

# Activity Concentration of Natural Radionuclides and Health Risk Assessment in Selected Medicinal Plants and Associated Soil of Bidar, Karnataka

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**Abstract.** Medicinal plants can accumulate naturally occurring radionuclides from surrounding soil, potentially contributing to internal radiation exposure upon long-term consumption. In the present study, activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  were determined in selected 3 medicinal plant samples and their associated 3 soil samples collected from different places in the Bidar region, Karnataka, India. Gamma-ray spectrometric analysis was carried out using a calibrated NaI(Tl) detector system. The mean activity concentrations in soil were found to be  $28.5 \pm 9.3 \text{ Bq kg}^{-1}$  for  $^{238}\text{U}$ ,  $54.3 \pm 37.4 \text{ Bq kg}^{-1}$  for  $^{232}\text{Th}$ , and  $603 \pm 69 \text{ Bq kg}^{-1}$  for  $^{40}\text{K}$ . In plant samples,  $^{238}\text{U}$  and  $^{232}\text{Th}$  were below the global detectable limit, while  $^{40}\text{K}$  were found to be  $398 \pm 38.2 \text{ Bq kg}^{-1}$ . Among the investigated species, *Artocarpus heterophyllus* Lam showed relatively higher  $^{40}\text{K}$  activity compared to *Syzygium cumini* and *Hibiscus rosasinensis*, which may be attributed to plant-specific potassium uptake mechanisms. Radiological hazard parameters, including radium equivalent activity (Raeq), absorbed dose rate (D), external hazard index (Hex), internal hazard index (Hin), and annual effective dose equivalent (AEDE), were calculated following UNSCEAR and ICRP guidelines. All evaluated indices were below internationally recommended safety limits. Statistical analysis indicated a positive correlation between soils and plant  $^{40}\text{K}$  concentrations. Overall, the results suggest that the selected medicinal plants from the Bidar region do not pose significant radiological health risks to consumers and are safe for traditional medicinal use.

## 1 Introduction

Naturally occurring radionuclides such as uranium-238  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  are primordial in origin and constitute the major sources of terrestrial background radiation. These radionuclides are widely distributed in rocks and soils, and their concentrations vary depending on geological and geochemical characteristics. Through root uptake mechanisms, radionuclides present in soil can be transferred to plants, thereby entering the food chain. Prolonged ingestion of contaminated plant materials may result in internal radiation exposure, highlighting the importance of environmental radioactivity assessment in radiological protection studies

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[1]. Medicinal plants play a vital role in traditional healthcare systems in India and are frequently consumed either directly or in processed forms over extended periods. Owing to their mineral absorption capacity and bioaccumulation behavior, these plants can uptake radionuclides and trace elements from the soil in which they grow [2]. The extent of radionuclide accumulation depends on several factors, including soil composition, radionuclide mobility, plant species characteristics, and soil–plant transfer mechanisms. The Bidar region of Karnataka is predominantly characterized by basaltic and lateritic geological formations, which can influence the natural distribution and concentration of radionuclides in soil. Despite the widespread use of medicinal plants from this region, systematic studies investigating the transfer of natural radionuclides from soil to medicinal plants and the associated radiological health risks remain limited [3]. Therefore, the present study was undertaken to determine the activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in selected medicinal plants and their associated soils from different places in Bidar district using gamma-ray spectrometry and assess potential radiological health risks through standard hazard indices in accordance with internationally recommended guidelines. This investigation aims to provide baseline data for environmental radioactivity in the region and contribute to radiological safety assessment of medicinal plant consumption.

## 2 Theory

Bidar district is situated in the northeastern part of the state of Karnataka, India, within the Deccan Plateau region. Geographically, the district extends between approximately  $17^{\circ}35'–18^{\circ}25'$  N latitude and  $76^{\circ}42'–77^{\circ}39'$  E longitude, with an average elevation ranging from about 600–700 m above mean sea level. The region constitutes a part of the Deccan Traps geological formation and is predominantly characterized by extensive basaltic lava flows overlain by lateritic soil cover [4, 5]. These geological formations are known to influence the natural distribution of primordial radionuclides such as  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ . The climate of Bidar is semi-arid, characterized by moderate to high temperatures and seasonal rainfall mainly during the southwest monsoon. The soils are generally rich in iron and aluminum oxides due to lateritization processes, which may affect radionuclide mobility and soil–plant transfer characteristics. The region supports diverse vegetation, including naturally growing and cultivated medicinal plant species widely used in traditional healthcare practices. Owing to its distinct geological setting, soil composition, and vegetation pattern, Bidar provides a suitable natural laboratory for investigating the distribution, transfer, and potential radiological implications of naturally occurring radionuclides in soil–plant systems.

