

Radiological Assessment of Natural and Artificial Radionuclide's in Soil and Medicinal Plants from Arid Areas on Yefren ,Libya North Africa

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Abstract

This study was conducted in four ecological areas in the city of Yefren, Libya, namely **Al-Shaqarna, Ain Al-Roumiya, Khashat Taqrboust, and Al-Qusair Forest**, during March 2023. These locations are separated by several kilometers and were selected to investigate the presence or absence of natural and artificial radionuclide's, including K-40, Th-232, Ra-226, and Cs-137, in **six** medicinal plant species belonging to different botanical families naturally growing in the study area. The investigated plants included the leaves and stems of *Rhus tripartita*, *Thymus capitatus*, *Artemisia herba-alba*, *Marrubium vulgare* L., *Capparis spinosa* L., and *Artemisia campestris* L., in addition to **six** associated soil samples collected from the rhizosphere of these plants. The radioactivity levels were determined using a high-purity gamma-ray spectrometry system. The results revealed variable levels of radionuclide concentrations in both soil and plant samples. The artificial radionuclide Cs-137 recorded the highest concentration in the soil associated with *R tripartita* (8.9209 Bq/kg), approaching the internationally permissible limit (10 Bq/kg), while the lowest concentration was detected in the soil of *A campestris* L. (1.5651 Bq/kg). Potassium-40 (K-40) exhibited the highest activity concentration in the soil of *T capitatus* (371.8 Bq/kg) and the lowest in the soil of *M vulgare* (293.9 Bq/kg). Radium-226 (Ra-226) showed the highest concentration in the soil of *C spinosa* L. (49.481 Bq/kg) and the lowest in the soil of *A campestris* L. (40.914 Bq/kg). Thorium-232 (Th-232) reached its highest concentration in the soil of *R tripartita* (23.38 Bq/kg) and the lowest in the soil of *A campestris* L. (13.59 Bq/kg). Regarding radionuclide uptake by plants, the study confirmed the presence of the artificial radionuclide Cs-137 in all examined plant samples. The highest uptake was recorded in *T capitatus* (0.6923 Bq/kg), whereas the lowest was observed in *C spinosa* L. (0.176 Bq/kg). Potassium-40 (K-40) showed the highest uptake in *C spinosa* L. (552.08 Bq/kg), while the lowest uptake was

recorded in both *A herba-alba* and *M vulgare* L. (142.9 Bq/kg). Radium-226 (Ra-226) exhibited the highest uptake in *T capitatus* (8.5732 Bq/kg) and the lowest in *R tripartita* (2.5732 Bq/kg). Thorium-232 (Th-232) recorded the highest uptake in *A campestris* L. (9.07 Bq/kg), whereas the lowest value was detected in *R tripartita* (1.68 Bq/kg). The detection of the hazardous artificial radionuclide Cs-137 in the soil associated with *R tripartita*, as well as its transfer to plant tissues, highlights the need for further investigations in other regions of the **Nafusa Mountains** to determine its potential sources and environmental pathways. Furthermore, variations were observed in radionuclide uptake rates, internal and external hazard indices, and transfer factors among the analyzed samples. To the best of our knowledge, this study represents the first radiological assessment of medicinal plants and associated soils conducted in the mountainous regions of Libya

Keywords: Natural and artificial radioactivity, medicinal plants, soil, Yefren, Libya.

Introduction

The Earth's crust contains numerous naturally occurring radioactive elements, including carbon-14, potassium-40, and the decay series of uranium-238 and thorium-232. Surface rocks, in particular, often contain elevated concentrations of uranium and thorium associated with sedimentary deposits. The levels of radioactivity in the environment resulting from these elements vary considerably depending on geographical location and meteorological conditions. Environmental radionuclides are of particular concern because of their bioavailability to plants, animals, and humans. Some radionuclides exhibit biological behavior similar to essential elements; for example, the alkali metal cesium-137 behaves metabolically in a manner similar to potassium. It is rapidly absorbed, circulates freely throughout the human body, and emits radiation to various tissues. Among the naturally occurring radionuclides of major significance to human exposure is K-40, which emits both beta and gamma radiation. These forms of ionizing radiation, primarily of internal origin, enter the human body through food and drinking water and are predominantly stored in muscle tissue. Th-232, another naturally occurring radionuclide, emits alpha particles and produces a decay series consisting of ten

radioactive progeny that emit alpha, beta, and gamma radiation. Ra-226 is one such progeny and possesses four known isotopes, the most prominent of which has a half-life of approximately 1,622 years (EPA, 2026; Arab Atomic Energy Agency, 1994; Eisenbud, 1987; Jabr, 2007; Youssef, 2007).

Thorium-232 (Th-232) is considered the second most important naturally occurring radionuclide after uranium in terms of environmental radiological significance, with an average activity concentration in soils of approximately 25 Bq/kg (Marouf, 1992). Stable cesium exists naturally as the isotope Cs-133, whereas cesium-137 (Cs-137) is an anthropogenic radionuclide produced mainly from nuclear weapons testing and nuclear accidents as a byproduct of nuclear fission. In contrast, cesium-134 (Cs-134) originates exclusively from nuclear reactor incidents through neutron activation processes (Eisenbud & Gesell, 1997; Marouf, 1992, as cited in Ali et al., 2015). Cesium-137 is considered one of the most environmentally significant artificial radionuclide's because of its relatively high yield during nuclear detonations and accidents, its moderate half-life of 30.2 years, and its ability to migrate within the environment and accumulate in the human body (International Atomic Energy Agency, 1982). Cs-137 strongly adsorbs to soil particles, particularly in clay-rich soils, making external exposure a more significant pathway than ingestion under certain environmental conditions (Cook, 2007; Maillie, 1985). The uptake of Cs-137 by plants is inversely related to the potassium content of the soil (IAEA, 1990; Bunzl & Krack, 1989, as cited in Ali et al., 2015). The global background concentration of Cs-137 in soils is estimated to be approximately 10 Bq/kg (Leung et al., 1990).

Radiation consists of electromagnetic waves or particles capable of causing biological damage when absorbed by living tissues. This energy can induce ionization within cells, leading to abnormal cellular division and potentially resulting in cancer, congenital abnormalities, and genetic mutations in future generations (Ghazi & Saleh, 2007). Humans are exposed to ionizing radiation from two principal sources: natural and anthropogenic radioactive materials. Naturally occurring radiation primarily arises from the decay series of radionuclide's such as Ur-238, uranium-235, Th-232,

and their progeny, in addition to K-40. Furthermore, cosmic radiation and radionuclide's naturally present within the human body also contribute to overall radiation exposure (Massri & Hamo, 2008).

Positively charged alpha particles are emitted from heavy radioactive elements such as radium and from certain synthetic radionuclide's. These particles may pose serious health hazards, particularly when inhaled or when they come into contact with open wounds or exposed tissues. Therefore, preventing the accumulation of alpha-emitting radionuclide's within the body is essential. Gamma rays, on the other hand, are highly energetic electromagnetic waves emitted during nuclear processes. They travel at the speed of light and possess high penetrating power, enabling them to pass through several centimeters of biological tissue and hundreds of meters in air. Gamma radiation is often emitted simultaneously with alpha or beta particles and originates from both natural and anthropogenic sources (Khudhur & Ghassan, 1984; Lilley, 1988).

Radioactive contamination may be transferred to plants either through uptake from contaminated soil or through atmospheric deposition onto aboveground plant surfaces. Consequently, radionuclide's can enter the human body directly through the consumption of contaminated plant materials or indirectly through animal-derived products such as meat and milk from livestock grazing on contaminated pastures. Radionuclide's such as sulfur-35, Cs-137, and C-14 are readily absorbed through the gastrointestinal tract and subsequently distributed throughout the body (Youssef, 2007; Abu-Khadra et al., 2008).

The transfer factor of radionuclide's varies according to location, season, time elapsed since contamination, radionuclide type, plant species, soil characteristics, and the concentrations of stable elements present in the soil (Martinez-Aguirre & Periañez, 1998). Numerous countries and international organizations have conducted studies measuring radionuclide activity concentrations in various food products (Al-Masri et al., 2000). Nevertheless, relatively few studies have investigated radioactive contamination in Arab countries, particularly Libya and mountainous regions

characterized by a high diversity of medicinal plants. Only limited investigations have been reported in countries such as Syria and Libya (Al-Masri et al., 2010; Al-Masri et al., 2012; Al-Baji & Al-Tir, 1999). Medicinal plants currently play an increasingly important role in agricultural and industrial production systems. They receive substantial attention in many countries because they constitute a primary source of plant-derived pharmaceutical compounds. These plants serve as raw materials for the extraction of bioactive substances, many of which are utilized as precursors in the synthesis of pharmaceutical products such as cortisone and sex hormones. This renewed interest has followed the recommendation of the World Health Organization to promote the use of herbal remedies and reduce dependence on synthetic chemical drugs because of their potential adverse side effects (FASRC, 1986; WHO, 2003).

