

Radiological Safety of Medicinal Herbal Oils: An Analytical Study Using Gamma Spectroscopy

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Abstract: Given the widespread consumption of herbal oils for therapeutic purposes, this research aimed to assess the levels of natural radioactivity in selected medicinal herbal oil samples of herbal medicinal oils, using low-energy gamma spectrometry equipped with high-purity germanium (HPGe) detector. Thirteen medicinal herbal oil samples were analyzed to determine the activities concentrations of (^{238}U), (^{232}Th), and (^{40}K). The results indicated that the average specific activities of ^{238}U , ^{232}Th , and ^{40}K were 11.519 Bq/kg, 2.2 Bq/kg, 77.77 Bq/kg, respectively. Furthermore, parameters such as radium equivalent activity, absorbed dose, internal and external hazard indices, annual gonadal dose equivalent (AGED), annual effective dose (AED), and excess lifetime cancer risk (ELCR) were evaluated, were respectively (20.149 Bq/kg, 9.411 nGy/h, 0.085, 0.054, 0.067 mSv/y, 0.058 mSv/y, 0.222). It was concluded that all these values, especially ELCR, were within the permissible limits set by the World Health Organization (WHO). These values are considered low compared to the global average limit, indicating minimal radioactive contamination. Accordingly, the medicinal herbal oils studied do not pose any radiological health risks to consumers.

1 INTRODUCTION

Radiation is present in all environments, as radionuclides are part of soil, rocks, water, food, and even the bodies of living organisms. Naturally Occurring Radioactive Materials (NORM) are found in two complex radioactive decay series: the uranium-238 (^{238}U) decay series and the thorium-232 (^{232}Th) decay series [1], [2]. Due to the nature of radioactive nuclides, a contaminated environment exerts stress on living organisms, which extends to subsequent generations within the same environment. This includes plants that thrive in environments contaminated by natural radiation or environments polluted due to anthropogenic radioactive contamination [3], [4]. Plants can absorb radionuclides from contaminated soils through their roots, allowing these radioactive elements to accumulate in plant tissues. Consequently, when these plants are processed, radionuclides may be transferred and concentrated in extracted products such as herbal oils [5]. Recently, due to the widespread adoption of alternative medicine or herbal medicine, the World Health Organization (WHO) has issued a resolution urging increased attention to herbal medicine. Referring to research on plants and

herbs, the active compound in a plant is typically concentrated in a specific part, such as the roots, leaves, bark, fruits, or flowers, and it is very rare for it to be distributed throughout all parts of the plant [6]. Medicinal herbs can be defined as any medicinal preparation derived from plant-based materials.

Herbal oil is an extract obtained from different parts of herbs and plants, which may come from the seed, leaves, or roots. Oils are characterized by their stability and do not evaporate into the air [7], [8]. The use of herbs for therapeutic purposes dates back to the beginning of civilization. The first to document information in the field of herbal formulation were Al-Razi and Ibn Sina, who are considered the founders of the Golden Age of Sciences. Natural medicines exist in various forms, including formulations such as tablets, powders, or extracts. Oils are among the oldest forms of medicinal herbal treatments and remain significant in the present time [9]. The use of herbs as a remedy depends on understanding their compositions that make them effective. Herbs contain compounds that interact with the human body in ways that promote healing and boost immunity. These substances, known as phytochemicals, are biologically active

substances that range from simple organic molecules to complex compounds [10]. Herbal remedies are used to treat minor health problems, such as nausea, constipation, headaches, digestive disorders, skin problems, and hair problems. Some medicinal herbs have been successful in treating certain chronic diseases, including respiratory problems, stomach ulcers, colitis, and arthritis [11].

Despite the widespread use of herbal oils in traditional and alternative medicine, there is a lack of data on natural radioactivity in herbal oils. The objective of this study is to measure natural radioactivity levels in selected herbal oil samples, assess radiation hazard parameters, estimate cancer risk probability, and evaluate potential genetic effects using low-energy gamma-ray spectroscopy.

This research is important to ensure the radiological safety of widely used herbal remedies and to support public health by providing data necessary for risk assessment and regulatory guidelines.

