15.4	10.95	200.5
S24	14.8	10.47	192.0
S25	17.2	12.18	223.2
Min.	13.2	9.37	171.5
Max.	23.7	16.84	308.4
STDEV	2.91	2.067	37.77
Average	16.7	11.866	217.2

4.2. Radiological hazard indices for medicinal plants

The activities of radium, thorium, and potassium equivalents, Ra_{eq}, Th_{eq}, and K_{eq} in different types of medicinal plants with seeds and roots parts have been presented in Table IV and measured from Eqs. (9), (10), and (11), respectively. The equations are based on the assumption that activities of 370 Bq/kg from radium-226, 260 Bq/kg from thorium-232, and 4810 Bq/kg from potassium-40 produce the same gamma radiation dose, which also represents the maximum permissible limits of activities of radium, thorium, and potassium equivalents.

The radium equivalent ranges from 23.74 to 13.19 Bq/kg with an average of 16.7 Bq/kg and a standard deviation of 2.91. For the thorium equivalent, it varies from 16.84 to 9.37 Bq/kg with an average of 11.866 Bq/kg and a standard deviation of 2.067. Potassium equivalent activity was between 308.39 and 171.52 Bq/kg with an average value of 217.2 Bq/kg and a standard deviation of 37.77.

TABLE V. The annual effective dose equivalent and excess lifetime cancer risk for all samples of medicinal plants with seeds and roots parts.

Sample	**AEDE (mSv/y)**			**ELCR** $\times 10^{-3}$		
	Out	In	Tot	Out	In	Tot
S1	0.0152	0.061	0.076	0.053	0.213	0.266
S2	0.0127	0.051	0.064	0.045	0.178	0.223
S3	0.0113	0.045	0.057	0.039	0.158	0.198
S4	0.0104	0.042	0.052	0.036	0.146	0.182
S5	0.0098	0.039	0.049	0.034	0.137	0.171
S6	0.0129	0.051	0.064	0.045	0.180	0.225
S7	0.0127	0.051	0.063	0.044	0.178	0.222
S8	0.0107	0.043	0.053	0.037	0.149	0.187
S9	0.0109	0.044	0.054	0.038	0.152	0.190
S10	0.0096	0.038	0.048	0.033	0.133	0.167
S11	0.0086	0.035	0.044	0.030	0.119	0.149
S12	0.0089	0.036	0.045	0.032	0.126	0.157
S13	0.0102	0.041	0.051	0.036	0.143	0.178
S14	0.0088	0.035	0.044	0.031	0.123	0.154
S15	0.0114	0.045	0.057	0.039	0.159	0.199
S16	0.0103	0.041	0.051	0.036	0.144	0.179
S17	0.0092	0.037	0.046	0.032	0.129	0.161
S18	0.0096	0.038	0.048	0.033	0.134	0.167
S19	0.0148	0.059	0.074	0.052	0.207	0.258
S20	0.0092	0.037	0.046	0.032	0.128	0.160
S21	0.0138	0.055	0.069	0.048	0.193	0.242
S22	0.0085	0.034	0.042	0.029	0.118	0.148
S23	0.0102	0.040	0.050	0.035	0.140	0.175
S24	0.0094	0.038	0.047	0.033	0.131	0.164
S25	0.0111	0.044	0.055	0.039	0.155	0.194
Min	0.0085	0.034	0.042	0.029	0.118	0.148
Max	0.0152	0.061	0.076	0.053	0.213	0.266
SD	0.0019	0.0075	0.0095	0.0067	0.0268	0.0334
Avg	0.0108	0.043	0.054	0.038	0.151	0.189

The highest radium, thorium, and potassium equivalent activities were observed in sample S2, while sample S11 had the lowest radium, thorium, and potassium equivalent concentrations. From Table IV, differences in the values of activities of radium, thorium, and potassium equivalents among other samples can also be observed. According to the UNSCEAR 2000 report and OECD report, the threshold values of radium equivalent activity, thorium equivalent activity, and potassium equivalent activity must be less than 370 Bq/kg, 260 Bq/kg, and 4810 Bq/kg, respectively. The results confirm that the highest and average values of the radium, thorium, and potassium equivalent activities are within the permissible world mean values.