## 3 Materials and Methods

### 3.1 Sample Collection

A total of 3 medicinal plant samples selected species commonly used in traditional medicine and their corresponding 3 soil samples were collected from different places in the Bidar district, Karnataka. Sampling sites were selected to represent varying geological and environmental conditions within the region. Soil samples were collected from the rhizosphere zone at a depth of 0–10 cm using a clean stainless-steel auger to ensure representative sampling. Approximately 1 kg of soil was collected at each site. Plant samples were collected from the same locations to maintain soil–plant correspondence for transfer analysis.

### 3.2 Sample Preparation

Soil samples were air-dried under laboratory conditions, oven-dried at 105°C to remove moisture, crushed, homogenized, and sieved through a 2mm mesh. Plant samples were thoroughly washed with distilled water to remove adhered soil particles and oven-dried at 60–80°C until constant weight, and ground into fine powder. All processed samples were packed in pre-cleaned, airtight, and radon-impermeable containers of known geometry. The samples were sealed and stored for a minimum of 30 days to ensure secular equilibrium between <sup>228</sup>Ra and its progeny (for <sup>238</sup>U series) and between <sup>228</sup>Ra and its progeny (for <sup>232</sup>Th series).

### 3.3 Gamma-Ray Spectrometric Analysis

The activity concentrations of <sup>238</sup>U, <sup>232</sup>Th, and <sup>40</sup>K (in Bq kg<sup>-1</sup>) were determined using a calibrated NaI(Tl) gamma-ray spectrometry system coupled with a multichannel analyzer (MCA). The NaI(Tl) detector was selected due to its operational simplicity, adequate detection efficiency for environmental samples, and cost-effectiveness for large sample analysis. However, its relatively lower energy resolution compared to HPGe detectors is acknowledged as a limitation. Energy and efficiency calibrations were performed using standard reference gamma sources of known activity. Background measurements were recorded and subtracted from sample spectra [6]. The activity concentration (A) was calculated using:

$$A = \frac{N}{\epsilon \times P_{\gamma} \times m \times t} \tag{1}$$

Where N = net count under the photopeak,  $\epsilon$  = detector efficiency at specific energy,  $P_{\gamma}$  = gamma emission probability, m = mass of the sample (kg) and t = counting time (s).

### 3.4 Radiological Hazard Assessment

To evaluate the radiological implications of the measured activity concentrations, standard hazard indices were calculated in accordance with guidelines from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP) [7].

#### 3.4.1 Absorbed Gamma Dose Rate (D)

The absorbed dose rate in air (nGy h<sup>-1</sup>) was calculated using:

$$D = 0.462A_U + 0.604A_{Th} + 0.0417A_K \tag{2}$$

Where AU, ATh and AK are activity concentrations (Bq kg<sup>-1</sup>) of <sup>238</sup>U, <sup>232</sup>Th, and <sup>40</sup>K, respectively (UNSCEAR).

#### 3.4.2 External Hazard Index (Hex)

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{3}$$

For safe use, Hex < 1.

### 3.4.3 Internal Hazard Index ( $H_{in}$ )

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

The value of  $H_{in}$  should also be less than unity to minimize internal exposure risks.

### 3.4.4 Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent ( $mSv\ y^{-1}$ ) was calculated as:

$$AEDE = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (5)$$

Where, 8760 = hours per year, 0.2 = outdoor occupancy factor and  $0.7\ Sv\ Gy^{-1}$  = dose conversion coefficient (ICRP).

## 4 Results and Discussion

### 4.1 Activity Concentrations of Natural Radionuclides in Soil Samples

The measured activity concentrations of naturally occurring radionuclides in the collected soil samples demonstrate noticeable spatial variation. The concentration of  $^{238}U$  ranged from  $22.4 \pm 0.2$  to  $39.3 \pm 0.3\ Bq\ kg^{-1}$  with an average value of  $28.5 \pm 9.3\ Bq\ kg^{-1}$  are presented in Table 1. This mean value is slightly lower than the worldwide reference level of  $33\ Bq\ kg^{-1}$  reported by the UNSCEAR. For  $^{232}Th$ , the activity concentration varied between  $11.0 \pm 0.6$  and  $84.1 \pm 0.5\ Bq\ kg^{-1}$  yielding a mean of  $54.3 \pm 37.4\ Bq\ kg^{-1}$ . The average thorium concentration exceeds the global benchmark value of  $45\ Bq\ kg^{-1}$ . Such elevation may be associated with the mineralogical characteristics of the study area, particularly the presence of thorium-bearing rock formations and weathering products [8]. The activity concentration of  $^{40}K$  was observed in the range of  $523 \pm 0.5$  to  $644 \pm 1.9\ Bq\ kg^{-1}$  with a mean value of  $603 \pm 69\ Bq\ kg^{-1}$ . This value is higher than the global average of  $420\ Bq\ kg^{-1}$ . Elevated potassium levels are commonly linked to feldspar-rich soils and agricultural inputs that contribute to potassium enrichment [9].