2 MATERIAL AND METHOD

2.1 Sample Collection and Preparation

In this paper, thirteen medicinal herbal oil samples, each with a volume of 50 ml, were collected from local markets, as shown in the Table 1. The samples were stored in 50 ml plastic containers for processing and measurement. The containers were sealed, and thick tape was wrapped around the lids to ensure airtight closure. The samples were stored for four weeks prior to measurement to allow for secular equilibrium between parent and daughter radionuclides.

Sample S12 is a commercial herbal oil labeled for female fertility, produced by Emad Company. The exact composition is not fully disclosed on the packaging, and it is marketed as a general-purpose women's care oil.

2.2 Radiation Detection System

It is crucial to evaluate the health risk of radiation for human's safety. The high-purity germanium detector was chosen for radionuclide analysis due to its excellent detection capability, allowing sufficient radionuclide quantities to be measured and radioisotope identification to be accurately determined. High-purity germanium detectors are a

type of semiconductor detector used to detect gamma radiation. They are the ideal choice for analyzing gamma spectra and are more efficient than silicon detectors. The main characteristics of HPGe detectors are their high atomic number, high purity, high conductivity, low average energy required for electron-hole pair formation, and small size. It is crucial to evaluate the health risk of radiation for human's safety. The high-purity germanium detector was chosen for radionuclide analysis due to its excellent detection capability, allowing sufficient radionuclide quantities to be measured and radioisotope identification to be accurately determined [12], [13].

A low-energy high-purity germanium (HPGe) detector (Model BE5030P), designed for enhanced sensitivity at low gamma-ray energies, was employed in this study. It features a 5000 mm² active area, 31.5 mm crystal thickness, and a 0.6 mm carbon epoxy window. The detector was cooled with liquid nitrogen at -196 °C to reduce thermal noise, with samples positioned approximately 5.5 mm from the detector face. Energy calibration was performed using standard gamma-ray sources to ensure accurate channel-to-energy conversion in the low-energy range. Efficiency calibration was conducted with certified reference sources of similar geometry. The detector resolution (FWHM) was approximately 450 eV at 5.9 keV, 720 eV at 122 keV, and 1800 eV at 1332 keV. Background spectra were measured under identical conditions and durations (1–2 hours) and subtracted from sample spectra. Measurements were with counting times ranging from one to two hours per sample, optimized for low-energy gamma-ray detection.

2.3 Calculations

2.3.1 Specific Radioactivity

Specific radioactivity is the number of radioactive decays per unit time per unit mass or concentration.

$$A = \frac{C}{\epsilon \cdot I_g \cdot m \cdot t} \quad (1)$$

where A is the radionuclide activity concentration (Bq/kg), C is the counting rate, ϵ is the detector efficiency for a given gamma ray energy, I_g is the absolute transmission gamma decay probability, m is the sample mass (kg) and t is the counting time (s) [14].

Table 1: Type and code of the samples.

No.	Code	Common name	Scientific name
1	S1	Paprika	Capsicum annum
2	S2	Fenugreek	Trigonella foenum-graecum
3	S3	Castor	Ricinus communis
4	S4	Marjoram	Origanum majorana
5	S5	Cloves	Syzygium aromaticum
6	S6	Oliban	Boswellia sacra
7	S7	Cresson	Lepidium sativum
8	S8	Avocado	Persea americana
9	S9	Onion	Allium cepa
10	S10	Sesame	Sesamum indicum
11	S11	Garlic	Allium sativum
12	S12	Fertilization for women	---
13	S13	Chamomile	Matricaria chamomilla

2.3.2 Chemical Concentration

The elemental concentrations were determined using the relationships shown in Table 2.

Table 2: Conversion of specific activity to chemical concentration [15].

Specific activity (Bq/kg)	Chemical concentrations
12.35 $^{238}_{92}U$	1 U ppm
4.06 $^{232}_{90}Th$	1 Th ppm
313 $^{40}_{19}K$	1 K %

2.3.3 Radium Equivalent

Due to the heterogeneous distribution of radioactive nuclides in oil samples, exposure estimates were standardized by calculating the radium equivalent activity. This allows for a comparison of specific activity as follows [16], [17]:

$$Ra_{eq} = A_U + 1.43 A_{Th} + 0.077 A_K \quad (2)$$

Were A_U, A_{Th}, A_K are the specific activity of $^{238}_{92}U, ^{232}_{90}Th$ and $^{40}_{19}K$ in (Bq/kg).

