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Examination of Medicinal Plants for Radionuclide Absorption and their Health Implications

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ABSTRACT

This study examined the concentrations of 40K, 238U, and 232Th radionuclides and evaluated the possible radiological health risks to medicinal plants found in Ewu, Edo State, Nigeria, using a NaI(Tl) gamma spectrometer. The six selected medicinal plants were *Mangifera indica, Dacryodes edulis, Terminalia catappa, Cymbopogon citratus, Anacardium occidentale, and Persea Americana*. The results showed that the activity concentrations for ^{40}K ranged from 146.59 ± 4.81 in *Persea americana* to 296.08 3.42 Bq/kg in *Cymbopogon citratus*, with a mean of 209.43 ± 5.14 Bq/kg; ^{238}U ranged from 2.25 ± 0.06 to 5.57 ± 0.15 Bq/kg, with a mean of 4.73 ± 0.15 Bq/kg; and ^{232}Th varied from 4.50 ± 0.35 to 12.07 ± 0.57 Bq/kg, with a mean of 8.00 ± 0.40 Bq/kg. The maximum and minimum activity concentrations of both ^{238}U and ^{232}Th were found in *Mangifera indica* and *Cymbopogon citratus*, respectively. The calculated average committed effective dose E_{CED} was 0.130 µSv/yr and the excess lifetime cancer risk (ELCR) has a mean of 0.00913 (×10^{-3}). The radiological hazard assessment of the investigated medicinal plants was well within the internationally recommended safe limits of 0.3 mSv/yr and >10^{-4} for E_{CED} and ELCR respectively. ^{232}Th contributes 54.91% of the total E_{CED}, while ^{238}U contributes the least to 6.35%. ^{232}Th exhibits a very strong, positive, and significant relationship with E_{CED} and the ELCR, and it contributes largely to the E_{CED} and ELCR due to ingestion of the examined herbal plant. Therefore, these medicinal plants are radiologically safe for human consumption.

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INTRODUCTION

The significance of medicinal plant materials' safety and quality has risen due to the global demand from health authorities, pharmaceutical industries, and the public at large (WHO, 2007). Most likely, the oldest strategy still in use today for helping people deal with illness is the use of medicinal herbs. In many traditional medical systems worldwide, medicinal plants have long been employed as a treatment. (WHO, 2007; Chandrashekara & Somashekarappa, 2016). The World Health Organization (WHO) has promoted the integration of traditional

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medicine's beneficial components into national healthcare systems to stimulate the use of traditional medicine worldwide (Oni *et al.*, 2011). This approach has served as an alternative medical technique, although concerns about estimated dosages and the sanitary state of the medications produced using this method have been addressed at various gatherings (Oni *et al.*, 2011).

Medicinal plants can be found in their natural state or processed (Saudi *et al.*, 2022). Physical, chemical, and biological pollutants can be found in herbal remedies (WHO, 2007). The human waste, animal manure, and sewage used as fertilizer can produce chemical and microbiological pollutants (WHO, 2007). The contamination of herbal material or products can occur at various stages of the manufacturing process (WHO, 2007). The consumption of medicinal plants with high levels of natural radioactivity can cause health problems (Sussa *et al.*, 2013; Kareem *et al.*, 2016). Since most medicinal products are applied topically to the skin or taken orally, radioactive substances present in large amounts may expose people to radiation both internally and externally, potentially harming humans (Oni *et al.*, 2011). The particular metabolic characteristics of plant species may lead to the accumulation of radionuclides in their organs, which may depend upon the physicochemical characteristics of the soil (Hashim *et al.*, 2019). An individual's annual effective dose from ingestion increases because of increased concentrations of radioactive elements in plants, increasing the risk of radiological harm. Actinides, activation products, and long- and short-lived fission products are a few examples of these radionuclides. For ^{238}U and ^{226}Ra, the lungs and kidneys are typically the sites of deposition; for ^{232}Th, the lungs, liver, or bones may all accumulate; and for ^{40}K, the body as a whole, but mostly in the muscles (Akhter *et al.*, 2007; Nahar *et al.*, 2018; Ugbede *et al.*, 2022). As a result, the immune system of the body may weaken in the face of many illnesses, leading to increased mortality (Nahar *et al.*, 2018; Ugbede *et al.*, 2022). The amount of radiation exposure depends on the intake of radionuclides, and its significance depends on other variables, such as age, metabolic kinetics, and weight (also known as the dose conversion factor), of the individual who ingests them (WHO, 2007). To determine whether people have been exposed to various radiation levels directly or indirectly in this regard, it is crucial to test the radioactivity of the environment and native herbs.