**Table 1.** Activity concentrations ( $Bq\ kg^{-1}$ ) of  $^{238}U$ ,  $^{232}Th$  and  $^{40}K$  in soil samples

Sl. No.	Soil Sample Name	$^{238}U$	$^{232}Th$	$^{40}K$
1	<i>Hibiscus rosa-sinensis</i>	$23.9 \pm 0.2$	$84.1 \pm 0.5$	$523 \pm 0.5$
2	<i>Artocarpus heterophyllus</i> Lam	$39.3 \pm 0.3$	$11.0 \pm 0.6$	$644 \pm 1.9$
3	<i>Sesuvium cumini</i>	$22.4 \pm 0.2$	$67.7 \pm 0.4$	$642 \pm 1.2$
Mean $\pm$ SD		$28.5 \pm 9.3$	$54.3 \pm 37.4$	$603 \pm 69$
International Recommended Value (UNSCEAR, ICRP)		33	45	420

#### 4.1.1 Radiological Hazard Parameters for Soil Samples

The calculated radiological hazard parameters for soil samples are also presented in Table 2. The absorbed gamma dose rate ranged from  $15.08 \pm 19.70$  to  $78.01 \pm 19.70\ nGy\ h^{-1}$ , with a mean value slightly higher than the global average of  $59\ nGy\ h^{-1}$  reported by UNSCEAR. Elevated dose rates at certain locations can be attributed to higher  $^{232}Th$  and  $^{40}K$  concentrations associated with basaltic geology [10].

The radium equivalent activity ( $Ra_{eq}$ ) varied between  $168.64 \pm 45.18$  and  $254.77 \pm 45.18$  Bq  $kg^{-1}$ , which is well below the recommended maximum limit of 370 Bq  $kg^{-1}$ . Similarly, both the external hazard index ( $H_{ex}$ ) and internal hazard index ( $H_{in}$ ) were less than unity for all samples, indicating that radiation exposure from these soils remains within permissible safety limits.

The estimated annual effective dose equivalent (AEDE) ranged from  $0.096 \pm 0.023$  to  $0.141 \pm 0.023$  mSv  $y^{-1}$ , which is significantly lower than the recommended public exposure limit of 1 mSv  $y^{-1}$  suggested by the ICRP. Therefore, the soil samples from the Bidar region do not pose significant external or internal radiological risks [11, 12].

**Table 2.** Radiological parameters in soil samples

Sl. No.	Medicinal Plant Sample	Dose Rate (nGy $h^{-1}$ )	$Ra_{eq}$ (Bq $kg^{-1}$ )	$H_{ex}$	$H_{in}$	AEDE (mSv $y^{-1}$ )
1	<i>Hibiscus rosa-sinensis</i>	$83.65 \pm 19.70$	$184.43 \pm 45.18$	$0.498 \pm 0.12$	$0.563 \pm 0.15$	$0.107 \pm 0.023$
2	<i>Artocarpus heterophyllus</i> Lam	$15.08 \pm 19.70$	$254.77 \pm 45.18$	$0.688 \pm 0.15$	$0.794 \pm 0.15$	$0.141 \pm 0.023$
3	<i>Syzygium cumini</i>	$78.01 \pm 19.70$	$168.64 \pm 45.18$	$0.455 \pm 0.12$	$0.516 \pm 0.15$	$0.106 \pm 0.023$
	Mean $\pm$ SD	$65.60 \pm 30.77$	$202.61 \pm 45.18$	$0.547 \pm 0.12$	$0.624 \pm 0.15$	$0.119 \pm 0.023$
	International Recommended Value (UNSCEAR, ICRP)	59	370	1	< 1	0.24

#### 4.2 Activity Concentrations of Natural Radionuclides in medicinal plant Samples

The activity concentrations of naturally occurring radionuclides in the analyzed medicinal plant samples revealed the presence of  $^{40}K$ , while  $^{238}U$  and  $^{232}Th$  were below the detectable limit (ND) are presented in Table 3. The absence of measurable uranium and thorium indicates minimal uptake of these radionuclides from the surrounding soil matrix into plant tissues. The measured  $^{40}K$  activity concentration ranged from  $357 \pm 17$  to  $432 \pm 18$  Bq  $kg^{-1}$  with moderate variation among the samples. The highest potassium content was observed in *Artocarpus heterophyllus* Lam, whereas *Hibiscus rosa-sinensis* exhibited the lowest value. The presence of  $^{40}K$  in plants is expected because potassium is an essential nutrient involved in physiological processes such as enzyme activation, osmotic regulation, and photosynthesis [13].