Among these medicinal species, *Capparis spinosa* L. (caper) is a perennial shrub believed to originate from the Mediterranean region. Its immature fruits, stems, and leaves are used as food condiments and possess medicinal properties, including diuretic, expectorant, anthelmintic, and sedative effects. It is also traditionally used in the treatment of gout and scurvy (Durzo & Alkire, 2000; Zafer et al., 2004). *Marrubium vulgare* L., commonly known as white horehound, is traditionally used for lowering blood glucose levels and treating joint pain, cough, anemia, and constipation. *Thymus capitatus* L. is used in the treatment of throat infections, gastrointestinal bacterial diseases, gastroenteritis, pulmonary disorders, and bronchial inflammations. *Artemisia campestris* L. is widely employed in folk medicine for treating fractures, bruises, cough, and chest infections. The bark of *Rhus tripartita* is traditionally used for treating gastric ulcers and stimulating muscular activity, whereas *Artemisia herba-alba* is used to relieve flatulence and to treat vitiligo as well as intestinal worms and parasites (Al-Qadi & Bushina, 1992). Due to the lack of previous studies evaluating the radiological content of medicinal plants growing in the **Nafusa** Mountain region of Libya, the present study was conducted to investigate the radiological background levels of selected dried medicinal plants

belonging to different botanical families and commonly used in traditional medicine in the city of Yefren. In addition, the study evaluated the soils in which these plants grow to determine the specific activity concentrations of naturally occurring radionuclides, including Th-232, Ra-226 and K-40 as well as the anthropogenic radionuclide Cs-137. The obtained results were compared with international safety standards in order to assess the presence or absence of radioactive contamination within the study area.

Materials and Methods

Study Area

The study was conducted in the city of Yefren, located west of Tripoli, Libya. Yefren covers an area of approximately 2.66 km² and lies at an elevation of 750 m above sea level. It is situated at a longitude of 12°31'33.81" E and a latitude of 32°03'46.95" N. The city is part of the Nafusa Mountain range, which is characterized by arid to semi-arid climatic conditions, with an average annual temperature of 18.9°C and a mean annual precipitation of 272 mm (Imran, 2013). The selected medicinal plants were chosen based on their abundance in the surrounding environment and the limited availability of previous studies investigating their radiological content. The investigation was conducted at four randomly selected locations within Yefren (Figure , 1):

Site 1 (S1): **Al-Shaqarna area**, located at 12°31'49.70" E and 32°04'20.59" N.

Site 2 (S2): **Khasha Taqurbest area**, located at 12°31'4.95" E and 32°04'29.05" N.

Site 3 (S3): **Ain Al-Rumiyya area**, located at 12°33'21.50" E and 32°00'59.89" N.

Site 4 (S4): **Al-Qusayr Forest area**, located at 12°33'6.94" E and 32°04'34.57" N.

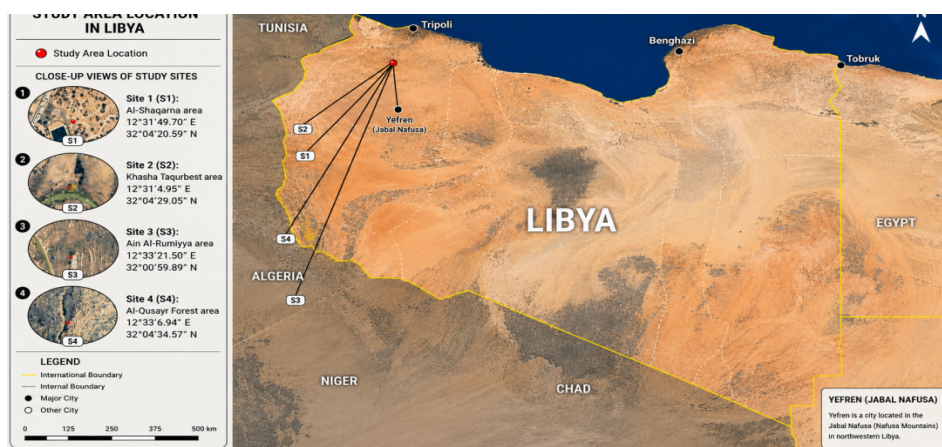


Figure 1. Study areas from which soil and medicinal plant samples were collected in the Yefren region. using Google Earth.

Soil Sampling and Preparation

Soil samples were collected during January and February 2023 at a rate of 100 kg from the rhizosphere of each medicinal plant species under investigation (Figure 8A), at a depth of 15 cm. The collected samples were thoroughly homogenized, and stones, weeds, and root debris were carefully removed. Subsequently, a representative 670 g sub-sample was randomly selected for radiometric analysis and transferred into 670 g L **Marinelli** beakers. The samples were initially air-dried and then oven-dried using a Heraeus Instrument electric drying oven at 105 °C for 24 h to eliminate residual moisture. Thereafter, the dried samples were finely ground and sieved through a 200 µm mesh sieve using a Haver & Boecker Haver EML 200 Digital sieve shaker (Figure 2), following the methodology described by (Al-Masri et al. (2012). Soil samples corresponding to *Cappari spinosa* and *Marrubium vulgare* were collected from Site S1 (Shaqarna), those corresponding to *Thymus. capitatus* from Site S3 (Ain Al-Rumiyya), those of *Artemisia herba-alba* and *Rhu .stripartita* from Site S2 (KhashaTaqurbest), and the soil of *Artemisia campestris* was collected from Site S4 (Qusayr Forest), all of which are mountainous locations within the city of Yefren Leaf and stem samples of the studied medicinal plants, which are among the most commonly used species in the region, were collected during January and February

2023. Approximately 100 kg of each plant species was collected (Table 1), from four different locations, with a sampling distance of 10 meters between individual plants within the same site. The plant samples were washed thoroughly with running water to remove surface dust and soil particles, then air-dried in the shade. They were subsequently cut into 8 cm segments (Figure, 6) re-dried in an electric oven to remove residual moisture, and then ground and stored until analysis, according to the procedure outlined by Al-Masri et al. (2012) Each plant and soil sample was assigned a unique sample code. All samples were then transferred to the Radiometric Measurement Center of the Atomic Energy Corporation located in **Khallat Al-Furjan, Tripoli**.

Table 1. Medicinal Plants Included in the Study

Local Name	Scientific Name	Family	Plant Part Used
Cappar	<i>Capparis spinosa</i> L.	Capparaceae	Leaves and stems
Wormwood	<i>Artemisia herba-alba</i>	Asteraceae	Leaves and stems
Thyme	<i>Thymus capitatus</i>	Lamiaceae	Leaves and stems
Sumac (Al-Jidari)	<i>Rhus tripartita</i>	Anacardiaceae	Leaves and stems
Desert Wormwood	<i>Artemisia campestris</i> L.	Asteraceae	Leaves and stems
White Horehound	<i>Marrubium vulgare</i> L.	Lamiaceae	Leaves and stems

Determination of Radionuclide's in Soil via Gamma Spectrometry

Dried soil and plant samples were homogenized and placed into 1000 mL Marinelli beakers (GA-MA and Associates, ING), achieving a net sample mass of 670 grams. These cylindrical containers feature a central cavity designed to accommodate the detector crystal, allowing the sample to completely surround the crystal and maximize detection efficiency. After filling, the containers were sealed tightly to prevent radon gas leakage and stored for four weeks to allow secular equilibrium between radium and its decay products to be established (Al-Masri and Al-Dabi, 2010; Hussein, 2018). The specific activity of radionuclide's in the soil samples was measured using a high-purity germanium (HPGe) gamma-ray spectrometer (Ortec,

Figure 3), known for its excellent energy resolution and high relative efficiency (30%). The spectrometry system was calibrated for both energy and efficiency using a certified standard source (EU152EGRK15), provided by the Accredited Calibration Laboratory “Laboratory Detalonnage”. The specific activity of radionuclide's was calculated using the method of Beck et al. (1972), based on the following formula

$$A = \frac{Net\ Count \times}{Eff \times W \times T \times I} \times 100$$

- **A** . Radioactive Activity
- **Net Count** is the background-corrected count rate for the peak of the radionuclide of interest,
- **Eff** is the detector's efficiency for the specific geometry and energy,
- **W** is the sample weight in grams,
- **T** is the counting time,
- **I** is the gamma emission probability (intensity) for the photopeak used in the analysis.

Soil and plant samples were prepared and analyzed at the Radiometric Measurement Laboratory of the Radiation Measurement Center in Tripoli. The measurements included the determination of radionuclide activities and the assessment of background radioactivity levels. Background radiation values were subtracted from the system readings to obtain net activity concentrations. A standard radioactive source, Eu-152, was used for calibration of the measurement system.



Figure 2. A 200 µm sieve (Haver EML 200 Digital T type).



Figure 3. High-Purity Germanium (HPGe) gamma-ray spectrometry system used for measurements.

Gamma Spectrometric Measurement of Natural and Artificial Radionuclide's

Dried environmental samples were homogenized and transferred into sealed 1 L into **Marinelli beakers** to ensure geometric reproducibility and prevent radon escape. The samples were then stored for a sufficient period to achieve secular equilibrium between radium and its short-lived decay products prior to gamma spectrometric analysis. Gamma-ray measurements were performed using a high-purity germanium (HPGe) detector system (ORTEC, USA). The detector has a relative efficiency of 30% and an energy resolution of 1.85 keV at 1.33 MeV (^{60}Co), ensuring high-resolution identification of gamma-emitting radionuclides under low-background conditions.