The ingestion of natural radionuclides and associated cancer risks from consuming tuber crops cultivated in Ebonyi suggests a potential threat of radiogenic cancer morbidity in adult individuals due to the presence of these naturally occurring radioactive materials (Ugbede *et al.*, 2023). Leafy vegetables grown using surface water irrigation in Lagos metropolis exhibit average specific activities of ^{226}Ra and ^{232}Th that surpass their corresponding WHO reference values by 40 and 56 times, respectively. This suggests a potential radiological impact on public health from the consumption of vegetables irrigated in Lagos metropolis (Adedokun *et al.,* 2019). In Barkin Ladi LGA, Plateau State, Nigeria, farmland soil and crop activity concentrations have been shown to increase the risk of health problems for farmers and consumers of crops (Jwanbot *et al.*, 2013). An assessment of the concentrations of natural radionuclides in fruits from markets in Ijebu-Ode town in Nigeria revealed that the highest concentrations of ^{40}K, ^{238}U and ^{232}Th were found in pineapple, orange, and mango, respectively, and the ingestion of these fruits poses no radiological health hazard to consumers (Sowole & Olaniyi, 2018). Numerous authors have documented radioactivity in medicinal plants in Nigeria's River State (Port Harcourt), Niger State, and Delta State (Njinga *et al.*, 2015; Oni *et al.*, 2011; Tchokossa *et al.*, 2013). In this study, Ewu was selected as the sampling site because it houses an ultramodern herbal drug manufacturing facility that utilizes local plants for production. The Pax Herbal Clinic & Research Laboratories was founded in 1996 to cultivate, identify, utilize, and promote herbal medicine with scientific excellence. This clinic produces more than fifty natural supplements that have been approved for public consumption by the National Agency for Food and Drug Administration (Adodo, 2022). No studies have been conducted in the study area on natural