2.3.4 Absorbed Dose

Absorbed dose is defined as the amount of energy transferred from radiation to matter, i.e. the energy absorbed by an object, measured in (Gy) unit. Were calculated using the following equation[5]:

$$D = 0.427 A_U + 0.662 A_{Th} + 0.043 A_K \quad (3)$$

Were A_U, A_{Th}, A_K are the specific activity of $^{238}_{92}U, ^{232}_{90}Th$ and $^{40}_{19}K$ in (Bq/kg).

2.3.5 External and Internal Hazard Index (Hex, Hin)

The determination of external hazard indices assists in estimating the expected gamma radiation dose, whereas internal hazard indices, which are more critical, contribute to assessing the dose received by an individual through the ingestion or inhalation of gamma emitters. Both indices were calculated using the given equations [18].

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

Were A_U, A_{Th}, A_K are the specific activity of $^{238}_{92}U, ^{232}_{90}Th$ and $^{40}_{19}K$ in (Bq/kg).

2.3.6 Annual Gonadal Equivalent Dose (AGED)

The Annual Gonadal Equivalent Dose (AGED) is a radiation measure used to estimate the equivalent radiation dose received by the gonads over a year. Due to the high sensitivity of reproductive organs to ionizing radiation, this measure is considered a key criterion in exposure assessment. Any damage to the genetic material (DNA) caused by radiation can potentially lead to genetic mutations, which may have long-term hereditary consequences [19], [20]. Were calculated as follows [21]:

$$AGDE (\mu Sv \cdot y^{-1}) = 3.09 A_U + 4.18 A_{Th} + 0.314 A_K \quad (6)$$

Were A_U, A_{Th}, A_K are the specific activity of $^{238}_{92}U, ^{232}_{90}Th$ and $^{40}_{19}K$ in (Bq/kg).

2.3.7 The Annual Effective Dose (AED)

Based on the absorbed dose, the annual effective internal and external doses were calculated as follows[22]:

$$\text{In AED} \left(\frac{\mu\text{Sv}}{\text{y}} \right) = D \times 8766 \times 0.8 \times 0.7, \quad (7)$$

$$\text{Out AED} \left(\frac{\mu\text{Sv}}{\text{y}} \right) = D \times 8766 \times 0.2 \times 0.7. \quad (8)$$

Where 0.7 Sv/Gy is the dose conversion factor, 0.2 and 0.8 are the external and internal occupancy factors, respectively, 8766 is the time conversion factor.

2.3.8 Excess Lifetime Cancer Risk (ELCR)

Calculating the probability of cancer incidence helps determine the percentage of individuals who may develop cancer as a result of receiving the annual effective dose [15].

$$\text{In ELCR} = \text{AED (indoor)} \times \text{DL} \times \text{RF}, \quad (9)$$

$$\text{Out ELCR} = \text{AED (outdoor)} \times \text{DL} \times \text{RF}. \quad (10)$$

DL is the average human lifespan is about 70 years, with RF representing the risk factor for radiation-induced cancer per sievert, with a value of 0.05 f, according to the ICRP (International Commission on Radiological Protection).

3 RESULTS AND DISCUSSION

Table 3 presents the specific activity results for uranium, thorium, and potassium, with average values of 11.519 Bq/kg, 2.2 Bq/kg, and 77.77 Bq/kg, respectively. Based on the conversion factors in Table 2, the calculated concentrations of these elements were 0.933 ppm, 0.542 ppm, and 0.248%, respectively. Regarding uranium, the highest concentration was found in the garlic oil sample, while the lowest was in chamomile oil (S13). The highest potassium concentration was observed in garden cress oil (S7), whereas the lowest was in onion oil (S9). Thorium was not detected in 12 samples and was only present in the onion oil sample (S9). There are several possible reasons for the presence of thorium in the onion sample. One possibility is that the onion was cultivated in soil naturally rich in thorium. Additionally, as a root vegetable that grows directly within the soil, onions may have a higher capacity to absorb elements from the soil more efficiently compared to other plants. By comparing all radioactive activity values with the globally permissible limit, it is evident that all values are significantly lower than the global average. Therefore, they are considered radiologically safe.