Energy and efficiency calibration of the system were carried out using a certified mixed radionuclide reference standard (Eu-152), supplied by an accredited calibration laboratory. The reference material contains multiple gamma-emitting isotopes, including Am-241, Cs-137, Sn-113, Ce-139, and Cd-109, covering a wide energy range suitable for efficiency curve construction. Natural and artificial radionuclide's were identified based on their characteristic gamma emission lines. K-40 activity was determined directly from its gamma peak at 1460 keV. The artificial radionuclide Cs-137 was quantified using its characteristic gamma emission at 661.6

keV. Th-232 activity was assessed indirectly through its decay progeny, primarily lead-212 (^{212}Pb) at 238 keV and actinium-228 (^{228}Ac) at 338 keV and 911 keV, assuming secular equilibrium within the decay series. The minimum detectable activity (MDA) values were calculated from background spectra acquired over a counting time of 100,000 s. The obtained MDA values were 8, 1, and 0.5 Bq/kg for K-40, Th-232, and Cs-137, respectively, in agreement with the method described by Al-Masri et al. (2012).

Radiological risk assessment

To assess the radiological hazards associated with soil and plant samples, the activity concentrations of radionuclides in both soil and plant tissues (leaves and stems) were determined. Parameters such as minimum detectable activity (MDA), external hazard index (Hex), internal hazard index (Hin), absorbed dose rate ($D\gamma$), radium equivalent activity (Raeq), and annual effective dose were calculated to evaluate potential exposure risks to the local population (Huddien., 2018).

Calculation of Radium Equivalent Activity (Raeq)

The radium equivalent activity (Raeq) was computed according to the method recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000), using the following formula:

$$Ra_{eq} \text{ (Bqkg}^{-1}\text{)} = A_{Ra} + (A_{Th} \times 1.43) + (A_K \times 0.077)$$

Where: represent the specific activity concentrations (Bq/kg) of Ra-226, Th-232, and K-40, respectively. A Raeq value of 370 Bq/kg corresponds to an annual effective dose of 1m Sv/y, which is considered the safety limit for the general public.

Calculation of External Hazard Index (Hex)

The external hazard index (Hex) was determined following the guidelines of the International Commission on Radiological Protection (ICRP, 1990). This index assesses whether the external exposure exceeds the recommended safety limit of 1mSv/y:

$$\text{Hex} = (\text{ARa} / 370) + (\text{ATh} / 259) + (\text{AK} / 4810) \leq 1$$

Where: A_{Ra} , A_{Th} and A_{k} are the activity concentrations of radium, thorium, and potassium radionuclide's respectively.

Calculation of Internal Hazard Index (Hin)

Internal exposure to radon gas and its progeny is evaluated using the internal hazard index (Hin), which is calculated according to Ngachin et al. (2007):

$$\text{Hin} = \text{ARa} / 185 + \text{ATh} / 259 + \text{AK} / 4810$$

Where : A_{Ra} , A_{Th} , A_{k} are the activity concentrations (Bq/kg) of Ra-226, Th-232, K-40) respectively.

Efficiency Calibration :

The detector efficiency is defined as the ratio between the number of incident gamma-ray photons striking the detector and the number of output pulses produced by it. The efficiency is usually less than 100%, according to the following equation:

$$100 \% \times \frac{N}{A.Iy.t} \text{ Where:}$$

- **N:** Net count rate (the area under the photo peak after subtracting the background radiation),
- **t:** Counting time in seconds,
- **Iy:** Gamma emission intensity (%) for each energy of the radioactive source,
- **A:** Final activity (Bq) of the radioactive source at time **t**, calculated using the decay equation.

Analysis of pH, Electrical Conductivity, and Organic Matter in Soil Samples:

The pH levels, electrical conductivity (EC in mS/cm), and organic matter content were analyzed for soil samples collected from the study area. Soil samples were taken from the root zones of medicinal plants at a depth of 15 cm. Each sample, weighing 250 grams, was placed in plastic bags and sent to the Soil and Water Laboratory at the Faculty of Agriculture, University of Tripoli, for necessary analyses.

Transfer Factor of Radiation from Soil to Plant:

The transfer factor (TF) was calculated based on the measured radioactive concentration in both soil and plant samples. The interpretation of TF values is as follows:

- **TF < 0.1:** Very low transfer,
- **$0.1 \leq \text{TF} \leq 1$:** Moderate transfer,
- **TF ≥ 1:** High transfer (the plant absorbs a high amount of radioactivity compared to the soil).

The transfer factor value depends on the type of radionuclide, plant species, soil characteristics, and environmental conditions such as moisture and temperature (IAEA, 2010).

$$\text{TF} = \frac{C_{\text{plant}}}{C_{\text{soil}}} \text{ Where:}$$

- C_{plant} Radioactivity concentration in plant tissues (Bq/kg),
- C_{soil} Radioactivity concentration in soil (Bq/kg).

Results and Discussion

Levels of Natural and Artificial Radioactivity in Soils Associated with Medicinal Plants .The results of the present study on natural and artificial radioactivity levels in soil samples collected from the study area, in comparison with those reported from several countries worldwide (Tables 2 and 3), revealed varying concentrations of natural radionuclide's in the analyzed soil samples associated with different medicinal plants. The average activity concentrations of the natural radionuclide Th-232 in soils associated with the medicinal plants *Rhus tripartita*, *Thymus capitatus*, *Artemisia herba-alba*, *Marrubium vulgare L.*, *Capparis spinosa L.*, and *Artemisia campestris L.* were 23.38, 17.21, 19.31, 48.15, 19.11, and 13.59 Bq/kg, respectively. These

concentrations fall within the internationally accepted range of 11–64 Bq/kg, with a worldwide average of approximately 30 Bq/kg. The highest concentration was recorded in the soil associated with *Marrubium vulgare*, whereas the lowest concentration was observed in the soil of *Artemisia campestris*.

The activity concentrations of Ra-226 in the same soil samples were 42.06, 47.32, 47.32, 45.62, 49.48, and 40.91 Bq/kg, respectively. These values exceed the global average of 35 Bq/kg reported by UNSCEAR (2000) (Table 2). The highest concentration was detected in the soil of *Capparis spinosa* (49.48 Bq/kg), while the lowest value was recorded in the soil of *Artemisia campestris* (40.91 Bq/kg). These concentrations are relatively higher than the global average and are comparable to values reported in some coastal regions of Ghana, where average concentrations of Ra-226, K-40, Th-232, and Cs-137 were 43 ± 6 , 393 ± 74 , 22 ± 1 , and 0.5 Bq/kg, respectively (Esther, 2023). The activity concentrations of the naturally occurring radionuclide K-40 ranged from 233.69 to 371.8 Bq/kg. The highest concentration was recorded in the soil of *Rhus tripartita* at Khshat Tagharbost (Site S2), whereas the lowest concentration was observed in the soil of *Marrubium vulgare* at Shaqarna (Site S1). In addition, the average distribution of radionuclide's across all four study sites was 4.99 Bq/kg for Cs-137, 312.18 Bq/kg for K-40, 45.45 Bq/kg for Ra-226, and 18.01 Bq/kg for Th-232. The average activity concentrations of the artificial radionuclide Cs-137 were 8.92, 6.75, 3.57, 1.87, 7.31, and 1.57 Bq/kg, respectively (Figure 4). The highest value was detected in the soil of *Rhus tripartita* at Khshat Tagharbost (Site S2), whereas the lowest value was observed in the soil of *Artemisia campestris* at Al-Qusayr (Site S4). Comparison with previous studies conducted in western and central Libya, including Zawiya (Sahoub, 2024; Algattawi et al., 2019), revealed noticeable variability in radionuclide concentrations (Table 6), which may be attributed to differences in soil physicochemical properties and organic matter content. Previous studies conducted in western and central Libya, as well as in Zawiya and Awlad Al-Shatti, reported no detectable levels of Cs-137. Therefore, the presence of this artificial radionuclide in the current study area may be associated

with radioactive dust transport originating from contaminated regions. This observation supports the hypothesis that Cs-137 in the local environment may serve as an indicator of anthropogenic radioactive contamination (Marwan, 2016). Cs-137 is considered one of the major anthropogenic sources of radioactive pollution. It emits beta radiation and can reach environmental components such as soil, water, and air through nuclear weapons testing and radioactive leakage from nuclear facilities. The background radiation level of Cs-137 is approximately 10 Bq/kg (C.E.H., 2002), which is close to the level recorded in the soil associated with *R. tripartita* at Khshat Tagharbost where the Cs-137 concentration reached 8.92 Bq/kg. This was followed by the soil associated with *Capparis spinosa* in the same area, with a concentration of 7.31 Bq/kg. During the period from 1950 to 1960, large quantities of Cs-137 were released into the environment as a result of atmospheric nuclear weapons testing (Ebert et al., 1990). One of the most significant sources of environmental contamination by Cs-137 was the Chernobyl nuclear disaster in Ukraine, which contributed to the global dispersion of radioactive fallout through atmospheric transport processes (Al-Sabah, 2000). However, the exact source of Cs-137 contamination in the present study area remains uncertain and requires further investigation. Cs-137 is known to accumulate in the human body due to its rapid absorption, and its emitted radiation may damage human tissues through ionization processes and abnormal cellular division, thereby representing a potential environmental health risk (Ghazi and Saleh, 2007). The presence of Cs-137 in soils from the study area may therefore be attributed to global or regional radioactive fallout associated with nuclear accidents such as the Chernobyl incident in 1986. Its distribution within the study area appears heterogeneous and is influenced by several environmental factors, including rainfall, wind speed and direction, timing of radioactive cloud deposition, soil type, erosion processes, and leaching by rainwater. Furthermore, radionuclide distribution is affected by the physicochemical properties of soils and by the behavior of Cs-137 itself, which tends to bind more strongly to clay-rich soils than to sandy or loamy soils (Ali et al., 2015). In addition, Cs-137

concentrations are inversely related to potassium levels in soil (Figure 5) (IAEA, 1991). Comparison of the present results with similar studies conducted in Arab and international regions (Table,3) showed that the detected Cs-137 concentrations are comparable to those reported in southern Tunisia. The highest reported activity concentration of Cs-137 was approximately 23 Bq/kg in the United States and 7.5 Bq/kg in Bangladesh (Shyamal et al., 2013; Akbar et al., 2016).