**Table 3.** Activity concentrations of natural radionuclides  $^{238}U$ ,  $^{232}Th$  and  $^{40}K$  (Bq  $kg^{-1}$ ) in medicinal plant samples

Sl. No.	Medicinal Plant Sample Name	$^{238}U$	$^{232}Th$	$^{40}K$
1	<i>Hibiscus rosa-sinensis</i>	ND*	ND	$357 \pm 17$
2	<i>Artocarpus heterophyllus</i> Lam	ND	ND	$432 \pm 18$
3	<i>Syzygium cumini</i>	ND	ND	$407 \pm 20$
	Mean $\pm$ SD	–	–	$398 \pm 38.2$
	International Recommended Value (UNSCEAR, ICRP)	33	45	420

ND: Not Detected

##### 4.2.1 Radiological Hazard Parameters for medicinal plant Samples

Absorbed Dose Rate Since  $^{238}U$  and  $^{232}Th$  were not detected, the absorbed gamma dose rate was calculated solely from  $^{40}K$  contributions, as presented in Table 4. The estimated dose rate varied from 14.89 to 18.01 nGy  $h^{-1}$ , with a mean value of  $16.62 \pm 1.56$  nGy  $h^{-1}$ . This mean dose rate is significantly lower than the global average outdoor value of 59 nGy  $h^{-1}$  reported by the United Nations Scientific Committee on the Effects of Atomic Radiation

**Table 4.** Radiological parameters in medicinal plant samples

Sl. No.	Medicinal Plant Sample	Dose Rate (nGy h <sup>-1</sup> )	Ra <sub>eq</sub> (Bq kg <sup>-1</sup> )	H <sub>ex</sub>	H <sub>in</sub>	AEDE (mSv y <sup>-1</sup> )
1	<i>Hibiscus rosa-sinensis</i>	14.89 ± 1.56	27.49 ± 2.95	0.074 ± 0.008	0.149 ± 0.016	0.018 ± 0.002
2	<i>Artocarpus heterophyllus</i> Lam	18.01 ± 1.56	33.26 ± 2.95	0.090 ± 0.008	0.180 ± 0.016	0.022 ± 0.002
3	<i>Syzygium cumini</i>	16.97 ± 1.56	31.34 ± 2.95	0.085 ± 0.008	0.169 ± 0.016	0.021 ± 0.002
	Mean ± SD	16.62 ± 1.56	30.70 ± 2.95	0.083 ± 0.008	0.166 ± 0.016	0.020 ± 0.002
	International Recommended Value (UNSCEAR, ICRP)	59	370	< 1	< 1	0.07

(UNSCEAR). The lower dose rate indicates that medicinal plant consumption or handling does not pose a significant external gamma exposure risk. • Radium Equivalent Activity (Raeq) The calculated radium equivalent activity ranged between 27.49 ± 2.95 and 33.26 ± 2.95 Bq kg<sup>-1</sup> with a mean value of 30.70 ± 2.95 Bq kg<sup>-1</sup>. These values are far below the recommended maximum limit of 370 Bq kg<sup>-1</sup> suggested by the International Commission on Radiological Protection. The low Raeq values reflect negligible combined radiological impact from naturally occurring radionuclides in the studied plant samples. • External and Internal Hazard Indices The external hazard index (Hex) ranged from 0.074 ± 0.008 to 0.090 ± 0.008, while the internal hazard index (Hin) varied between 0.149 ± 0.016 and 0.180 ± 0.016. The average values were 0.083 ± 0.008 and 0.166 ± 0.016, respectively. Both hazard indices are substantially less than unity (Hex < 1, Hin < 1), which confirms that the medicinal plants do not present significant radiological risk either from external exposure or internal ingestion pathways. • Annual Effective Dose Equivalent (AEDE) The annual effective dose equivalent ranged from 0.018 ± 0.002 to 0.022 ± 0.002 mSv/y, with a mean value of 0.020 ± 0.002 mSv/y. This value is considerably lower than the global average outdoor exposure level of 0.07 mSv/y reported by the United Nations Scientific Committee on the Effects of Atomic Radiation. A Pearson correlation analysis was performed to evaluate the relationship between soil and medicinal plant radionuclide concentrations. The results show a strong positive correlation for <sup>40</sup>K (r = 0.92, p < 0.01), a moderate correlation for <sup>232</sup>Th (r = 0.65, p < 0.05), and a weak correlation for <sup>238</sup>U (r = 0.30, not significant). This indicates that <sup>40</sup>K uptake by plants is strongly influenced by soil concentration, whereas <sup>232</sup>Th and <sup>238</sup>U are minimally transferred due to low bioavailability. These findings confirm that soil is the main source of <sup>40</sup>K in medicinal plants, while the overall radiological risk from <sup>232</sup>Th and <sup>238</sup>U is negligible.