Table 3: Activity and chemical concentration of uranium, thorium and potassium of oil samples.

Sample Code	Activity (Bq/kg)			Chemical concentration		
	²³⁸ U	²³² Th	⁴⁰ K	U (ppm)	Th (ppm)	K (%)
S1	12.4±1.4	BDL	100.96	1.004	BDL	0.323
S2	9.8±1.4	BDL	71.20± 2.4	0.794	BDL	0.227
S3	11.5±1.3	BDL	85.20±3.9	0.931	BDL	0.272
S4	13.8±0.6	BDL	137.68±6.3	1.117	BDL	0.440
S5	9.960.6	BDL	BDL	0.806	BDL	BDL
S6	12.4±1.6	BDL	81.50±3.9	1.004	BDL	0.260
S7	14.7±1.3	BDL	140.70±6.8	1.190	BDL	0.450
S8	14.6±1.2	BDL	113.20±6.54	1.182	BDL	0.362
S9	11.7±1.3	16.500±0.23	2.96±0.07	0.947	4.064	0.009
S10	11.9±1.4	BDL	108.17	0.964	BDL	0.346
S11	15.6±1.4	BDL	78.70±3.4	1.263	BDL	0.251
S12	12.77±1.23	BDL	5.29±.12	1.034	BDL	0.017
S13	3.03±0.07	BDL	100.29±5.4	0.245	BDL	0.320
Average	11.519	2.200	77.770	0.933	0.542	0.248
Standard deviation	3.172	0.257	4.576	1.127	48.104	0.154
Global average [23]	35	30	400	2.83	7.38	1.28
B.D.L = Below Detection Limit. The maximum value. The minimum value.						

The radium equivalent activity (Raeq), absorbed dose rate (D), internal hazard index (Hin), and external hazard index (Hex) were calculated. As shown in Table 4, the average values for these parameters are 20.149 Bq/kg, 9.411 nGy/h, 0.085, and 0.054, respectively. These values are considerably lower than the global averages.

Figure 1 illustrates the relationship between uranium radioactivity and radium equivalent activity, where the red points represent the data and the blue line shows the linear regression. The regression equation $y=1.1713x+5.8602$

indicates that for each unit increase in uranium radioactivity, Raeq increases by approximately 1.1713 Bq/kg, with an intercept of 5.8602 Bq/kg. The regression coefficient $R^2=0.2933$ indicates a weak linear correlation, meaning that only about 29.33% of the variation in Raeq is explained by uranium radioactivity.

Figure 2 shows that sample S9 has the highest internal and external hazard indices, 0.128 and 0.096, respectively, while the lowest values were recorded for sample S13. This indicates a lower associated health risk for sample S13 compared with the others.

Table 4: Radiological hazard indices of the analyzed oil samples.

Sample Code	Raeq (Bq/kg)	D (nGy/h)	H(in)	H(ex)
S1	20.174	9.636	0.088	0.055
S2	15.282	7.246	0.068	0.041
S3	18.060	8.574	0.080	0.049
S4	24.401	11.813	0.103	0.066
S5	9.960	4.253	0.054	0.027
S6	18.676	8.799	0.084	0.050
S7	25.534	12.327	0.109	0.069
S8	23.316	11.102	0.102	0.063
S9	35.523	16.046	0.128	0.096
S10	20.229	9.733	0.087	0.055
S11	21.660	10.045	0.101	0.059
S12	13.177	5.680	0.070	0.036
S13	10.752	5.606	0.037	0.029
Average	20.149	9.411	0.085	0.054
Standard deviation	6.859	3.193	0.024	0.019
Global average[5], [23]	370	≤ 1	≤ 1	55

The maximum value.
 The minimum value.

