



EVALUATION OF GAMMA-EMITTING RADIONUCLIDES IN MEDICINAL HERBS USED FOR INFANT CARE IN IGBOKODA, SOUTHWESTERN NIGERIA.

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Abstract

Concerns about the safety of herbal remedies used in infant care have increased, particularly regarding exposure to naturally occurring radionuclides. This study assessed the activity concentrations of uranium-238 (²³⁸U), thorium-232 (²³²Th), and potassium-40 (⁴⁰K) in medicinal herbs commonly used for infants in Igbokoda, Ondo State, Southwestern Nigeria. Twelve herb samples were selected based on traditional use for treating infant ailments. A thallium-doped sodium iodide gamma-ray spectrometry system (NaI(Tl)) was used to determine radionuclide concentrations. Radiological health indices, including absorbed dose rate, annual effective dose (AED), external and internal hazard indices (Hex and Hin), excess lifetime cancer risk (ELCR), and annual committed effective dose (Eave), were calculated and compared with international safety standards. The activity concentrations of ²³⁸U, ²³²Th, and ⁴⁰K ranged from 3.05–9.61, 1.26–5.94, and 43.16–256.24 Bq·kg⁻¹, respectively, remaining within UNSCEAR-recommended limits. *Carica papaya* showed the highest absorbed dose rate (13.90 nGy·hr⁻¹), while *Azadirachta indica* recorded the lowest (5.66 nGy·hr⁻¹). AED values ranged from 0.028 to 0.068 mSv·yr⁻¹, representing only 2.8%–6.8% of the ICRP's public dose limit. Hazard indices (Hex: 0.041–0.087; Hin: 0.049–0.113) were below 1, and ELCR values ranged from 0.097 to 0.239. The mean Eave was 0.324 mSv·yr⁻¹. The results indicated no significant radiological risks to infants under normal herbal use. However, periodic monitoring is recommended, especially for *Zingiber officinale* and *Carica papaya*, which showed higher radionuclide uptake. These findings offer baseline data for radiological safety and public health policy.

Keywords: medicinal herbs, infants, radiological risk, gamma spectrometry, Igbokoda, Nigeria.

Introduction

Traditional medicine remains a fundamental component of healthcare in many African societies, including Nigeria, where medicinal herbs are extensively utilized for treating various ailments (Mahomoodally, 2013). Infants are among

the most vulnerable population groups benefiting from these natural remedies, for whom herbal preparations are often employed to manage common health issues (Liheluka et al., 2023). The global use of plant-derived medicines is well documented, with raw plant materials and their extracts playing a crucial

role in traditional and modern healthcare systems (Chaachouay and Zidane, 2024; Niazi and Monib, 2024). Approximately 25% of modern pharmaceutical drugs are estimated to be derived from medicinal plants, most of which belong to the flowering plant category (Maldonado, 2021).

Fokunang *et al.* (2011) define traditional medicine as encompassing therapeutic practices that have existed for centuries, often predating the development and widespread adoption of modern medical systems, yet continuing to be an essential part of contemporary healthcare. A WHO survey further indicates that nearly 70–80% of the global population relies on traditional medicine, predominantly from plants (WHO, 2002). This high dependency is attributed to the increasing emphasis on Primary Health Care (PHC) and Basic Health Care (BHC) advocacy, particularly in resource-limited settings (WHO, 2002).

The cultural significance of herbal medicine in Nigeria is deeply rooted in indigenous knowledge systems, passed down through generations as an alternative healthcare means (Akunna *et al.*, 2023). While traditional medicine enjoys widespread acceptance due to its perceived efficacy and accessibility, there remains a paucity of scientific research on its potential radiological health implications.

Naturally occurring radioactive materials (NORMs), including Uranium-238 (^{238}U), Thorium-232 (^{232}Th), and Potassium-40 (^{40}K), exist in the environment and can be absorbed by plants from the soil, water, and atmosphere (Tettey-Larbi *et al.*, 2013). These natural radionuclides originate from geological sources, in contrast to anthropogenic radionuclides, which result from human activities such as nuclear testing, industrial processes, and medical applications. The accumulation of these radionuclides in medicinal plants poses

potential health risks when consumed in significant amounts, particularly for infants whose developing organs are more susceptible to radiation exposure (Abdelfadeel *et al.*, 2023). Assessing the radiological risks associated with medicinal herbs used in infant care is critical for ensuring their safety and mitigating any long-term adverse health effects.