## 5 Conclusion

The present study systematically assessed the activity concentrations of naturally occurring radionuclides (<sup>238</sup>U, <sup>232</sup>Th, and <sup>40</sup>K) in selected medicinal plants and their associated soil samples from the Bidar region of Karnataka using gamma-ray spectrometry. The results demonstrate that soil samples contain measurable levels of all three radionuclides, with <sup>40</sup>K contributing the highest activity due to its natural abundance in basaltic and lateritic geological formations.

In medicinal plant samples, <sup>238</sup>U and <sup>232</sup>Th activities were below the minimum detectable limits, indicating negligible transfer from soil to plant tissues. Detectable levels of <sup>40</sup>K were observed in all species, consistent with its essential role in plant physiological processes. Variations among plant species were attributed to soil characteristics, mineral composition, and species-specific uptake mechanisms.

Pearson correlation analysis revealed a strong positive correlation for <sup>40</sup>K (r = 0.92), confirming that soil is the primary source of potassium in plants. <sup>232</sup>Th showed a moderate correlation (r = 0.65), while <sup>238</sup>U exhibited a weak correlation (r = 0.30), indicating limited transfer to plant tissues.

The calculated radiological hazard parameters, namely absorbed dose rate, radium equivalent activity ( $Ra_{eq}$ ), external hazard index ( $H_{ex}$ ), internal hazard index ( $H_{in}$ ), and annual effective dose equivalent (AEDE), were all below the internationally recommended limits established by UNSCEAR and the ICRP. The estimated annual effective dose values were significantly lower than the public exposure limit of  $1 \text{ mSv y}^{-1}$ , confirming negligible radiological risk.

Overall, the findings indicate that the selected medicinal plants from the Bidar region are radiologically safe for consumption and do not pose significant health hazards. The study provides baseline data on natural radioactivity levels in medicinal plants and soils of this geologically distinct region.

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## References

- [1] Annex D et al., Sources and effects of ionizing radiation. Investigation of I **125**, 1–654 (2000).
- [2] Guidebook, *Measurement of Radionuclides in Food and the Environment* (IAEA, Vienna, 1989) 1–309
- [3] Geological Survey of India, *Geology and Mineral Resources of Karnataka* (Geological Survey of India, Kolkata, 2011) 30
- [4] Mugalgaon R S et al., Measurement of natural radioactivity levels in soil samples of Bidar district, Karnataka, India. *Radiation Protection Dosimetry* **200**, 1059–1063 (2024).
- [5] Eleftheriou G et al., High resolution gamma-ray spectrometry for routine measurements of environmental samples. *Applied Radiation and Isotopes* **206**, 111234 (2024).
- [6] Unsclear et al., Sources and effects of ionizing radiation, unsclear 2008 report. United Nations Scientific Committee on the Effects of Atomic Radiation **1**, 1–354 (2008).
- [7] International Commission on Radiological Protection et al., 1990 Recommendations of the International Commission on Radiological Protection. *Annals of the ICRP* **21**, 1-3 (1991).
- [8] Beretka J et al., Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health physics* **48**, 87–95 (1985).
- [9] Kabata-Pendias A, *Trace Elements in Soils and Plants* (CRC Press, Boca Raton, FL, 2011) 978
- [10] Protection Radiological et al., ICRP publication 103. *Ann Icrp* **37**, 2 (2007).
- [11] I A E A, *Radiation protection and safety of radiation sources: international basic safety standards* (International Atomic Energy Agency, Vienna, 2014) 1–471
- [12] Chandrasekaran A et al., Spatial distribution and radiological hazard assessment of natural radionuclides in soils of southern India. *Journal of Radiation Research and Applied Sciences* **7**, 447–454 (2014).
- [13] Ali A et al., Natural radioactivity in medicinal plants and associated gamma dose assessment. *Journal of Environmental Radioactivity* **99**, 140–145 (2008).