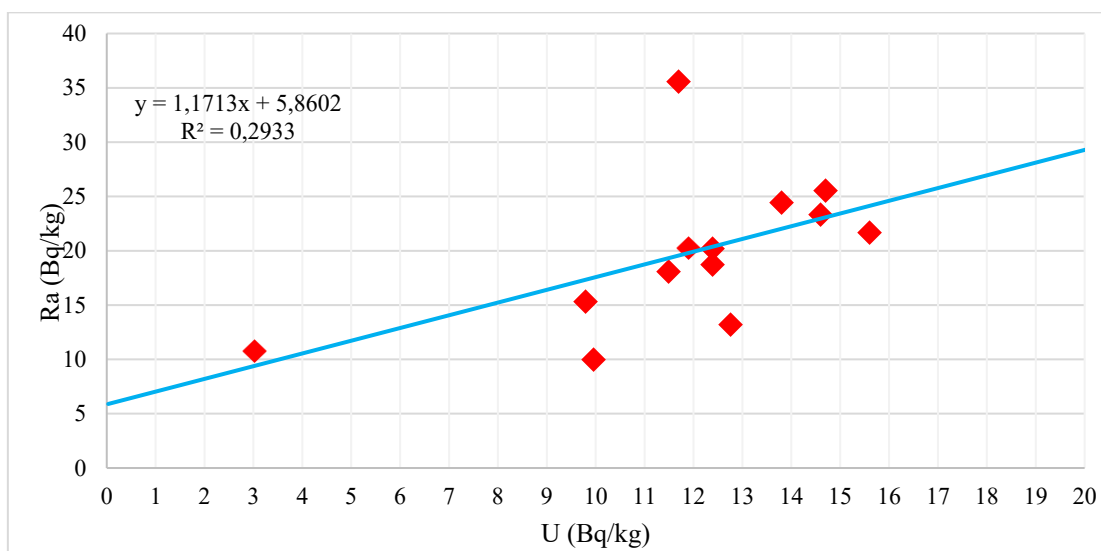


Figure 1: The correlation between uranium specific activity and radium specific activity in the oil samples. The red dots represent data points; the blue line shows the linear regression trend where $R^2 = 0.2933$.

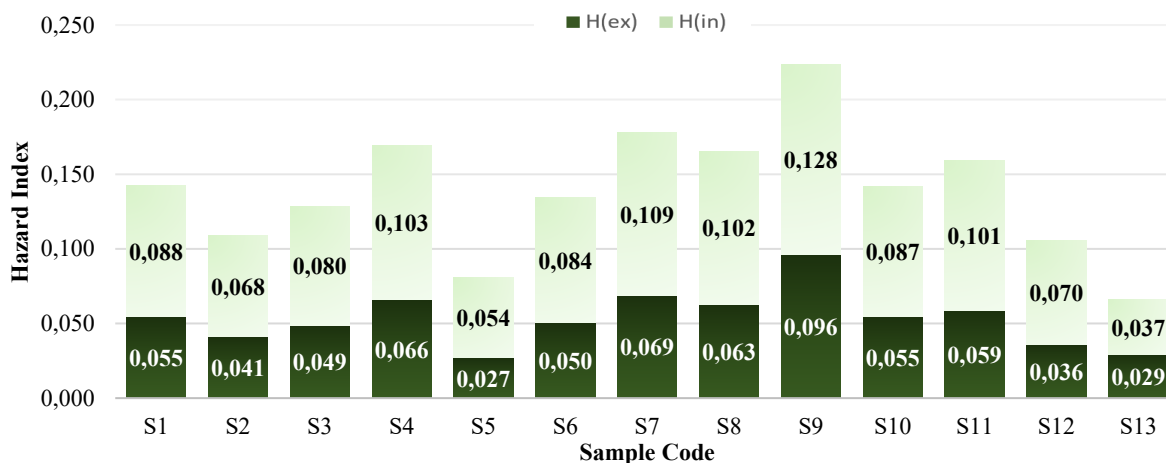


Figure 2: External (Hex) and Internal (Hin) hazard indexes for oil samples.

Table 5: AGDE, AEDE and ECLR (Indoor, outdoor and total).