Medicinal plants absorb radionuclides from their environment through root uptake, foliar absorption, and atmospheric deposition, and the accumulation of radioactive isotopes in these plants is influenced by factors such as soil composition, climatic conditions, and plant species characteristics (IAEA, 2007). Consuming these plants can introduce radioactive elements into the human body, increasing internal radiation exposure and posing potential health risks, including genetic mutations and cancer (Saudi *et al.*, 2022). These medicinal plants absorb radionuclides through multiple pathways, including root uptake from contaminated soils, foliar absorption from atmospheric particles, and deposition through irrigation or rainfall (Tettey-Larbi *et al.*, 2013). The extent of radionuclide accumulation in plants is influenced by numerous factors, such as soil composition, climatic conditions, plant species, and local environmental dynamics (Kabir *et al.*, 2024). When these plants are consumed directly or as herbal extracts, radioactive elements may be introduced into the human body, contributing to internal radiation exposure. Prolonged exposure to these radionuclides has been associated with increased risks of genetic mutations, cellular damage, and cancer (Abdelfadeel *et al.*, 2023). Several studies, including that of Arogunjo *et al.* (2005) and Saudi *et al.* (2022), have examined radionuclide concentrations in food crops and medicinal plants, revealing varying levels of natural radioactivity, with some exceeding established safety

thresholds. However, there is a notable gap in research focusing on traditional medicinal herbs used for infant healthcare in coastal environments such as Igbokoda, Ondo State. Given the unique ecological characteristics of coastal regions, including high humidity levels, soil erosion, and exposure to marine sediments, there is a possibility that radionuclide uptake in medicinal plants differs from that in inland areas. This calls for targeted investigations to establish region-specific data on the radiological safety of these herbs.

While the role of NORMs in plant and animal metabolism has been documented, their implications for the administration of medicinal plants remain underexplored. Unlike edible crops, which have been the primary focus of nutritional and toxicological studies, medicinal plants are often overlooked in radiological risk assessments. Although some commonly consumed plants, such as ginger, onion, pawpaw, and mango, possess medicinal properties, ingesting radionuclides through medicinal plant use is not widely recognized as a significant concern. Consequently, there is limited information on the concentrations of naturally occurring radioactive materials in medicinal plant preparations and their extracts in Nigeria. Most notably, existing literature seldom addresses how radionuclide exposure from medicinal herbs specifically impacts infant health in coastal areas, leaving a critical gap in environmental health and public safety knowledge. This study fills this gap by providing empirical data on radionuclide concentrations in medicinal herbs used for infant care in Igbokoda and evaluating their potential radiological risks.

Given that infants are particularly vulnerable to radiation exposure (Kutanzi *et al.*, 2016), assessing the radiological risks associated with the commonly used

medicinal herbs in their care is essential. This study aims to bridge the knowledge gap by investigating ^{238}U , ^{232}Th , and ^{40}K activity concentrations in selected medicinal herbs used for infants. The findings will provide a foundational reference for radiological health assessments in the region and contribute to evidence-based policy recommendations.

The significance of this research extends beyond ensuring the safety of traditional medicinal practices. The study will provide vital information on the radiological hazards of therapeutic herbs, which will help regulatory agencies create safe usage standards. Furthermore, it will contribute to broader efforts in environmental radiation monitoring and formulating sustainable public health policies. Ensuring the safety of traditional herbal remedies is vital for maintaining their role as a trusted healthcare resource while safeguarding public health, particularly for vulnerable populations such as infants.

Materials and Methods

Description of the Study Area

Igbokoda, the administrative center of Ilaje Local Government Area in Ondo State, Nigeria, is in a coastal region characterized by diverse sedimentary formations (Ilori *et al.*, 2024; Ogunrayi *et al.*, 2024). Geographically, it lies between latitudes $6^{\circ}10'$ N and $6^{\circ}25'$ N and longitudes $4^{\circ}39'$ E and $4^{\circ}53'$ E, stretching along the coastal sand bars from Okitipupa to the Atlantic Ocean. The terrestrial areas are elevated 8 to 10 meters above sea level, with an average annual temperature of 27°C and annual precipitation of approximately 2030 mm (Adegun and Olusoga, 2020).

The region's geology primarily consists of sands, clays, shales, and some limestone, forming part of the Niger Delta basin's lowland terrain with elevations below 15 meters above sea level. Its coastal location leads to significant saline water intrusion,

which impacts soil and groundwater quality (Ogunrayi *et al.*, 2024).

Fishing is the primary occupation of the indigenous population, supported by related activities such as boat building, net making and mending, and trade. According

to the 2006 population census, Ondo State has an estimated population of approximately 170,123,740 people, with around 290,615 residing in Ilaje LGA (NPCC, 2006). Figure 1 displays a map of Ondo State, highlighting Igbokoda as the study area.



Figure 1: Map of Ondo State showing Igbokoda, the study area.

Sample collections

Plant samples were collected from various locations within Igbokoda, a coastal Ondo State, Southwestern Nigeria coastal region. These locations were strategically selected to capture the environmental variability across the study area. The sampling sites were precisely mapped using a Germinetrex 10 geographical positioning system (GPS) for accuracy in location identification, as presented in Table 1.

Twelve infant-herb samples were collected, each chosen based on their local usage for treating infant diseases within the

community. The herbs were gathered directly from the ground, ensuring minimal contamination by handling. Each sample weighed approximately 200 g, which is considered sufficient for laboratory analysis based on standard collection protocols.