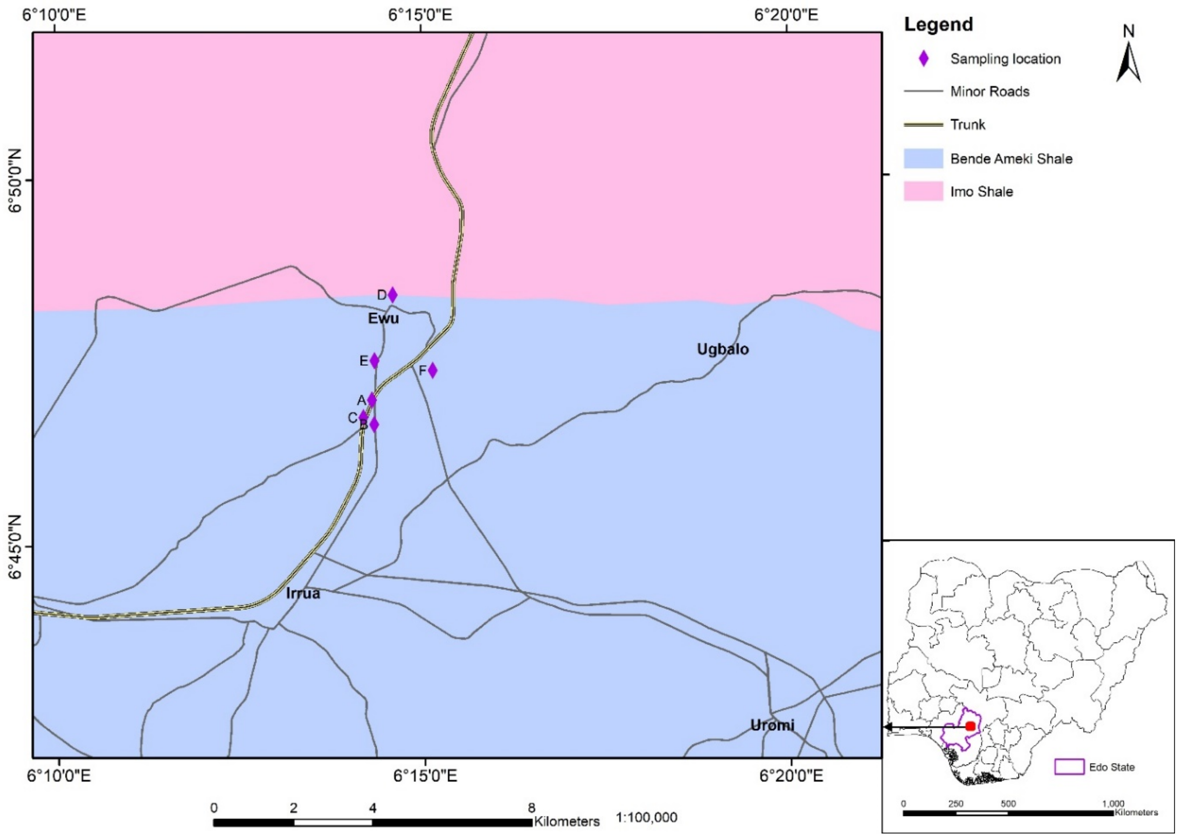

Fig. 1. Map showing the study location

radionuclides in medicinal plants. It is crucial to assess radionuclide concentrations in medicinal plants to avoid subjecting consumers to radiation (Abojassim & Lawi, 2018). Therefore, this study aimed to investigate the levels of natural radionuclides and health concerns related to radiological exposure to medicinal herbs produced in Ewu, Edo State, Nigeria. The objectives of this study were to determine the levels of ^{40}K, ^{238}U, and ^{232}Th radionuclides in medicinal plants and to assess the risk of radiological effects on the general public through estimation of excess lifetime cancer risk. The findings of this study can be utilized as a baseline value for radioactivity in medicinal plants in Esan Land, Edo State, Nigeria.

MATERIALS AND METHODS

The sampling area

The medicinal herbs chosen for this study originated from Ewu in Edo State's Esan-Central Local Government Area. The study location is shown in Fig. 1. The town is 200 feet above sea level in the plateau region of Edo State and 100 kilometres north of Benin city, the state's capital. Agbede, Irrua, and Ekpoma form the northern, southeast, and southwest borders of Ewu, respectively (Omonhinmin, 2017). Although farming constitutes most of the population's work, government employees, students, traders, and other workers occasionally engage in it. The existence of a modern herbal manufacturing company (Pax Herbals) has greatly influenced interest in the cultivation of herbs for both private and commercial use; as a result, the majority of these people have extensive native knowledge of traditional medicine, as it is their main source of healthcare and income.

Table 1. Names and uses of the selected medicinal plants

Sample Code	Scientific Name	Common name	Uses	References
A	*Mangifera indica*	Mango tree	To treat diabetes, restlessness, gall and kidney stones, respiratory problems, dysentery	Swaroop *et al.*, 2018
B	*Dacryodes edulis*	African Pear	To treat wounds, skin diseases, dysentery and fever	Omonhinmin, 2012; Makouate & Lekagne, 2022
C	*Terminalia catappa*	Umbrella tree	Gonorrhea, ulcers, cough, catarrh, haemoptysis, cholagogues, astringent, cardiac tonic	Njinga *et al.,* 2015
D	*Cymbopogon citratus*	Lemmon grass	For detoxification, stomachache, respiratory disorder, relief from edema	Toungos, 2019
E	*Anacardium occidentale*	Cashew tree	Malaria, elephantiasis, leprosy, ringworms, scurvy, diabetes, warts, anthelmintics, typhoid fever	Njinga *et al.*, 2015
F	*Persea americana*	Avocado	To improve glucose tolerance for people with diabetes, lower cholesterol, assist in weight loss, improve vision	Noorul *et al.,* 2016

Geology of the study area

The study area is underlain by sedimentary rocks that consist of crystalline basement rocks (Osayande & Christopher, 2019). The area is situated on a relatively flat plateau called the Esan Plateau, which is approximately 466 meters above sea level (Akinbode, 1983). The climate of the study area is humid subtropical, with two major seasons: the wet season (April to November) and the dry season (December to March). The vegetation is dominated by broadleaved trees that form dense layered stands (Osayande & Christopher, 2019).