Sample Code	AGDE	AED (µSv/y)			ELCR		
		Indoor	Outdoor	Total	Indoor	Outdoor	Total
S1	0.070	0.047	0.012	0.059	0.182	0.046	0.228
S2	0.053	0.036	0.009	0.044	0.137	0.034	0.171
S3	0.062	0.042	0.011	0.053	0.162	0.041	0.203
S4	0.086	0.058	0.014	0.072	0.223	0.056	0.279
S5	0.031	0.021	0.005	0.026	0.080	0.020	0.100
S6	0.064	0.043	0.011	0.054	0.166	0.042	0.208
S7	0.090	0.061	0.015	0.076	0.233	0.058	0.291
S8	0.081	0.054	0.014	0.068	0.210	0.052	0.262
S9	0.106	0.079	0.020	0.098	0.303	0.076	0.379
S10	0.071	0.048	0.012	0.060	0.184	0.046	0.230
S11	0.073	0.049	0.012	0.062	0.190	0.047	0.237
S12	0.041	0.028	0.007	0.035	0.107	0.027	0.134
S13	0.041	0.028	0.007	0.034	0.106	0.026	0.132
Average	0.067	0.046	0.012	0.058	0.178	0.044	0.222
Standard deviation	0.021	0.016	0.004	0.020	0.060	0.015	0.075
Global average [15], [24]	0.3	0.42	0.08	0.5	1.16	0.29	1.45

The maximum value.
 The minimum value.

Table 5 presents the data for both gonadal radiation exposure and the annual effective dose, which is divided into internal, external, and total components. It also shows the cancer risk probability, likewise divided into internal, external, and total. The values follow the same trend, where the lowest values for all parameters are observed in sample S5, highlighted in green, indicating low radiation levels in this sample. Sample S9, highlighted in blue, has the highest values, suggesting a higher concentration of radionuclides. All values fall within the permissible limits set by the World Health Organization,

indicating that the medicinal herbal oils in this study do not pose a risk to consumers.

Figure 3 is a line graph that shows the variation of different (AGED) values across each sample. The values range between 0.03 and 0.10, with noticeable fluctuations among the samples, indicating differences in the composition of the oils in terms of radionuclide concentrations.

Figure 4a is a bar chart divided into two parts: the light color represents the internal annual effective dose, while the dark color represents the external annual effective dose. All internal dose values are higher than the external ones. As shown in Figure 4b,

the difference is clear, with the internal dose accounting for 80% of the total dose, whereas the external dose represents only 20%. This indicates that most of the radiological risk comes from being in enclosed environments and internal exposure, while outdoor radiation exposure is less significant.

Figure 5 is a bar chart illustrating the values of cancer risk probability. Each bar is divided into two

sections: the lighter portion represents internal risk, while the darker portion represents external risk. All internal values are significantly higher than the external ones, accounting for approximately 80% of the total values. This indicates that radiation risks from outdoor exposure are much lower compared to those from internal exposure and enclosed environments.

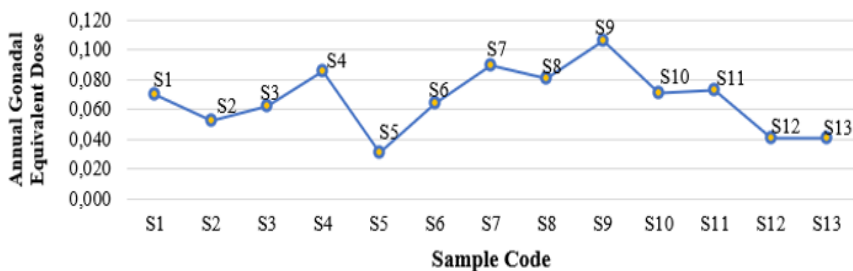


Figure 3: Annual gonadal equivalent dose (AGED) value for each oil sample.