The collection process followed the guidelines outlined in International Atomic Energy Agency (IAEA) Report No. 295 (IAEA, 1989), ensuring consistency and compliance with international best practices. Additional recommendations from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2008) and the

methodological framework described by Ilori and Chetty (2020) were incorporated to enhance sample integrity. After collection, all samples were securely packaged to prevent cross-contamination during transport. They were then sent to the laboratory, where gamma-ray spectrometry

was employed to analyze the radionuclide concentrations. This analytical method was chosen due to its high sensitivity and precision in detecting radioactive isotopes, which are critical for assessing potential radiological hazards in herbs consumed for medicinal purposes.

Table 1: Sample Details of Collected Medicinal Plants used for Infants, their Botanical Information, and Geographic Coordinates.

Sample Code	North	East	Botanical Names	Family	Common Name	Local Names	Plant Parts Used
H ₁	006°21'16.1"	004°47'54.7"	<i>Ananas comosus</i>	Bromeliaceae	Pineapple	Ope Oyinbo	Fruits
H ₂	006°21'15.0"	004°47'52.8"	<i>Azadirachta indica</i>	Meliaceae	Neem Tree	Dongoyaro	Leaves
H ₃	006°21'27.4"	004°48'12.5"	<i>Carica papaya</i>	Caricaceae	Pawpaw	Ibepe	Leaves
H ₄	006°21'16.2"	004°47'54.1"	<i>Citrus aurantifolia</i>	Rutaceae	Lime	Osanwewe	Leaves
H ₅	006°21'16.9"	004°47'54.5"	<i>Cymbopogon citratus</i>	Poaceae	Lemon Grass	Kooko Oba	Leaves
H ₆	006°21'27.2"	004°48'17.8"	<i>Jatropha curcas</i>	Euphorbiaceae	Physic nut	Lapalapa	Leaves
H ₇	006°21'27.6"	004°48'18.0"	<i>Mangifera indica</i>	Anacardiaceae	Mango	Mangoro	Leaves
H ₈	006°21'22.9"	004°47'58.2"	<i>Momordica charantia</i>	Cucurbitaceae	African cucumber	Ejinrin Were	Leaves
H ₉	006°21'14.1"	004°47'52.1"	<i>Ocimum gratissimum</i>	Lamiaceae	Basil	Efinrin nla	Leaves
H ₁₀	006°21'43.5"	004°48'14.6"	<i>Psidium guajava</i>	Myrtaceae	Guava	Guofa	Leaves
H ₁₁	006°21'16.4"	004°47'54.2"	<i>Vernonia amygdalina</i>	Asteraceae	Bitter Leaf	Ewuro	Leaves
H ₁₂	006°21'35.2"	004°47'28.8"	<i>Zingiber officinale</i>	Zingiberaceae	Ginger	Atale	Rhizomes

Samples Preparation

The traditional infant medicinal herb samples were thoroughly cleaned, and the edible portions typically consumed by infants were chopped into pieces and air-dried for seven days, which were carried out in the Physics Laboratory at Olusegun Agagu University of Science & Technology, Okitipupa, Nigeria. The cleaned samples were subsequently oven-dried at 70°C until a constant dry weight was achieved for each sample (IAEA, 1989; Abdelfadeel *et al.*, 2023). The dried samples were ground into

fine powders using an electric blender and passed through a 2 mm mesh sieve to ensure homogeneity (Ilori and Chetty, 2020). The sieved samples were then weighed into pre-weighed 100 ml Polyvials clear plastic pill bottles to determine the dry weight of each herb sample. The bottles were sealed and stored for at least 28 days to allow natural radionuclides and their short-lived progeny to reach secular radioactive equilibrium (Deli *et al.*, 2019). The sample containers had similar geometric dimensions to the reference standard sources to ensure proper calibration

(IAEA, 1989; 2007). Finally, the samples were counted for 43,200 seconds using a NaI(Tl) gamma-ray spectrometry detector system to measure the radionuclide activity concentrations in the dry infant-herb samples (Ebibuolami *et al.*, 2021).

Radioactivity measurement

The activity concentration of radionuclides in herbal samples was measured using a thallium-doped sodium iodide (NaI(Tl)) gamma-ray spectrometry system at the Radiation Physics Research Laboratory, Ladoke Akintola University, Ogbomosho, Oyo State, Nigeria. The system included a well-shielded detector and a multichannel analyzer (MCA2100R) linked to a computer. Gamma spectra were analyzed using Palmtop MCA software. Detector efficiency calibration was conducted using reference standard sources traceable to the Analytical Quality Control Service (AQCS, USA), which certified the radionuclides' activities. Calibration was performed under identical sample and reference geometry. Gamma transition energies of 1764.5, 2614, and 1640.8 keV were used to determine the activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in the samples, corresponding to the characteristic gamma emissions of these radionuclides. These energies were chosen for their high detection efficiency and minimal spectral interference, ensuring accurate identification and quantification of the radionuclides in the herbal samples. The mass of the sample depends on the density of the sample material. The specific activity concentration of a radionuclide in a sample is typically measured in Becquerel per kilogram ($\text{Bq}\cdot\text{kg}^{-1}$) and can be calculated using the equation (Oddone *et al.*, 2008):

$$A_c = \frac{C_{\text{net}} - C_B}{P_{E,T_c,M}} \quad (1)$$

Where A_c , C_{net} , C_B , P_B , ϵ , T_c , and M represent the radioactivity concentration of

radionuclides in the samples (measured in $\text{Bq}\cdot\text{kg}^{-1}$) the net peak area in the sample spectrum, the corresponding net peak area in the background spectrum, the gamma emission probability (gamma yield), the detector efficiency, the sample counting time, and the sample mass, respectively.