Sample collection and preparation

Samples of six (6) different medicinal plant parts (2 kg each) commonly used and available in the localities of Ewu were collected. Table 1 shows the medicinal plants and their medical uses.

The part used in the selected medicinal plants was the leaf. The fresh leaves of the selected medicinal plants were collected within the locality of Ewu town, Esan LGA, Edo State, Nigeria, in September 2022. The plants were identified and authenticated by Professor J.C. Okafor Herbarium, Pax Herbal Clinic & Research Laboratories, Ewu, Nigeria, and voucher specimens were deposited. The leaves were treated separately by sorting, rinsed under running water, and air-dried at room temperature for 5 days to remove surface moisture. Thereafter, the plants were separately transferred into an oven maintained at 50°C for another 2 days before pulverizing into powder using an electric milling machine (Chris Norris, England) (Owolabi *et al.*, 2019), and 300 g of each sample was packaged into a labelled and tightly sealed polyethylene plastic containers, 8.6 cm in diameter and 5.8 cm high. They were kept for 1 month to guarantee long-term balance in the ^{238}U and ^{232}Th along with their corresponding offspring (Popoola *et al.*, 2019). The samples were then transported to the Radiation and Health Physics Laboratory of the Ladoke Akintola University of Technology, Ogbomoso, Nigeria, for gamma spectrometric analysis.

Gamma spectrometry measurement

A 3" × 3" NaI(Tl) detector made by Princeton Gamma Tech in the USA was used as the basis of the gamma spectrometry equipment. The detector is protected from background radiation by a cylindrical lead shield. A Gamma Spectacular (type GS-2000 Pro) multichannel analyser was connected to the detector, and the computer was connected to the analyser for display. Theremino software was used to acquire the data and analyse the gamma-ray spectra. The software is essential in the gamma spectrometry configuration as it facilitates data acquisition from the NaI(Tl) detector, provides real-time display features, and providing tools for in-depth analysis. These functionalities are crucial for interpreting the composition of the materials under analysis through gamma-ray spectra.

The NaI(Tl) spectrometry system was calibrated to determine the qualitative and quantitative relationships between the peak position in the spectrum and the related gamma-ray energy. With the use of the Radioactive Source Set of 8 (RSS8), which can be traced to Spectrum Techniques LLC, USA, the detector's energy was calibrated. Energy calibration was used to determine the detector's energy level and ability to detect radionuclides at the measured energy level and register their location. The efficiency calibration was carried out using reference source traceable to AQCS, USA. Calibration of efficiency was conducted by counting standard sources containing known radionuclides with known activity levels. It serves as a reference sample to quantify the efficiency level of the detector. Standard sources are intended for the detection of radionuclides such as ^{40}K, ^{238}U, and ^{232}Th in medicinal plants. The efficiency of the detector for the radionuclides is ^{40}K (0.44×10^{-2}), ^{214}Bi (0.271×10^{-2}), and ^{208}Tl (0.141×10^{-2}). These values are used in a mathematical relationship, as expressed in equation (1), to determine the radioactivity concentration of unknown radionuclides in medicinal plants.

The background gamma-ray distribution was calculated by counting an empty container for 36000 s before sample analysis. Once the sealed samples had reached a state of secular equilibrium, they were all sequentially placed on the detector for analysis. Every sample was counted for the same amount of time as the container's empty counterpart. The activity concentration A (Bq/kg) of each detected radionuclide in the sample was measured as follows:

$$A = \frac{C_{net}}{P_{\gamma} \times \varepsilon \times m \times t} \tag{1}$$

where C_{net} is the net peak count for each radionuclide present in the sample after subtracting the background count from the gross count, P_{γ} is the absolute gamma-ray emission probability of the identified radionuclide, ε is the obtained full energy peak efficiency for each identified radionuclide, *m* is the mass of the sample and t is the counting time. The most notable radionuclides found in the samples were identified as having energies of 1460.0 keV (^{40}K), 1764.5 keV of ^{214}Bi (^{238}U), and 2614.7 keV of ^{208}Tl (^{232}Th).