Th-232 concentrations in the investigated soils were within the permissible limits established by (UNSCEAR.,2000). which reported a global average of approximately 30 Bq/kg for naturally occurring radioactive materials in soils. Th-232 is considered one of the most radio logically significant naturally occurring radionuclide's after uranium. Similar studies conducted in Kirkuk Governorate, Iraq, reported average Th-232 activity concentrations of approximately 25 Bq/kg (Akbar et al., 2016). K-40 another naturally occurring radionuclide, emits characteristic gamma radiation at an energy of 1460 keV and has a worldwide average soil activity concentration of approximately 370 Bq/kg (Adnan., 1995). The current study revealed differences in natural radioactivity levels compared with those reported by(Akbar et al.,2016). who analyzed surface soil samples collected from Iraq. Their results showed average activity concentrations of 379.3 Bq/kg for K-40, 22.06 Bq/kg for Th-232, and 19.3 Bq/kg for Cs-137 in dust storm soil samples. Although most activity concentrations were within internationally accepted safety limits, elevated Cs-137 levels were observed in dust storm samples. The study also highlighted the presence of Ra-226, which has a half-life of approximately 1600 years and is considered one of the most important naturally occurring radionuclide's contributing to human radiation exposure from natural sources (Youssef, 2007; Arab Atomic Energy Agency, 1994; Eisenbud, 1987). In the Shagharna region Ra-226 activity concentrations were within the internationally accepted range reported by UNSCEAR (2000). Comparison of the activity concentrations of natural radionuclide's (K-40, Ra-226, and Th-232) in the present study area with those reported from other countries (Table, 3) revealed noticeable variations. Potassium and radium concentrations were relatively high

compared with levels reported in Egypt, China, Japan, Iran, and Jordan. Natural radioactivity in soils is influenced by several environmental factors, including geological formations, land use, climatic conditions, and fertilizer application (Saleh et al., 2007). The distribution of natural and artificial radionuclides in the present study was evaluated at a soil depth of 15 cm only. Therefore, additional studies are recommended to investigate radionuclide distribution at multiple soil depths. Previous studies have demonstrated that radionuclide concentrations generally decrease with increasing soil depth in uncultivated soils. For example, (Copplestone et al., 2001) reported reductions in radionuclide concentrations with increasing depth in soils collected from inland regions of Bangladesh. Their results showed decreases in Ra-226 concentrations from 23.55 Bq/kg at 0–5 cm depth to 22.94 Bq/kg at 15–20 cm depth, while Cs-137 concentrations decreased from 2.6 to 1.9 Bq/kg. These findings indicate that radionuclide distribution in soils is influenced not only by mineral composition but also by rapid water infiltration through sandy soil pore channels. Finally, the precise source of Cs-137 contamination in the Yefren region remains unidentified. Further comprehensive investigations are therefore required to evaluate its persistence, environmental behavior, and radiological impact, as well as to compare the obtained findings with proposed scientific hypotheses and environmental scenarios.

Soil Sample Analyses:

Measurements of pH (acidity and alkalinity), electrical conductivity (EC) in mS/cm, and organic matter content were conducted on soil samples collected from the rhizosphere (root zone) of medicinal plants at a depth of 15 cm. The samples were packed in plastic bags (250 grams each per plant species) and sent to the Soil and Water Laboratory, Faculty of Agriculture, University of Tripoli, for the necessary analyses.

Table 2. Average Activity Concentrations of Natural and Artificial Radionuclides in Medicinal Plant Soils

Sample Code	Plant Name (Scientific & Local)	Sample Weight (kg)	A(K-40) (Bq/kg)	A(Ra-226) (Bq/kg)	A(Th-232) (Bq/kg)	Cs-137 (Bq/kg)
S.R.r - 1	<i>R. tripartita</i>	1.460	335.6	42.06	23.38	8.9209*
S.T.C - 2	<i>T. capitatus</i>	1.130	371.8	47.3151	17.21	6.7494
S.A.h - 3	<i>A. herba-alba</i>	1.410	320.09	47.324	19.31	3.569
S.M.V - 4	<i>M. vulgare</i>	1.170	293.9	45.622	15.48	1.870
S.C.s - 5	<i>C. spinosa</i>	0.980	317.99	49.481	19.11	7.3122
S.A.c - 6	<i>A. campestris</i>	1.450	233.69	40.914	13.59	1.5651
—	Mean Concentrations	—	312.18	45.452	18.013	4.997
—	Global Safety Limits (UN, 2000)	—	400	35	30	10

The Cs-137 activity level in the soil of *R. tripartita* is approaching the internationally permissible limits.

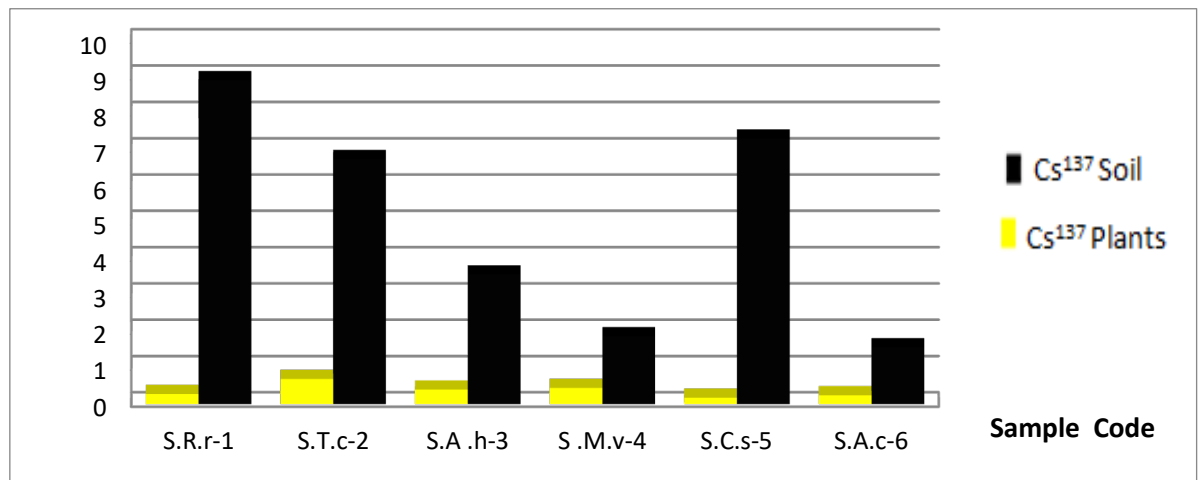


Figure 4. Levels of artificial radioactivity (Cs-137) in soil samples from medicinal plants:

- **S.R.r-1:** Soil of *R. tripartita*
- **S.T.C-2:** Soil of *T. capitatus*
- **S.A.h-3:** Soil of *A. herba-alba*
- **S.M.V-4:** Soil of *M. vulgare*
- **S.C.s-5:** Soil of *C. spinosa*
- **S.A.c-6:** Soil of *A. campestris*

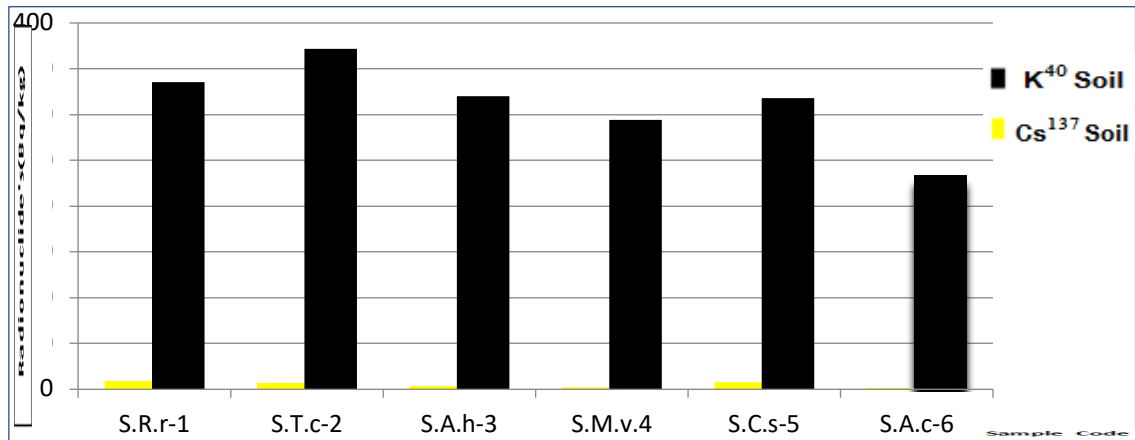


Figure 5. Graphical representation of the correlation between K-40 and Cs-137 concentrations in the soils of medicinal plants in the study area.