The estimated internal and external hazard indices, H_{in} and H_{ex}, were also determined from Eqs. (13) and (12), respectively. The estimated internal hazard index of the study ranged from 0.069 in sample S1 to 0.039 in samples S11, S14, and S22 with an average value of 0.049 and a standard

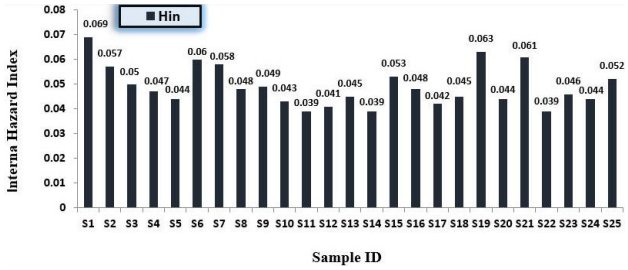

FIGURE 9. The internal hazard index $H_{\rm in}$ for medicinal plant samples with seeds and roots parts.

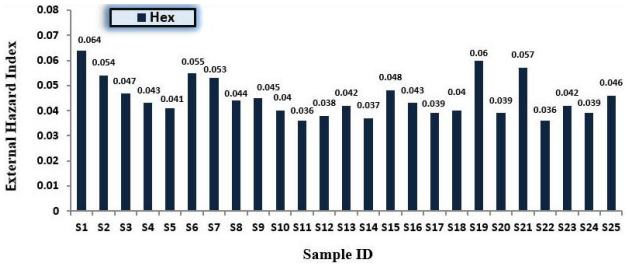

FIGURE 10. The external hazard index $H_{\rm ex}$ for medicinal plant samples with seeds and roots parts.

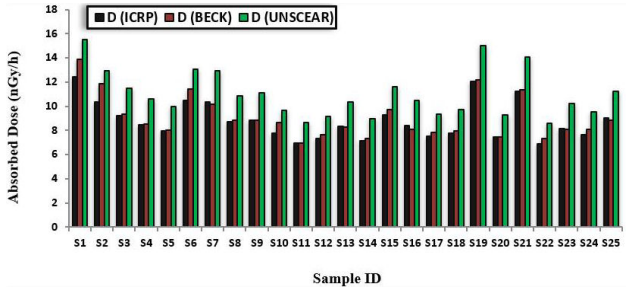

FIGURE 11. The absorbed dose $D_{\rm ICRP}$, $D_{\rm Beck}$, and $D_{\rm UNSCEAR}$ for medicinal plant samples with seeds and roots parts.

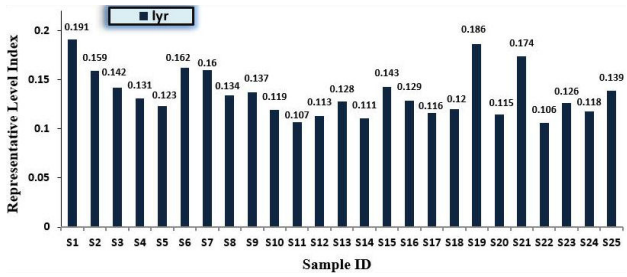

FIGURE 12. The representative level index I_γ for medicinal plant samples with seeds and roots parts.

deviation of 0.008. The external hazard index of the study was found in the range of 0.064 to 0.036 with an average value of 0.045 and a standard deviation of 0.0078; the highest value was obtained in sample S1 and the lowest in samples S11 and S22. From Figs. 9 and 10, it was observed that the value of the internal hazard index is higher than that of the external hazard index. For radon and its short-lived progeny to produce a negligible hazardous effect to respiratory organs from plants used in treatment of various diseases, both the external and internal hazard indices should be less than 1. The highest values of internal and external hazard indices did not exceed the upper limit of 1, the limit established by the European Commission on Radiation Protection (EC, 1999) to keep the radiation hazard insignificant. The values of the two hazard indices are less than the unity of the international permissible value, which authenticates the safety of using plants for therapeutic purposes and hence they are safe to be considered for human use.