A measuring system's detection limits (DL) represent its operational capabilities without sample influence (Proctor, 2008). In this study, the detection limit was determined using equation 2, following the methodologies outlined by Ilori *et al.* (2025):

$$DL(\text{Bq}\cdot\text{kg}^{-1}) = 4.66 \sqrt{\frac{C_b}{t_b} k} \quad (2)$$

Where t_b represents the background counting period in seconds, k is the conversion factor used to convert counts per second (cps) to activity concentration ($\text{Bq}\cdot\text{kg}^{-1}$), and C_b denotes the net background count for the corresponding peak. This study utilized a NaI(Tl) gamma-ray spectrometry detector system with detection limits of 3.2, 4.1, and 15.5 $\text{Bq}\cdot\text{kg}^{-1}$ for ^{238}U , ^{232}Th , and ^{40}K , respectively, with any measurements below these thresholds considered below the detector's detection limit.

Results and Discussion

Activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in the studied samples

The concentrations of naturally occurring radionuclides (^{238}U , ^{232}Th , and ^{40}K) in the analyzed medicinal plant samples varied significantly across species (Table 2). ^{238}U ranged from 3.05 $\text{Bq}\cdot\text{kg}^{-1}$ in *Ananas comosus* to 9.61 $\text{Bq}\cdot\text{kg}^{-1}$ in *Zingiber officinale*, with a mean of 6.09 $\text{Bq}\cdot\text{kg}^{-1}$. ^{232}Th values spanned 1.26 $\text{Bq}\cdot\text{kg}^{-1}$ in *Psidium guajava* to 5.94 $\text{Bq}\cdot\text{kg}^{-1}$ in *Zingiber officinale*, averaging 3.60 $\text{Bq}\cdot\text{kg}^{-1}$. ^{40}K , the most abundant radionuclide, ranged from 43.16 $\text{Bq}\cdot\text{kg}^{-1}$ in *Azadirachta indica* to 256.24 $\text{Bq}\cdot\text{kg}^{-1}$ in *Carica papaya*, with a mean of 170.67 $\text{Bq}\cdot\text{kg}^{-1}$. According to UNSCEAR (2000), the reference activity limits for ^{238}U and ^{232}Th in food are approximately 10 $\text{Bq}\cdot\text{kg}^{-1}$, while typical ^{40}K values in plants range between 100 and 1000 $\text{Bq}\cdot\text{kg}^{-1}$ due to its natural occurrence. All measured

radionuclide levels fall well within or below these benchmarks. Although *Zingiber officinale* and *Carica papaya* exhibited the highest concentrations of $^{238}\text{U}/^{232}\text{Th}$ and ^{40}K , respectively, their levels do not exceed the recommended safety thresholds. The elevated ^{40}K levels compared to ^{238}U and ^{232}Th can be attributed to its essential role in plant metabolism and the influence of potassium-rich fertilizers, which enhance

soil ^{40}K content and its subsequent plant uptake. These findings indicate that regular consumption of the sampled medicinal plants is unlikely to pose radiological health risks. However, continued monitoring is advised to ensure safety among vulnerable groups such as infants and pregnant women, particularly for plants with higher radionuclide content. Figure 2 illustrates the radionuclide distribution in the analyzed samples.

Table 2: Activity concentrations of radionuclides in the selected infant herbs from the study area.