Table 3. Comparison of Natural Radionuclide Concentrations (K-40, Ra-22, and Th-232) in Soil from the Current Study and Other Global Regions

Country	Cs-137 (Bq/kg)	K -40 (Bq/kg)	Ra-22 (Bq/kg)	Th-232 (Bq/kg)	Reference
Egypt	0 – 35.7	41.5 – 418	5.3 – 66.8	5 – 37.3	Nada et al., 2019
Taiwan	0 – 12.1	195.3 – 640	44.7 – 106	12.2 – 44.2	Tsai et al., 2008
China	–	9 – 1800	2 – 440	1 – 360	United Nations, 2000
India	2.88 – 1	38 – 760	7 – 81	14 – 160	Kannan et al., 2002
Japan	–	15 – 990	6 – 98	2 – 88	United Nations, 2000
Iran	–	121.8 – 244.8	8 – 55	5 – 42	United Nations, 2000
Jordan	1.9 – 5.3	121.8 – 244.8	16.3 – 57.3	7.6 – 16.2	Ababneh et al., 2009
Switzerland	–	40 – 1000	10 – 900	4 – 70	United Nations, 2000
Spain	10 – 60	25 – 1650	6 – 250	2 – 210	Gomez et al., 1997
Greece	1.8 – 11.1	15 – 1570	1 – 240	1 – 190	Papaefthymiou et al., 2007
USA	23	472	–	36.2	Marouf, 1992
Bangladesh	7.5	256.4	–	68.2	Marouf, 1992
Tunisia	8.72	284.2	–	19.5	Marouf, 1992

Country	Cs-137 (Bq/kg)	K -40 (Bq/kg)	Ra-22 (Bq/kg)	Th-232 (Bq/kg)	Reference
Yemen	21.7	284.2	—	37.8	Marouf, 1992
Yefren, Libya	4.997	312.178	45.452	18.013	Current Study

Table 4. Mean Activity Concentrations of Radionuclide's in Soils and Medicinal Plants in the Study Area

Radionuclide	Mean Activity (Bq/kg)
Cs-137	4.9977
K-40	312.178
Ra-	45.452
Th-232	18.013



Figure 6. Sampling procedures: Collection of soil and plant samples, and cutting of plant parts in the study area.

Levels of Natural and Anthropogenic Radioactivity in Medicinal Plants

The results of the present study (Table, 5) revealed the occurrence of natural radioactivity in the analyzed medicinal plant samples, with activity concentrations varying considerably among species according to their botanical families and the sampling locations. Such variation may be attributed to several factors, including elemental concentrations in both soil and plants, radionuclide chemical speciation, and the physicochemical properties of the soil (Karim, 2016). The measured activity concentrations of Th-232 in the investigated plant species — *Rhus tripartita*, *Thymus*

capitatus, *Artemisia herba-alba*, *Marrubium vulgare* L., *Capparis spinosa* L., and *Artemisia campestris* L. — were 1.68, 3.55, 2.96, 2.77, 3.44, and 9.07 Bq/kg, respectively (Figure, 10). The highest concentration was recorded in *A. campestris* L., whereas the lowest value was observed in *R. tripartita*. In addition, Ra-226 was detected in all examined plant species, with activity concentrations of 2.5732, 8.4702, 6.0613, 5.1312, 6.5124, and 3.3177 Bq/kg, respectively. The highest Ra-226 concentration was measured in *T. capitatus* (8.4702 Bq/kg) at site S3, whereas the lowest concentration was found in *A. campestris* L. (3.3177 Bq/kg) at site S4. K-40 was also detected in all plant samples, with activity concentrations of 200.27, 177.4, 404.4, 142.9, 552.08, and 318 Bq/kg, respectively. Considerable variation in K-40 levels was observed among the studied species. In general, K-40 concentrations were markedly higher than those of ²³²Th-232, possibly due to differences in organic matter content and clay composition in the soil (Karim, 2016). The highest K-40 activity concentration (552.08 Bq/kg) was recorded in *C. spinosa* collected from site S1, whereas the lowest value was observed in *Marrubium vulgare* (142.9 Bq/kg) from the same site. Variations in radionuclide concentrations among plant species may also reflect differences in the distances between collection sites as well as variations in soil organic matter content (Table ,10). These findings are consistent with those reported by Al-Kufi and Hady (2019), who analyzed 40 medicinal plant samples obtained from Iraqi markets using a high-efficiency thallium-doped sodium iodide detector. Their results indicated that most radionuclide concentrations were within internationally accepted safety limits and posed no significant radiological risk for medicinal or therapeutic use. Regarding anthropogenic radioactivity, Cs-137 was detected in all investigated plant species, with mean activity concentrations of 0.2776, 0.6923, 0.398, 0.446, 0.176, and 0.2776 Bq/kg, respectively. The highest Cs-137 concentration was observed in *T. capitatus* (0.6923 Bq/kg) from site S3, whereas the lowest value was recorded in *Capparis spinosa* L. (0.176 Bq/kg) from site S1. These concentrations were below the internationally recommended safety limit of 1 Bq/kg and are in agreement with the findings of Al-Masri et al. (2012), who reported Cs-

^{137}Cs concentrations close to the detection limit (5 Bq/kg dry weight) in 38 imported medicinal plant samples analyzed in Syria. Comparison of the present findings with studies conducted in other countries, particularly Bangladesh, demonstrated considerable variation in ^{137}Cs concentrations among medicinal plants (Table,7) (Coppelstone et al., 2001). Such differences may be associated with variations in plant species, soil physicochemical characteristics, climatic conditions, and rainfall patterns, all of which influence radionuclide mobility, especially in sandy soils. The 1986 Chernobyl nuclear accident resulted in extensive environmental contamination by anthropogenic radionuclides, particularly Cs-137, prompting international efforts to monitor radionuclide distribution in environmental compartments, including food products and medicinal plants (Butkus et al., 2006). In Syria, Al-Masri et al. (2012) reported higher radionuclide concentrations in imported medicinal plants compared with locally produced plants, especially in leaves and flowers. The detection of Cs-137 in the present study differs from observations reported by (Eisenbud and Gesell., 1987) and (Marouf.,1992), as cited by (Ali et al., 2015). These authors indicated that Cs-137 is commonly associated with nuclear reactor incidents, whereas Cs-137 is more frequently detected in environmental studies because of its higher production yield during nuclear explosions, longer environmental persistence, and greater mobility. Furthermore, Cs-137 strongly adsorbs onto clay-rich soils, potentially contributing to higher external radiation exposure compared with internal exposure through ingestion. The present findings are also in agreement with those of (bin Ashour et al.,2013), who reported low Cs-137 concentrations in tobacco plants cultivated in Libya, ranging from 0.000850 to 0.001500 Bq/g. The occurrence of Cs-137 in the investigated area may originate from radioactive fallout associated with global nuclear weapon tests and nuclear incidents, as suggested by Hussein (2018), who reported upward migration of radionuclides from soil to plants. In recent years, reduced plant growth and lower leaf production have been observed in some medicinal plant species within the study area. This may be associated with radionuclide uptake through plant roots followed by translocation to leaves, flowers,

fruits, and seeds (Marouf, 1992). Exposure to ionizing radiation may damage plant cell walls and cellular membranes and, depending on the exposure dose, may also contribute to genetic mutations and carcinogenic effects in humans (Mohammed and Ahmed., 2007). Therefore, further investigations are required to better understand the transport pathways and accumulation dynamics of Cs-137 in the study area. The relatively low transfer efficiency of Cs-137 from soil to plants, compared with Th-232, Th-228, and K-40, may be attributed to its limited bioavailability and restricted root uptake. These processes are strongly influenced by soil characteristics, including organic matter content, exchangeable potassium levels, soil pH, and moisture conditions (Frissel et al., 2002). In addition, elevated K-40 concentrations in soil may reduce Cs-137 uptake because of competitive ion absorption mechanisms. Further studies are therefore recommended to evaluate these interactions and compare the obtained results with the average Cs-137 concentrations reported by the International Atomic Energy Agency (IAEA) for herbaceous plant leaves, which range from 0.02 to 3.2 Bq/kg.