The absorbed dose $D_{\rm ICRP}$, $D_{\rm Beck}$, and $D_{\rm UNSCEAR}$ of naturally occurring radionuclides in different samples of medicinal plants with seeds and roots parts had been determined and are shown in Fig. 11. The absorbed dose was measured in nGy/h from Eq. (14) depending on ICRP60, where the highest value of 12.4 nGy/h was recorded in sample S1 and the lowest absorbed dose of 6.89 nGy/h was found in sample S22, with an average value of 8.79 nGy/h and a standard deviation of 1.556. The absorbed dose was also determined from Eq. (15), derived by Beck. The average absorbed dose was found to be 9.068 nGy/h with a standard deviation of 1.781, varying from 13.88 nGy/h in sample S1 to 6.96 nGy/h in sample S11. Another calculation of absorbed dose was based on UNSCEAR, Eq. (16), where the absorbed dose ranges from 15.49 to 8.6 nGy/h with an average value of 10.98 nGy/h and a standard deviation of 1.945.

The lowest absorbed dose was recorded for sample S22 while the highest absorbed dose was observed in sample S1. From the figure, it can be seen that there was a variation in the absorbed dose measured from the three equations according to the type of sample and the equation used. We also observe that the absorbed doses $D_{\rm ICRP}$ and $D_{\rm Beck}$ were comparable and less than the absorbed dose $D_{\rm UNSCEAR}$. According to the UNSCEAR report 2000, the worldwide average absorbed dose rate in air measured from gamma radiation is 60 nGy/h, and all the results of the absorbed dose rate are below the world average value.

The results of the gamma representative level index I_γ were also measured from Eq. (17). The results varied from 0.106 to 0.191 Bq/kg with an average value of 0.136 Bq/kg and a standard deviation of 0.024. The highest gamma representative level index was found in sample S1, whereas the lowest was recorded for sample S22. Figure 12 shows the representative level index according to the type of samples. I_γ is important to monitor the radiation present inside the human body and to compute the risk of radionuclides in the human body when exposed to a gamma radiation dose from radionuclides in medicinal plants. The obtained results of the representative gamma index I_γ for all samples were lower than 1 Bq/kg, the recommended safety limit of the European Commission (EC, 1999).

Table V also contains the results of the calculated outdoor $(\mathrm{AEDE_{out}})$, indoor $(\mathrm{AEDE_{in}})$, and total annual effective dose equivalent $(\mathrm{AEDE_{tot}})$ of natural radionuclides ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K in the medicinal plants of seeds and roots parts. The values for $\mathrm{AEDE_{out}}$, calculated

from Eq. (18), varied from 0.0085 mSv/y to 0.0152 mSv/y with an average value of 0.0108 mSv/y and standard deviation 0.0019. For $AEDE_{in}$, calculated from Eq. (19), it varied from 0.034 mSv/y to 0.061 mSv/y with an average value of 0.0432 mSv/y and standard deviation 0.0075. For $AEDE_{tot}$, calculated from Eq. (20), it ranged from 0.042 mSv/y to 0.076 mSv/y with an average value of 0.0539 mSv/y and standard deviation 0.0095. The minimum and maximum values of $AEDE_{out}$, $AEDE_{in}$, and $AEDE_{tot}$ were found in samples S22 and S1, respectively. Table V shows the discrepancy in the values of AEDE for different samples. All the results are below the worldwide average annual effective dose equivalent of 0.48 mSv/y, of which 0.41 mSv/y comes from indoor and 0.07 mSv/y from outdoor, as recommended by UNSCEAR 2000, and thus all the present AEDE values are within the average values reported worldwide.