S/Code	Botanical Names	^{238}U (Bq.kg ⁻¹)	^{232}Th (Bq.kg ⁻¹)	^{40}K (Bq.kg ⁻¹)
H ₁	<i>Ananas comosus</i> (L). Merr	3.05 ± 1.06	2.75 ± 1.32	104.30 ± 14.12
H ₂	<i>Azadirachta indica</i> A. Juss.	7.92 ± 2.17	3.19 ± 1.94	43.16 ± 15.41
H ₃	<i>Carica papaya</i> L.	6.35 ± 1.22	4.33 ± 1.33	256.24 ± 30.60
H ₄	<i>Citrus aurantifolia</i> (Christm.) S	3.47 ± 1.46	2.47 ± 1.50	127.38 ± 25.82
H ₅	<i>Cymbopogon citratus</i> (DC.) Straps.	7.43 ± 1.29	4.08 ± 1.84	206.74 ± 17.86
H ₆	<i>Jatropha curcas</i> L.	8.32 ± 3.04	4.21 ± 2.51	133.26 ± 20.99
H ₇	<i>Mangifera indica</i> L.	4.85 ± 1.11	3.05 ± 1.17	196.45 ± 19.28
H ₈	<i>Momordica charantia</i> L.	6.47 ± 2.91	5.16 ± 1.32	153.27 ± 19.13
H ₉	<i>Ocimum gratissimum</i> L.	5.42 ± 1.06	3.24 ± 1.49	238.75 ± 27.34
H ₁₀	<i>Psidium guajava</i> L.	5.81 ± 1.82	1.26 ± 1.02	187.84 ± 21.59
H ₁₁	<i>Vernonia amygdalina</i> Schreb.	4.38 ± 1.22	3.57 ± 1.25	215.80 ± 22.26
H ₁₂	<i>Zingiber officinale</i> Roscoe	9.61 ± 3.05	5.94 ± 2.42	184.83 ± 17.86
	Minimum	3.05 ± 1.06	1.26 ± 1.02	43.16 ± 15.41
	Maximum	9.61 ± 3.05	5.94 ± 2.42	256.24 ± 30.60
	Average	6.09 ± 1.47	3.64 ± 1.59	251.15 ± 21.02

The variation in activity concentrations among the medicinal plants can be attributed to differences in their absorption efficiencies of radionuclides. Some plant species exhibit a greater capacity to absorb specific radionuclides from the soil, leading to variations in radionuclide levels within their tissues (Shuaibu et al., 2025). Additionally, the inherent properties of radionuclides, particularly their half-lives, play a crucial role, as those with longer half-lives persist in the environment and biological systems for extended periods, leading to higher activity concentrations in the plants that absorb them (Beresford et al., 2015).

The ratio of ^{232}Th to ^{238}U in the medicinal plant samples is generally greater than one, indicating that ^{232}Th is present in higher concentrations than ^{238}U . This trend aligns with findings from similar studies worldwide, as reported by

Tetty-Larbi et al. (2013), suggesting a consistent pattern in the distribution of these radionuclides in medicinal plants.

Furthermore, the study reveals a notably high activity concentration of ^{40}K in the medicinal plants, which appears to be influenced by agricultural practices. Using potassium-rich fertilizers significantly contributes to elevated ^{40}K levels in the soil, which plants subsequently absorb. Beyond the influence of fertilizers, the naturally efficient potassium uptake mechanisms of certain plants also contribute to elevated ^{40}K levels, indicating that some species inherently absorb potassium more effectively than other elements, which helps explain the high ^{40}K concentrations observed in medicinal plants (Xu et al., 2020).

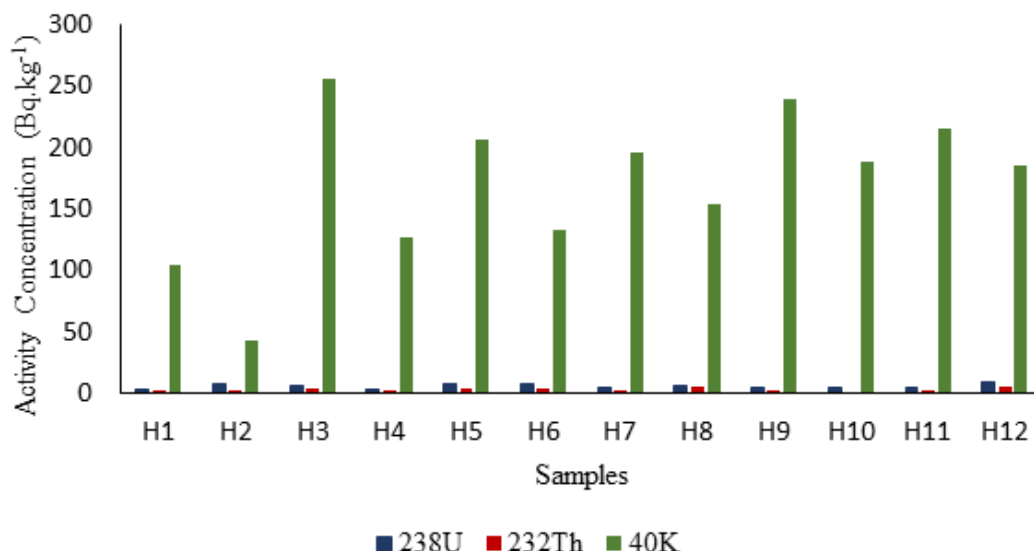


Figure 2: Distribution of radionuclides in the analyzed samples.

Radiological Risk Assessments

Absorbed Dose Rate (D)

The absorbed dose rate (D) is the amount of radiation absorbed in the air at a height of 1 meter above the ground (Adziz and Khoo, 2018).

$$D = 0.462 \times A_U + 0.604 \times A_{Th} + 0.0417 \times A_K \quad (3)$$

where D is the absorbed dose rate in nGy.hr⁻¹, A_U, A_{Th}, and A_K are the activity concentrations of ²³⁸U, ²³²Th, and ⁴⁰K in Bq.kg⁻¹, respectively.