Table 5. Mean concentrations of natural and artificial radionuclide's in medicinal plants (Bq/kg)

Sample Name (Plant)	Sample Code	Sample Weight (kg)	K-40 Bq/kg	Ra-226 Bq/kg	Th-232 Bq/kg	Cs-137 Bq/kg
<i>Rhus tripartita</i>	P.R.r - 1	0.580	200.27	2.5732	1.68	0.2776
<i>Thymus capitatus</i>	P.A.h - 3	0.500	177.40	8.4702	3.55	0.6923
<i>Artemisia herba-alba</i>	P.C.s - 5	0.420	142.90	5.1312	2.77	0.4460
<i>Marrubium vulgare L.</i>	P.M.V - 4	0.480	142.90	5.1312	2.77	0.4460
<i>Capparis spinosa L.</i>	P.A.c - 6	0.670	552.08	6.5124	3.44	0.1760
<i>Artemisia campestris L.</i>	P.T.C - 2	0.540	200.27	3.3177	9.07	0.2776

Radiological Hazard Indicators

The study revealed that the values of absorbed dose rate (D_r), radium equivalent activity (R_{eq}), external hazard index (H_{ex}), and internal hazard index (H_{in}),

calculated using standard equations (Table 7), varied among the soil samples associated with the studied medicinal plants. The Raeq values for the soils of *Rhus tripartita*, *Thymus capitatus*, *Artemisia herba-alba*, *Marrubium vulgare*, *Capparis spinosa*, and *Artemisia campestris* were 101.33, 100.56, 99.59, 90.38, 101.29, and 78.34 Bq/kg, respectively. These values were higher than those reported by (Hussein.,2018) for soils cultivated with eggplant and green pepper in Iraq, where Raeq values ranged from 77.73 ± 2.72 to 89.41 Bq/kg. Despite these variations, all Raeq values recorded in the present study remained well below the internationally recommended safety limit of 370 Bq/kg (UNSCEAR, 2000; Mahur et al., 2008). The Hex values ranged from 0.21 to 0.27, with the highest values observed in the soils of *Rhus tripartita*, *Thymus capitatus*, and *Artemisia herba-alba*, whereas the lowest value was recorded in *Marrubium vulgare*. Similarly, the Hin values ranged from 0.32 to 0.41, with the highest value observed in *Capparis spinosa* soils and the lowest in *Artemisia campestris*. All calculated values of Hex, Hin, and the gamma index ($I\gamma$) were below unity, indicating that the radiation levels in these soils do not pose significant radiological health risks according to international standards (Agbalagba et al., 2012). Graphical analyses (Figures, 8 and 9) demonstrated strong linear relationships between $I\gamma$ and $D\gamma$, $I\gamma$ and Hex, $I\gamma$ and Raeq, as well as between Raeq and Hex, with high coefficients of determination (R^2). These findings are consistent with global reference data reported by UNSCEAR (2000), which indicated absorbed dose rates ranging from 0.018 to 0.093 $\mu\text{Gy/h}$. Figure 7 further illustrates that the Raeq values obtained in the present study differed from those reported by Hussein (2018) for Syrian soils, where Raeq values ranged from 63.48 Bq/kg in green pepper soils to 89.41 Bq/kg in eggplant soils at site 4. Internationally, the estimated average Raeq value was reported as 77.73 ± 2.72 Bq/kg. Nevertheless, all values obtained in this study remained within internationally accepted safety limits (UNSCEAR, 2000; Mahur et al., 2008; Agbalagba et al., 2012). Absorbed dose rates also varied among plant species and their corresponding soils (Figure, 10). The highest absorbed dose in soil was observed in *Thymus capitatus*, whereas the lowest was recorded in

Artemisia campestris. In contrast, among plant tissues, *Capparis spinosa* exhibited the highest absorbed dose, while *Rhus tripartita* showed the lowest. Assessment of absorbed doses from different radiation types requires the application of radiation weighting factors to estimate their biological impacts, commonly referred to as the equivalent dose. Variations in equivalent dose may contribute to increased risks of certain cancers, particularly in radiosensitive organs, as well as potential genetic effects associated with prolonged exposure to low radiation doses. However, equivalent dose is not suitable for evaluating the severity of biological effects resulting from high radiation exposure. Therefore, continuous environmental monitoring and further individual dose assessments are strongly recommended. Moreover, artificial radionuclide's may present greater health risks when their concentrations exceed natural background levels, which can vary according to dietary habits and environmental conditions (Samad et al., 2010; United Nations Programme, 2016).

Table 6. Absorbed dose rates, hazard indices, and radium equivalent activities in soil and plant tissues

Sample Name Plants of :	Sample Code	Radium Equivalent Activity (Beq/kg)	External Hazard Index(H _{ex})	Internal Hazard Index(H _{in})	Absorbed Dose Rate(nGy/h)
<i>R. rtipartita</i>	S.R.r – 1	101.33	0.27	0.39	47.85
<i>T. capitatus</i>	S.T.C – 2	100.56	0.27	0.40	47.93
<i>A. herba-alba</i>	S.A.h – 3	99.59	0.27	0.40	47.10
<i>M. vulgare L</i>	S.M.V – 4	90.38	0.24	0.37	42.84
<i>C. spinosa L</i>	S.C.s – 5	101.29	0.27	0.41	47.88
<i>A. campestris L</i>	S,A.c – 6	78.34	0.21	0.32	37.00
Level of Absorbed Dose Rates ,Hazard Indices and Radium Equivalent Activity of Radionuclides in the Leaves and Stems of Medicinal Plants					
<i>R. rtipartita</i>	P.R.r – 1	20.40	0.06	0.06	10.52
<i>A. campestris L</i>	P.T.C – 2	40.77	0.11	0.12	20.35
<i>T. capitatus</i>	P.A.h – 3	27.20	0.07	0.10	13.46
<i>M. vulgare L</i>	P.M.V – 4	20.10	0.05	0.07	10.01
<i>A. herba-alba</i>	P.C.s – 5	41.43	0.11	0.13	21.38
<i>C. spinosa L</i>	P,A.c – 6	53.94	0.15	0.16	28.00
Reference thresholds: Raeq = 370 Bq/kg (UNSCEAR, 2000) ; Hex < 1; Hin < 1 (Agbalagba et al., 2012)	–	370 Bq/kg	1Bq/kg	1Bq/kg	–

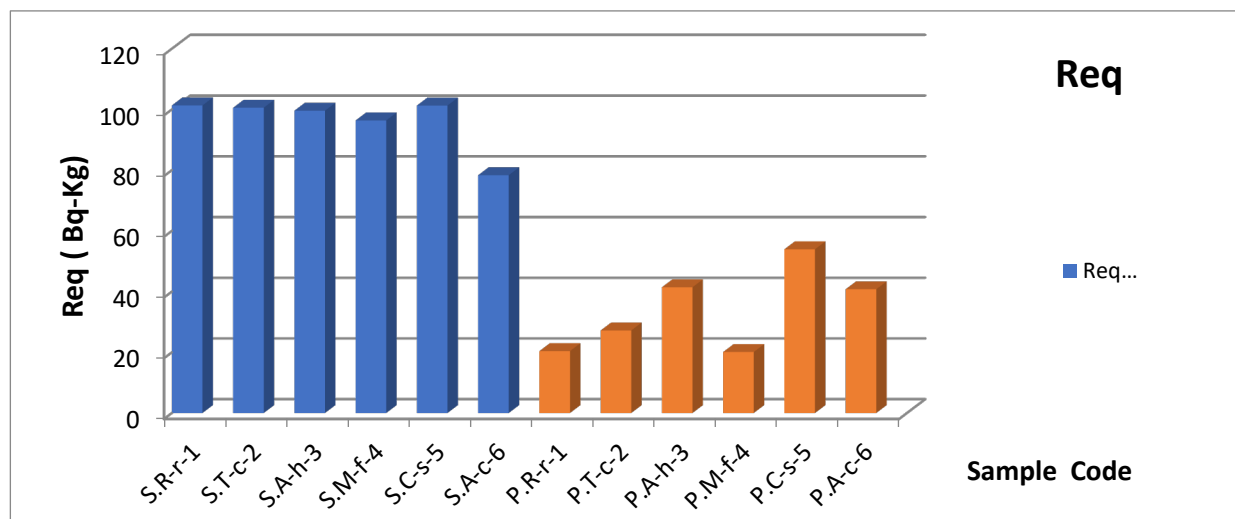


Figure 7. Calculated values of the Ra-226 equivalent activity in soil and associated medicinal plants (expressed in Bq/kg).

Legend:

S.R.r-1 = Soil of *Rhus tripartita*

S.T.c-2 = Soil of *Thymus capitatus*

S.A.h-3 = Soil of *Artemisia herba-alba*

S.M.v-4 = Soil of *Marrubium vulgare* L.

S.C.s-5 = Soil of *Capparis spinosa* L.

S.A.c-6 = Soil of *Artemisia campestris* L.