Additionally, Table V provides the outdoor $(ELCR_{out})$, indoor $(ELCR_{in})$, and total excess lifetime cancer risk $(ELCR_{tot})$ resulting from ingesting natural radionuclides in the medicinal plants with roots and seeds parts during an individual's life span, obtained from Eqs. (21), (22), and (23), respectively. Samples S1 and S22 had the maximum and minimum values of $ELCR_{out}$, $ELCR_{in}$, and $ELCR_{tot}$. $ELCR_{out}$ ranged from 0.029×10^{-3} to 0.053×10^{-3} with an average value of 0.038×10^{-3} and standard deviation 0.0067×10^{-3}. For $ELCR_{in}$, it ranged from 0.118×10^{-3} to 0.213×10^{-3} with an average value of 0.151×10^{-3} and standard deviation 0.0286×10^{-3}. The $ELCR_{tot}$ was estimated from 0.148×10^{-3} to 0.266×10^{-3} with an average value of 0.189×10^{-3} and standard deviation 0.0334×10^{-3}. The variation in ELCR due to the type of samples is demonstrated in Table V. All The values are lower compared with the world value of (0.29×10^{-3} for outdoor, 1.16×10^{-3} for indoor, and 1.45×10^{-3} for total) ELCR according to the UNSCEAR 2000 report. Therefore, the radiological hazard related to the consumption of the naturally occurring radionuclides in these samples is trivial.

5. Conclusions

The extended consumption of plants by people for prolonged periods of time might produce chronic or subtle health hazards. Therefore, the plants or any part of plants used for different types of diseases must be checked for the existence of contaminants of radioactive elements in order to make them safe for local and pharmaceutical consumption. The specific activities of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K of different medicinal plants were below the world average values based on the UNSCEAR report. The overall results of the study show that the activity concentration of ^{40}K had the highest values and the activity concentrations were not uniform and varied from plant to plant because the distribution of natural radionuclides in plant samples was influenced by the geological conditions and the activities. Radium, thorium, and potassium equivalent activities values were also lower than the permissible maximum limits based on the UNSCEAR report. It is important to study the medicinal plants and calculate the hazard indices in order to understand the potential radiological health risk and gain a more elaborate view of radiation levels in plant samples when they are used in the treatment of diseases. All the results are well below the world average values. This indicates that the radiation levels of the plant samples under study do not pose any risk to health; therefore, the study serves as a guide for medicinal plants and continuous environmental monitoring.

1. L.D. Vieira *et al.*, Multielement analysis of plant extracts with potential use in the treatment of peptic ulcers by synchrotron radiation total reflection X-ray fluorescence, *PeerJ* **6** (2018) e5375, https://doi.org/10.7717/peerj.5375
2. Y. Li, D. Kong, Y. Fu, M.R. Sussman, and H. Wu, The effect of developmental and environmental factors on secondary metabolites in medicinal plants, *Plant Physiol. Biochem.* **148** (2020) 80, https://doi.org/10.1016/j.plaphy.2020.01.006
3. D.M. Asiminicesei, D.I. Fertu, and M. Gavrilescu, Impact of heavy metal pollution in the environment on the metabolic profile of medicinal plants and their therapeutic potential, *Plants* **13** (2024) 913, https://doi.org/10.3390/plants13060913
4. N.N. Garba *et al.*, Investigation of natural radionuclides and radiation shielding potential of some commonly used building materials in Northwestern Nigeria, *Sci. Rep.* **14** (2024) 9696. https://doi.org/10.1038/s41598-024-26671-1
5. A.S. Alaamer, Assessment of human exposures to natural sources of radiation in soil of Riyadh, Saudi Arabia, *Turk. J. Eng. Environ. Sci.* **32** (2008) 229-234
6. A. Abbasi, H.M. Zakaly, and B.M. Alotaibi, Radioactivity concentration and radiological risk assessment of beach sand along the coastline in the Mediterranean Sea, *Mar. Pollut. Bull.* **195** (2023) 115527. https://doi.org/10.1016/j.marpolbul.2023.115527
7. M.U. Khandaker, K. Asaduzzaman, A.F.B. Sulaiman, D.A. Bradley, and M.O. Isinkaye, Elevated concentrations of naturally occurring radionuclides in heavy mineral-rich beach sands of Langkawi Island, Malaysia, *Mar. Pollut. Bull.* **127** (2018) 654, https://doi.org/10.1016/j.marpolbul.2017.12.050
8. G.M. Suresh, R. Ravisankar, A. Rajalakshmi, S. Sivakumar, A. Chandrasekaran, and D.P. Anand, Measurements of natural gamma radiation in beach sediments of north east coast of Tamilnadu, India by gamma ray spectrometry with multivariate statistical approach, *J. Radiat. Res. Appl. Sci.* **7** (2014) 7-17. https://doi.org/10.1016/j.jrras.2013.09.004