The absorbed dose rate (D) results showed that *Carica papaya* recorded the highest value (13.90 nGy.hr⁻¹), followed by *Ocimum*

gratissimum (12.67 nGy.hr⁻¹) and *Zingiber officinale* (12.53 nGy.hr⁻¹). In comparison, *Azadirachta indica* had the lowest (5.66 nGy.hr⁻¹), as shown in Table 3. These differences likely reflect species-specific uptake influenced by environmental conditions, soil composition, and plant physiology. Compared to the global average outdoor absorbed dose rate of 59 nGy.hr⁻¹ (UNSCEAR, 2000), all values fall significantly below international thresholds, indicating negligible external radiological risk during the handling or using these herbs.

Table 3: Radiological hazard indices of radionuclides in the selected infant herbs from the study area.

Sample	D	AED	Hex	H _{in}	ELCR	E _{ave}
H ₁	5.93	0.029	0.041	0.049	0.102	0.212
H ₂	5.66	0.028	0.043	0.064	0.097	0.204
H ₃	13.90	0.068	0.087	0.104	0.239	0.431
H ₄	7.07	0.035	0.045	0.055	0.121	0.227
H ₅	12.31	0.060	0.079	0.099	0.211	0.383
H ₆	9.67	0.047	0.066	0.089	0.166	0.325
H ₇	10.63	0.052	0.066	0.079	0.182	0.321
H ₈	9.71	0.048	0.069	0.087	0.167	0.364

H ₉	12.67	0.062	0.077	0.091	0.217	0.370
H ₁₀	10.60	0.052	0.060	0.075	0.182	0.257
H ₁₁	11.25	0.055	0.070	0.082	0.193	0.353
H ₁₂	12.53	0.061	0.087	0.113	0.215	0.442
Mean	10.16	0.050	0.066	0.082	0.174	0.324
Max.	13.90	0.068	0.087	0.113	0.239	0.442
Min.	5.66	0.028	0.041	0.049	0.097	0.204

Annual Effective Dose (AED)

The AED estimates the radiation dose received by an individual due to environmental exposure (Mamun, 2024). Thus, to estimate the annual effective dose, one has to consider the conversion factor from the absorbed dose in the air to the effective dose and the indoor occupancy factor.

$$AED = D \times T \times C_F \times O_F \times 10^6 \quad (4)$$

where AED is the annual effective dose (mSv.yr⁻¹), D is the absorbed dose rate (nGy.hr⁻¹), and T is the annual time in hours (8,760 hr.yr⁻¹). In the UNSCEAR (2000) report, a value of 0.7 SvGy⁻¹ was used as a conversion factor (C_F) from the absorbed dose in the air to the effective dose received by adults for environmental exposure, and 0.8 for the indoor occupancy factor (O_F), implying that 80% of the time is spent indoors, on average, around the world, 10⁻⁶ is the unit conversion from nGy to mSv. The recommended annual radiation dose limit for the public is 1 mSv.yr⁻¹, per the International Commission on Radiological Protection (ICRP) guidelines.

Infant consumers' AED ranged from 0.028 mSv.yr⁻¹ (*Azadirachta indica*) to 0.068 mSv.yr⁻¹ (*Carica papaya*), with a mean of 0.050 mSv.yr⁻¹. These values are well below the ICRP's public exposure limit of 1 mSv.yr⁻¹ (ICRP, 1991), representing only a small fraction (2.8%–6.8%) of the recommended limit. The relatively higher AED in *Carica*

papaya may be linked to the elevated ⁴⁰K content typical of fruit-bearing plants. In contrast, the lower AED in *Azadirachta indica* suggests minimal radionuclide uptake. Nonetheless, the estimated exposures pose no significant health concern.

External (H_{ex}) and Internal (H_{in}) Hazard Indices

The external hazard index (H_{ex}) assesses the potential external radiation hazard from NORMs in medicinal plants.

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

The internal hazard index (H_{in}) accounts for the potential hazard from inhaling or ingesting radionuclides.

$$H_{in} = \frac{A_u}{185} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (6)$$

H_{ex} ≤ 1 and H_{in} ≤ 1 indicate acceptable external and internal exposure levels are within safe limits (Mbonu and Ben, 2021).

Hazard indices for external (H_{ex}) and internal (H_{in}) exposure ranged from 0.041–0.087 and 0.049–0.113, respectively, with mean values of 0.066 and 0.082. The highest values remained well below the safety limit of 1, confirming that radiological hazards from external contact and ingestion are within acceptable bounds. While *Zingiber officinale* and *Carica papaya* showed relatively elevated indices, they still fall under safe exposure levels. However, due to their slightly higher

values, continued monitoring is advisable for frequent users and sensitive groups such as infants.