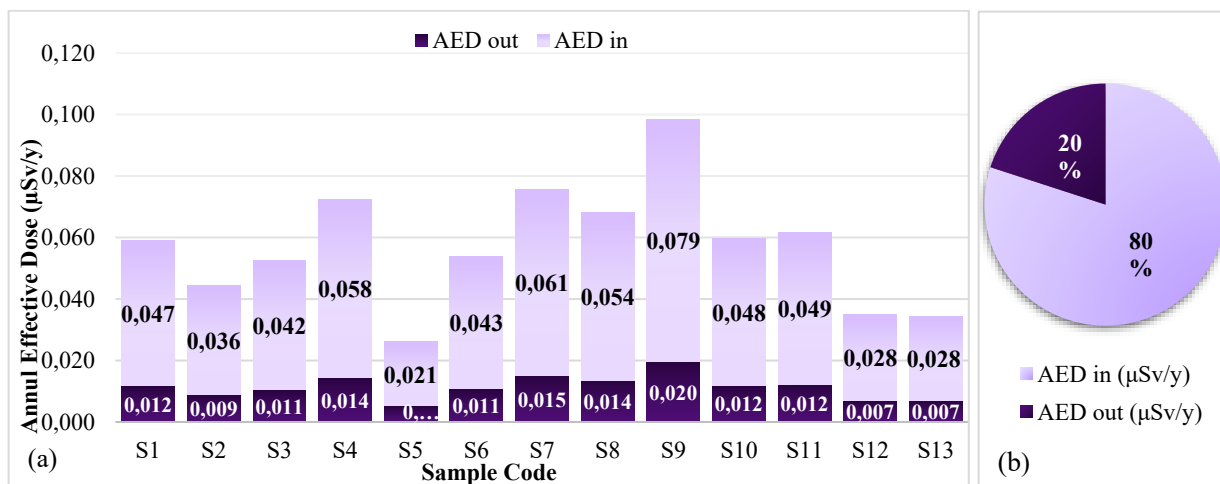


Figure 4: AED analysis for oil samples: a) AED (indoor, outdoor) for oil samples; b) proportional contribution of internal and external AED.

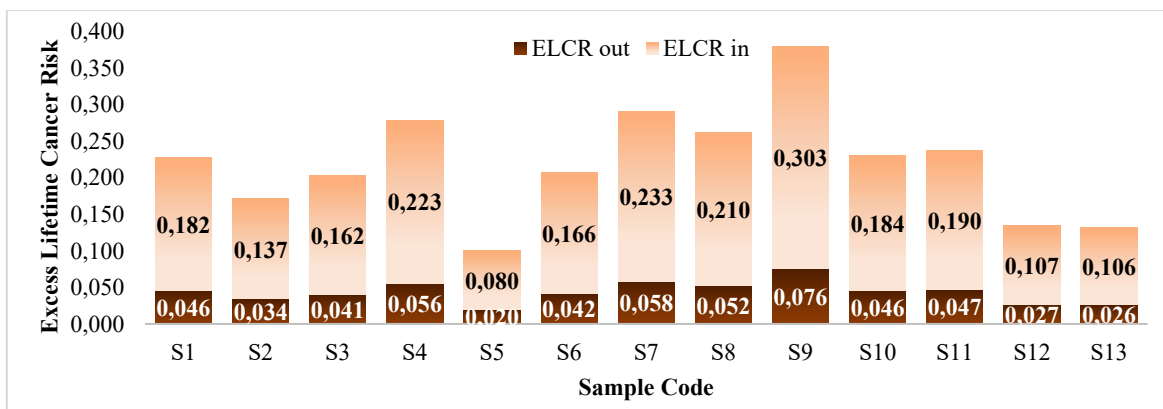


Figure 5: ELCR (indoor, outdoor) for oil samples.

4 CONCLUSIONS

The results confirm that all the medicinal herbal oils are radiologically safe for human consumption and therapeutic use. Sample S11 (garlic oil) showed the highest concentration of uranium, and sample S9 (onion oil) was the only sample containing detectable thorium. Therefore, continuous monitoring of oils derived from root-based plants is recommended. Soil quality should be monitored, and cultivation should be done in low-radiation soils to minimize the uptake of radionuclides. In summary, this study confirms that the analyzed herbal oils do not pose a significant radiological threat to consumers, supporting their continued use in traditional and alternative medicine.

In light of the increasing global use, a broader evaluation of herbal medicines and assessment of their radiological safety are essential. Future studies should therefore expand their scope to include a wider range of herbal oil types and investigate the effects of soil composition, agricultural practices, and the refining process on the transfer of radionuclides.

Overall, this research contributes to the radiological monitoring of herbal oils and provides data for international health authorities. It also reinforces the need for regular quality control to ensure that the products in use remain safe and beneficial for public health.

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