9. UNSCEAR, Sources and Effects of Ionizing Radiation: UNSCEAR 2000 Report to General Assembly with Scientific Annexes, United Nations Scientific Committee on the Effects of Atomic Radiation, New York, United Nations, 2000
10. U.S. Environmental Protection Agency (EPA), Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings, **80** (2015) 4155-4187
11. UNSCEAR, Sources and Effects of Ionizing Radiation, Report to General Assembly, with Annexes, United Nations Scientific Committee on the Effects of Atomic Radiation, New York, United Nations, 1993
12. A.A. Abojassim, H.N. Hady, and Z.B. Mohammed, Natural radioactivity levels in some vegetables and fruits commonly used in Najaf Governorate, Iraq, *J. Bioenergy Food Sci.* **3** (2016) 113-123
13. A. E. Adeniji, O. O. Alatise, and A. C. Nwanya, Radionuclide concentrations in some fruit juices produced and consumed in Lagos, Nigeria, *American Journal of Environmental Protection*, **2** (2013) 37-41. DOI: 10.11648/j.ajep.20130202.11
14. A. Abbasi, M. Algethami, O. Bawazeer, and H. M. Zakaly, Distribution of natural and anthropogenic radionuclides and associated radiation indices in the southwestern coastline of Caspian Sea, *Mar. Pollut. Bull.* **178** (2022) 113593. https://doi.org/10.1016/j.marpolbul.2022.113593
15. S. Z. Akhi, R. Khan, M. S. Basir, M. A. Habib, M. A. Islam, K. Naher, and D. K. Roy, Exploring the alteration of environmental radioactivity in terms of compositional elements of heavy minerals in an anthropogenically affected urban river: Radiological and ecological risks assessment, *Mar. Pollut. Bull.* **206** (2024) 116694. https://doi.org/10.1016/j.marpolbul.2024.116694
16. D. D. K. T. S. Malaysia, Radiological impact of drinks intakes of naturally occurring radionuclides on adults of central zone of Malaysia, *Malays. J. Anal. Sci.* **16** (2012) 187-193
17. M. Eisenbud and T. F. Gesell, *Environmental radioactivity from natural, industrial and military sources*, Elsevier, Amsterdam (1997)
18. M. Alias, Z. Hamzah, A. Saat, M. Omar, and A. K. Wood, An assessment of absorbed dose and radiation hazard index from natural radioactivity, *Malays. J. Anal. Sci.* **12** (2008) 195-204
19. K. Chandrashekara and H. M. Somashekarappa, Estimation of radionuclides concentration and average annual committed effective dose due to ingestion for some selected medicinal plants of South India, *J. Radiat. Res. Appl. Sci.* **9** (2016) 68-77
20. S. Sultana, J. Ferdous, and M. M. Haque, Natural radioactivity and hazards assessment in medicinal plants in Bangladesh, *J. Health Sci.* **10** (2020) 20.
21. G. B. Cengiz and I. Caglar, Estimation of natural radioactivity of some medicinal or herbal plants used in Kars, Turkey, *Acta Pharm. Sciencia* **57** (2019) 133.
22. S. A. Okoor, K. M. Abumurad, E. M. Ababneh, M. J. Abdallah, and A. A. A. Tawalbeh, Natural radioactivity concentrations and dose assessment in selected medicinal plants consumed in Jordan, *Fresenius Environ. Bull.* **28** (2019) 5179.
23. M. Živković, N. Zlatić, D. Krstic, and M. Stanković, Health risk assessment of natural and artificial radionuclides in medicinal plants, *Kragujevac J. Sci.* **43** (2021) 15.