Excess Lifetime Cancer Risk (ELCR)

The ELCR estimates the probability of developing cancer over a lifetime due to radiation exposure (Ezekiel, 2017).

$$\text{ELCR} = \text{AED} \times L \times \text{RF} \quad (7)$$

where ELCR is the excess lifetime cancer risk, AED is the annual effective dose (mSv.yr^{-1}), L is the average lifespan (typically 70 years), and RF is the risk factor (0.05 Sv^{-1}), as recommended by ICRP for stochastic effects).

The ELCR ranged from 0.097 (*Azadirachta indica*) to 0.239 (*Carica papaya*), with an average of 0.174. Although these values remain below the ICRP's suggested risk thresholds, the highest values—observed in *Carica papaya*, *Cymbopogon citratus*, and *Ocimum gratissimum*—warrant attention for individuals with long-term, high-frequency use. While the overall cancer risk remains low, evaluating cumulative exposure over time is recommended, particularly in vulnerable populations.

Average Annual Committed Effective Dose (E_{ave})

The average annual committed effective dose, E_{ave} , refers to the estimated radiation dose an individual is expected to receive annually from ingesting NORMs in medicinal plants (Mostafa *et al.*, 2021). This dose accounts for the cumulative effect of radionuclide intake over a specific period. It is calculated using the expression (Hossen *et al.*, 2024):

$$E_{\text{ave}} = \sum_{i=1}^n A_i \times \text{DCF}_i \times \text{IR} \quad (8)$$

E_{ave} is the average annual committed effective dose (mSv.yr^{-1}), A_c is the activity concentration of each radionuclide (Bq.kg^{-1}), DCF_i is the dose conversion factor for each radionuclide (mSv.Bq^{-1}) given as 4.5×10^{-5} , 2.3×10^{-4} , and 6.2×10^{-6} for ^{238}U , ^{232}Th ,

and ^{40}K (UNSCEAR, 2008), IR is the ingestion rate of the medicinal plants (kg.yr^{-1}), representing the annual consumption rate.

Infants' ingestion rate of medicinal plants in Nigeria varies with cultural practices, plant types, and administration frequency. Small doses of liquid preparations of such medicinal herbs are typically administered once or twice daily for 3 to 7 days to manage minor ailments, with some treatments lasting longer (Aworinde and Erinoso, 2015). An average daily dose of 5 mL administered over 30 days per year reflects sporadic use during illness or for preventive care. Converting 1 mL of decoction to 1 gram of plant material yields an estimated annual ingestion rate of 150 g.yr^{-1} . This estimate aligns with traditional dietary patterns, where infants consume smaller amounts, and medicinal plants are used cautiously due to potential risks (Oyedemi *et al.*, 2018). Studies on radionuclide ingestion rates in traditional settings often report values between 100 and 200 g.yr^{-1} for infants (Chandrashekara and Somashekarappa, 2016; Biira *et al.*, 2021; Kadhim *et al.*, 2025), supporting the 150 g.yr^{-1} assumption for radiological risk assessments in Igbokoda, Ondo State, Nigeria.

The E_{ave} ranged from $0.204 \text{ mSv.yr}^{-1}$ in *Azadirachta indica* to $0.442 \text{ mSv.yr}^{-1}$ in *Zingiber officinale*, with a mean of $0.324 \text{ mSv.yr}^{-1}$. Even at its peak, the E_{ave} values are below the ICRP's 1 mSv.yr^{-1} threshold (ICRP, 1991), reinforcing that radiation exposure from these herbs, under standard consumption patterns, is unlikely to pose health risks.

Statistical Analysis

Table 4 shows the One-Way ANOVA test result table for comparing mean concentrations of radionuclides (^{238}U , ^{232}Th , and ^{40}K).

Table 4: One-Way ANOVA Summary Table for Comparison of Radionuclide Concentrations

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Statistic	p-Value
Between Groups	Significant	2	Significant	89.07	5.01 × 10 ⁻¹⁴
Within Groups	-	33	-	-	-
Total	-	35	-	-	-

The one-way ANOVA test shows a statistically significant difference in the mean concentrations of ²³⁸U, ²³²Th, and ⁴⁰K across the plant samples. With an F-statistic of approximately 89.07 and a p-value far below 0.05, the analysis confirms that not all radionuclides are present at similar levels. Post hoc analysis using Tukey's HSD reveals that ⁴⁰K concentrations

are significantly higher than those of ²³⁸U and ²³²Th. In contrast, ²³⁸U and ²³²Th concentrations are closer to overlapping ranges, consistent with their non-significant differences (Figure 3). This suggests that potassium (⁴⁰K), an essential nutrient, is more readily absorbed by plants than uranium and thorium, which may be taken up in smaller, less consistent amounts.