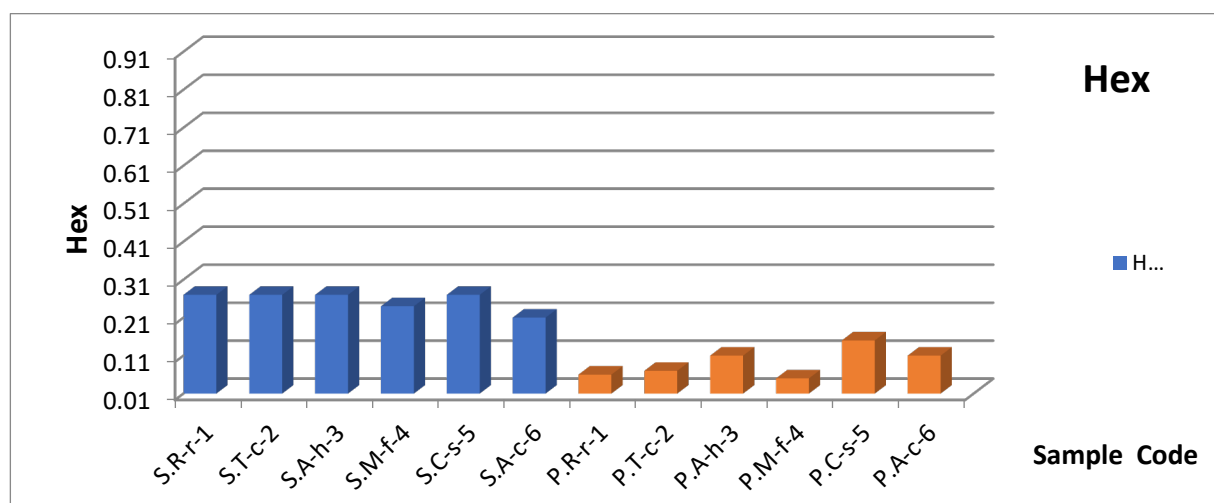


Figure 8. External hazard index levels in soil and medicinal plants

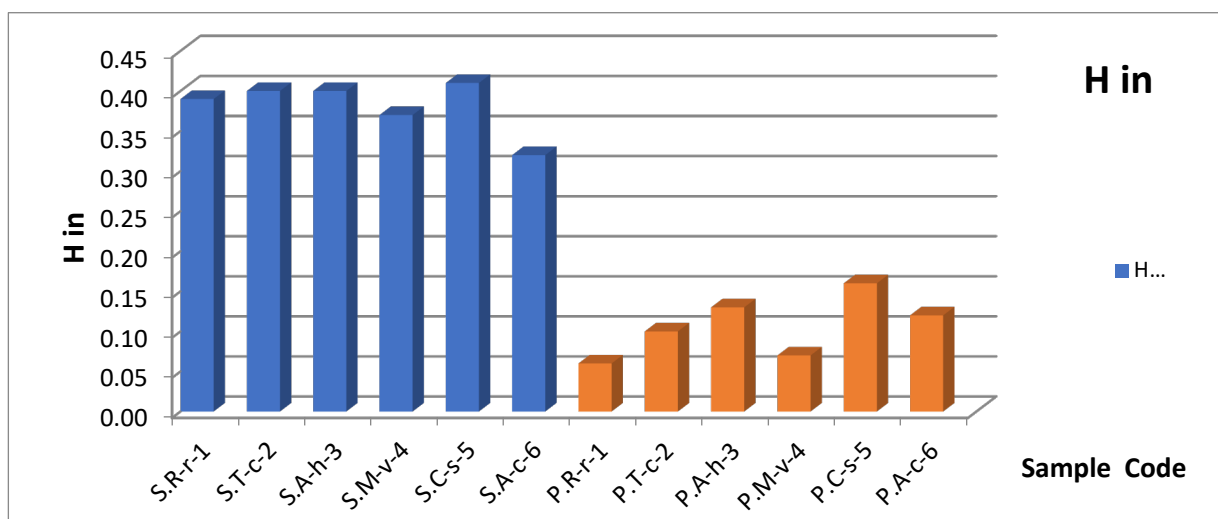


Figure 9. Internal hazard index levels in soil and medicinal plants.

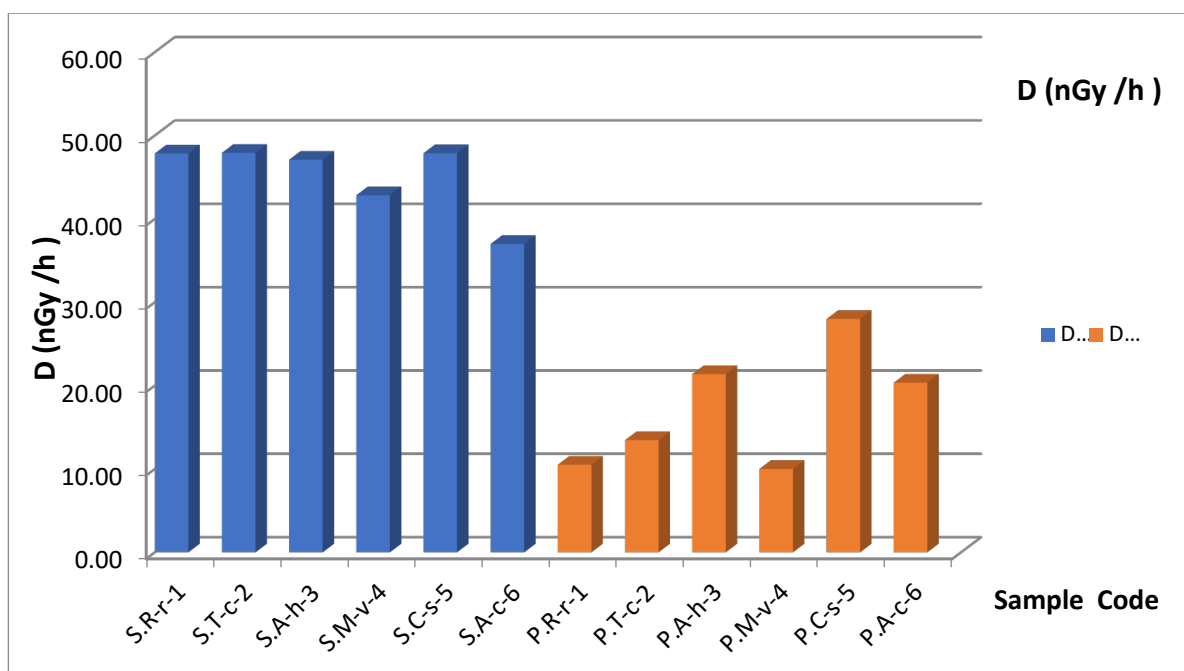


Figure 10. Transfer factor (TF) levels of radioactive elements from soil to medicinal plants in the study area.

Table 7. Comparison of Radioactivity Levels in Studied Medicinal Plants (Yefren/Libya) and Medicinal Plants from Chittagong, Bangladesh

Medicinal Plant, Yefren/Libya	Cs-137 (Bq/kg)	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)
<i>Rhus tripartita</i>	0.2776	200.27	2.5732	1.68
<i>Thymus capitatus</i>	0.6923	177.40	8.4702	3.55
<i>Artemisia herba-alba</i>	0.4460	142.90	5.1312	2.77
<i>Marrubium vulgare L.</i>	0.4460	142.90	5.1312	2.77
<i>Capparis spinosa L.</i>	0.1760	552.08	6.5124	3.44
<i>Artemisia campestris L.</i>	0.2776	200.27	3.4400	9.07
Averages	0.3859	235.97	5.2097	3.88
Medicinal Plants, Chittagong/Bangladesh	Cs-137 (Bq/kg)	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)
<i>Allium cepa</i>	0.08 ± 0.01	95.81 ± 2.04	0.70 ± 0.13	3.11 ± 0.24
<i>Amaranthus spinosus</i>	0.24 ± 0.04	180.74 ± 4.26	1.42 ± 0.26	4.36 ± 0.34
<i>Chenopodium album</i>	0.15 ± 0.03	205.03 ± 6.4	1.51 ± 0.15	4.60 ± 0.85
<i>Cynodon dactylon</i>	0.32 ± 0.05	112.21 ± 2.87	1.55 ± 0.07	2.89 ± 0.17
<i>Eleusine indica</i>	0.17 ± 0.02	146.49 ± 5.85	1.03 ± 0.06	5.15 ± 0.59
<i>Portulaca oleracea</i>	0.17 ± 0.02	134.95 ± 3.68	1.21 ± 0.10	3.08 ± 0.24
Averages	0.18 ± 0.028	145.87 ± 0.21	1.23 ± 0.11	3.86 ± 0.40

Table 8. Internationally Accepted Limits of Radioactive Elements (as per IAEA guidelines)

Radionuclide	Permissible Annual Dose	Half-Life
Cs-137	1 mSv/year	30.2 years
K-40	2.48 μ Sv = 0.00248 mSv	1.25 billion years
Ra-226	1 mSv/year	1,622 years
Th-232	1 mSv/year for civilians	14.05 billion years

Table 9. Conversion of Cs-137 Concentrations in Soil from Bq/kg to mSv/year

Medicinal Plant	Cs-137 in Soil (Bq/kg)	Dose in Plants (mSv/y)	Cs-137 in Plant (Bq/kg)	Dose (mSv/y)	Transfer Factor / sievert (Sv)
<i>Rhus tripartita</i>	8.9209	0.116	0.2776	0.0036	1.3×10^{-5}
<i>Thymus capitatus</i>	6.7490	0.0877	0.6923	0.0090	=
<i>Artemisia herba-alba</i>	3.5690	0.0640	0.3980	0.00517	=
<i>Marrubium vulgare L.</i>	1.8700	0.02431	0.4460	0.0058	=
<i>Capparis spinosa L.</i>	7.3122	0.0951	0.1760	0.00229	=
<i>Artemisia campestris L.</i>	1.5651	0.0335	0.2409	0.00313	=

Soil Chemical Properties and Their Influence on Radionuclide Uptake

Soil analysis (Table, 10) revealed variation in electrical conductivity (EC), pH and organic matter content across the study area. Soils in the region were slightly alkaline, with low to moderate salinity, and generally poor in organic matter. This low organic content may reduce nutrient and water uptake efficiency due to limited decomposition of organic residues. The radionuclide transfer from soil to plants is a crucial environmental safety indicator in nuclear facility impact assessment models. It aids in predicting radionuclide concentrations in food crops and estimating radiation doses to humans. Transfer processes depend on multiple factors such as soil type, pH, solid-liquid partition coefficient, exchangeable potassium, clay content, organic carbon, and other soil properties (Absalom et al., 1999).