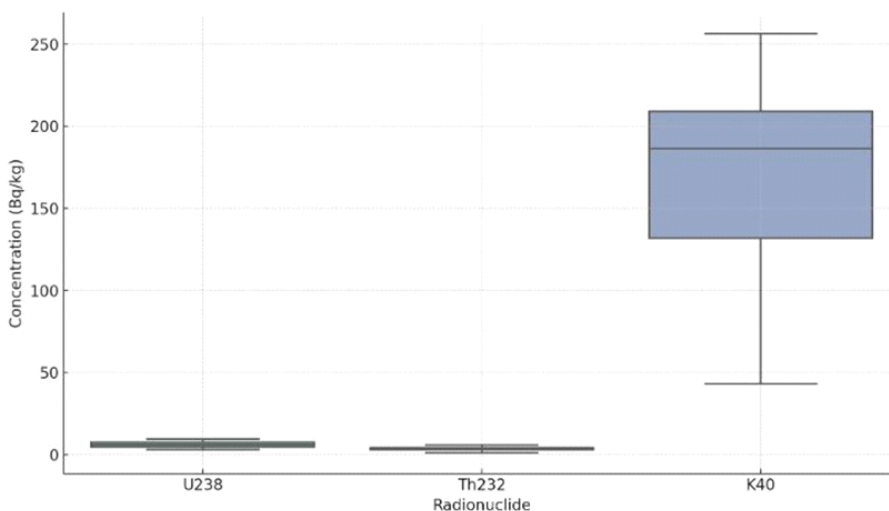


Figure 3: Comparison of Radionuclide Concentrations Across Plant Samples.

Table 5: Pearson Correlation Matrix of ²³⁸U, ²³²Th, and ⁴⁰K in Selected Medicinal Plants.

	²³⁸ U	²³² Th	⁴⁰ K
²³⁸ U	1.000	0.847	0.303
²³² Th	0.847	1.000	0.469
⁴⁰ K	0.303	0.469	1.000

Table 5 shows the Pearson correlation matrix for the radionuclides studied in the plant samples of this study. The Pearson correlation analysis reveals notable

relationships among the radionuclides ²³⁸U, ²³²Th, and ⁴⁰K in the examined plant species. A strong positive correlation between ²³⁸U and ²³²Th (r = 0.847) suggests that these

radionuclides may originate from similar environmental sources, with their accumulation likely governed by shared geochemical pathways and soil characteristics. In contrast, ^{40}K shows a moderate correlation with ^{232}Th ($r = 0.469$) and a weak correlation with ^{238}U ($r = 0.303$), reflecting a more independent accumulation

pattern. This is consistent with the essential role of potassium in plant physiology, as ^{40}K is a naturally occurring isotope that is actively regulated by plants based on biological demand, unlike ^{238}U and ^{232}Th , which are passively absorbed depending on environmental availability.

Table 6: t-Test Comparison of Absorbed Dose Rates in Medicinal Plants with Global Average.

Parameter	Value
Number of Samples (n)	12
Sample Mean Dose Rate (nGy/h)	10.09
Sample Standard Deviation (nGy)	2.39
Standard Error of the Mean (SE)	0.69
UNSCEAR Global Average (nGy/yr)	59.00
t-Statistic	-70.88
Degrees of Freedom (df)	11
p-Value	< 0.0001
Statistical Significance ($\alpha = 0.05$)	Significant

The t-test results, as shown in Table 6, show a significant deviation between the mean absorbed dose rate from the sampled medicinal plants and the UNSCEAR global average of 59 nGy/hr. The average dose rate across the 12 plant species was approximately 10.09 nGy/hr, with a standard deviation of 2.39 nGy/hr, indicating a relatively narrow distribution of values. The calculated t-value of -70.88 is well beyond the critical t-value for a 95% confidence level, confirming that the difference is statistically significant. This result demonstrates that these plants' absorbed dose rates from radionuclides are substantially lower than the global average radiation level recommended by UNSCEAR. These lower radiation levels may be due to the geochemical characteristics of the soil or the plants' selective uptake of radionuclides. From a public health perspective, this finding suggests minimal radiological risk associated with these

plants' consumption or medicinal use in the sampled region.

Conclusion

This study highlights both the cultural significance and potential radiological risks of using traditional medicinal herbs in infant healthcare within Igbokoda, a coastal town in Ondo State, Nigeria. Traditional medicine remains a primary form of healthcare for many rural Nigerians, especially in treating infant ailments, but its safety has largely escaped scientific scrutiny. The research reveals that medicinal plants, while therapeutically valuable, can absorb naturally occurring radioactive materials like uranium-238, thorium-232, and potassium-40 from their environment. This is particularly concerning in Igbokoda due to its unique coastal and soil conditions, which may increase the likelihood of radionuclide uptake. Infants are especially vulnerable to such exposures due to their developing biological systems. Despite the common use

of these herbs, little attention has been paid to their radiological safety. Addressing this gap, the study employed gamma-ray spectrometry to assess radionuclide levels in twelve widely used herbs, using globally recognized protocols to ensure accuracy. The findings point to the urgent need for routine radiation monitoring, development of safety guidelines, and regulatory oversight in the use of traditional medicines, especially for sensitive populations like infants. Ultimately, while traditional medicinal plants remain vital to healthcare in Nigeria, their use must be balanced with measures to ensure biological safety, calling for expanded research and proactive policy interventions.

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