Table 10. Selected Soil Chemical Properties in the Study Area

Plant Species Soil	PH	EC (mS/cm)	Organic Matter Content (%)
<i>Rhus tripartita</i>	7.8	0.69 (moderate)	2.0 (moderate to low)
<i>Thymus capitatus</i>	7.8	0.50 (low)	0.8–1.0 (poor)
<i>Artemisia herba-alba</i>	7.7	1.51 (slightly high)	0.8–1.2 (low)
<i>Marrubium vulgare L.</i>	7.8	0.67 (low)	1.0–1.3
<i>Capparis spinosa L.</i>	7.5	2.90 (high)	0.3–1.0
<i>Artemisia campestris L.</i>	7.9	0.33 (low)	0.5–0.8 (very low)
Control (Unplanted Soil)	7.7	0.53 (low)	0.8–1.8 (moderate to low)
Optimal Organic Matter %			3–5%

Table 11. Levels of natural radioactivity in some Libyan regions

Reference	Intern al Hazar d Index(H_{in})	Ext ern al Hazar d Ind ex(H_{ex})	msv/y I.P.L	msv/ y I.P.L	m sv /y	nG y/h I.P .L	nGy/ h	$K^{40}Bq$ /kg	Th^{232} Bq/kg	Ra^{226} Bq/kg	Libyan regions
(Algattawi et al.,2019)	-	-	-	-	-	-	-	400> 129± 7	<76 ±130	<52 ±73 5	Western and Central Libya
	-	-	-	-	-	-	21.5 60<	-	-	-	Absorbe d dose
	-	-	1 >	0.30	-	-	-	-	-	-	Annual dose
(Sahoub,2 024)	-	-	-	-	-	-	-	257	4.1	27	Wadi Al- Shatea
	-	-	-	-	1. 5	90. 9	-	-	-	-	Absorbe d dose
	-	-	0.11	-	-	-	-	-	-	-	Annual dose
	0.72	0.5 2	-	-	-	-	-	-	-	-	External Hazard Index
	-	-	-	-	-	-	-	169.5	5.5	26.5	Al-Zawia
	-	-	-	-	-	22. 5	22.5	-	-	-	Absorbe d dose
	-	-	-	-	0. 02 8	-	-	-	-	-	Annual dose
	1 >	1 >	-	-	-	-	-	-	-	-	Danger indicator

I.P.L = International Permissible Limit

Transfer Factor of Radionuclide's from Soil to Plants

The results of this study (Table, 12) revealed significant differences in the transfer factors (TF) of radionuclide's between various medicinal plant species and soils. Notably, Cs-137 exhibited a high transfer factor in *Marrubium vulgare L* while it was very low in *Rhus tripartita*. Other plant species showed moderate transfer rates. In contrast, K-40 exhibited generally high transfer factors across all plants, while Ra-226 had the lowest values, averaging 0.1 in most cases, which can be interpreted as moderate transfer. Meanwhile, Th-232 demonstrated high transfer rates in *Thymus capitatus* and *Artemisia campestris L* lower rates in *Rhus tripartita* and moderate values in the remaining species. These variations are attributed to differences in plant species and soil properties (Table, 10). The radionuclide uptake also differs between medicinal plants and agricultural crops. According to (Oufni et al. (2011) .when determining the transfer factors of uranium Th-232 using solid-state nuclear track detectors (SSNTD) in the roots, stems, and leaves of *Artemisia* and *Thymus* species in organically poor soils under high temperatures in southeastern Morocco, the uptake was highest in roots. Uranium activity reached 8.38 Bq/kg in roots, followed by 6.02 Bq/kg in leaves and 5.00 Bq/kg in stems. Th-232 activity was 2.53 Bq/kg in roots, 1.96 Bq/kg in leaves, and 1.64 Bq/kg in stems. Cs-137 was not detected in that study. In another study conducted in arid and semi-arid regions of Turkey, the transfer factors of Cs-137 in wheat *Triticum aestivum* clover in *Trifolium sp* and *purslane sp* (*Portulaca oleracea*) were reported as 0.005, 0.02, and 0.092 Bq/kg, respectively. Th-232 and Ra-226 showed very low transfer factors, indicating their limited uptake from soil) Dirican et al., 2025. (Furthermore, in a study from Vietnam) Van et al., 2020 (the transfer factors for Ra-226, Th-232, and K-40 in vegetables, fruits and other crops were found to range from 0.04–0.69, 0.08–0.97, and 1–16 Bq/kg, respectively).

Table 12. Transfer Factor (TF) of Radionuclide's from Soil to Medicinal Plants

Medicinal Plant Species	Cs-137 / TF	K-40 / TF	Ra-226 / TF	Th-232 / TF
<i>Rhus tripartita</i>	0.03	0.5	0.06	0.07
<i>Thymus capitatus</i>	0.1	0.4	0.1	0.2
<i>Artemisia herba-alba</i>	0.1	0.4	0.1	0.1
<i>Marrubium vulgare L.</i>	0.2	0.4	0.1	0.1
<i>Capparis spinosa L.</i>	0.1	1.7	0.1	0.1
<i>Artemisia campestris L.</i>	0.1	2.3	0.1	0.2

Conclusions and Recommendations

Conclusions

This study was conducted to assess the activity concentrations of naturally occurring radionuclide's Ra-226, Th-232, and K-40 as well as the anthropogenic radionuclide Cs-137 in soils and selected medicinal plants collected from the Yefren region, northwestern Libya. The obtained results demonstrated that the activity concentrations of Ra-226, Th-232 and K-40 in both soil and plant samples were generally within the internationally recommended limits established by the International Commission on Radiological Protection (ICRP) and other global radiological safety guidelines. However, detectable levels of Cs-137 were identified in several samples, indicating the presence of anthropogenic radioactive contamination in the study area.

Among the analyzed samples, the highest concentration of Cs-137 in soil was recorded in association with the *Rhus tripartita* plant ($8.9209 \text{ Bq kg}^{-1}$), while its leaves contained $0.2776 \text{ Bq kg}^{-1}$. In thyme *Thymus capitatus* content of Cs-137 activity concentrations reached 6.749 Bq kg^{-1} in soil and $0.6923 \text{ Bq kg}^{-1}$ in plant tissues. These findings confirm the transfer of anthropogenic radionuclide's from soil to vegetation, raising concerns regarding the potential long-term radiological impact on ecosystems and human health, particularly because medicinal plants are widely consumed by local populations.

The study further revealed that ^{40}K exhibited substantially higher activity concentrations than Ra-226 and Th-232 across all investigated samples, reflecting the natural abundance of potassium-bearing minerals in the geological formations of the region. Variations in radionuclide concentrations among sampling sites may be attributed to differences in lithology, climatic conditions, soil composition, and organic matter content. Despite these variations, the calculated radiological hazard indices, including internal and external hazard

parameters, remained below internationally accepted safety thresholds. Nevertheless, the continuous environmental persistence and bioaccumulation potential of radionuclide's particularly Cs-137 owing to its long physical half-life and radio toxicity may represent a future health concern if exposure continues over extended periods. The increasing incidence of cancer cases reported in certain parts of the region warrants further scientific investigation to evaluate possible environmental and radiological contributing factors, although direct causal relationships cannot be conclusively established based solely on the present study. Importantly, the detection of Cs-137 in the absence of clearly identified local radioactive sources highlights the need for comprehensive environmental monitoring programs in the **Jabal Nafusa** region. The present study therefore provides valuable baseline radiometric data that can contribute to the establishment of a national environmental radioactivity database and support the development of radiological protection policies and environmental safety standards in Libya.

Recommendations

*Continuous environmental radiological monitoring programs should be established in the Yefren and **Jabal Nafusa** regions to assess temporal variations in radionuclide concentrations in soils, water resources, and medicinal plants.

*A comprehensive national database for environmental radioactivity in Libya should be developed to provide baseline reference values for future radiological assessments and environmental protection strategies.

*Additional large-scale studies are recommended to investigate the sources, distribution, and ecological behavior of Cs-137 in Libyan ecosystems, particularly in medicinal and edible plants.

*Periodic radiological screening of medicinal plants intended for human consumption should be implemented to ensure public safety and minimize long-term exposure risks.

*Advanced epidemiological and environmental studies should be conducted to evaluate potential associations between environmental radioactive contamination and the increasing prevalence of cancer and other chronic diseases in the region.

*National radiological safety regulations and permissible limits for radionuclide's in soils, medicinal plants, and agricultural products should be established in accordance with international recommendations issued by the ICRP and the International Atomic Energy Agency (IAEA).

*Public awareness programs should be promoted to educate local communities about environmental radiation, safe use of medicinal plants, and methods for reducing potential radiological exposure.

*Further multidisciplinary research integrating environmental radioactivity, geology, plant uptake mechanisms, and public health data is strongly recommended to better understand radionuclide transfer pathways and their long-term environmental implications.

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Declarations

Ethics Approval

This article does not involve any studies conducted on human participants or animals by the author. Conflict of Interest The author declares that there are no conflicts of interest regarding the publication of this manuscript.

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