Estimation of radiological hazard

After determining the values of the specific activity concentrations of individual naturally occurring radionuclides in medicinal plants, the effects of radiation on human health were evaluated using the radiation hazard.

Average committed effective dose (E_{CED})

The E_{CED} for ingestion of naturally occurring radionuclide materials (NORM) in medicinal plants was calculated using the expression in equation (8) (Saudi *et al.*, 2022; Tettey-larbi *et al.*, 2013):

$$E_{CED} = A_c * DCF_{ing} * C_r \tag{8}$$

where E_{CED} is the average annual committed effective dose; A_c is the activity concentration of each radionuclide in the plant sample; DCF_{ing} is the dose conversion coefficient for ingestion of each radionuclide (i.e., 6.2×10^{-9} mSv/Bq, 4.5×10^{-8} mSv/Bq, and 2.3×10^{-7} mSv/Bq for ^{40}K, ^{238}U, and ^{232}Th, respectively, for an adult (UNSCEAR, 2000); and C_r is the rate of consumption from intake of NORM in medicinal plants.

Although there is no set dosage for medicinal plants in Nigeria, it was assumed that a patient requires 100 mL/day of herbal preparation or product to successfully treat a common condition (Njinga *et al.*, 2015). As a result, it was assumed that the medicinal plants used in the present study consumed NORM at a rate of 1 kg/yr (Alade *et al.*, 2020; Njinga *et al.*, 2015).

Excess lifetime cancer risk (ELCR)

This has to do with the potential for a lifelong case of cancer at a specific level of exposure. It is expressed as a number that indicates the number of additional cancers that could be detected in a specified number of individuals. This occurs following exposure to a carcinogen at a particular dose. It was calculated as outlined by (Orosun *et al.,* 2018; Popoola *et al.*, 2019; Saudi *et al.*, 2022) as follows:

$$ELCR = E_{CED} \times DL \times RF \tag{9}$$

where E_{CED} is the average annual committed effective dose equivalent, RF is the fatal risk factor and DL is the duration of life. The RF to the public is taken to be $0.05\ \mathrm{Sv/y}$ (Popoola *et al.*, 2019), the DL is 54.5 years, and the life expectancy at birth is in Nigeria (WHO, 2015).

RESULTS AND DISCUSSION

Activity concentrations in the selected medicinal plants

The activity concentrations of ^{40}K, ^{238}U, and ^{232}Th obtained for the medicinal plant samples in Ewu are presented in Table 2. The activity concentrations in the medicinal plant samples for ^{40}K ranged from 146.59 ± 4.81 (in *Persea americana*) to 296.08 ± 3.42 Bq/kg (in *Cymbopogon citratus*), with a mean of 209.43 ± 5.14 Bq/kg; for ^{238}U, the activity ranged from 2.25 ± 0.06 to 5.57 ± 0.15 Bq/kg, with a mean of 4.73 ± 0.15 Bq/kg; and for ^{232}Th, the activity varied from 4.50 ± 0.35 to 12.07 ± 0.57 Bq/kg, with a mean of 8.00 ± 0.40 Bq/kg. The maximum and minimum

Table 2. Activity concentration (Bq/kg) of natural radionuclides in the medicinal plant samples

Sample Code	Scientific Name	^{40}K	^{238}U	^{232}Th
A	*Mangifera indica*	241.39 ± 6.16	5.57 ± 0.15	12.07 ± 0.57
B	*Dacryodes edulis*	202.14 ± 5.64	4.97 ± 0.29	7.76 ± 0.18
C	*Terminalia catappa*	185.67 ± 5.41	5.31 ± 0.09	9.19 ± 0.50
D	*Cymbopogon citratus*	296.08 ± 3.41	2.25 ± 0.06	4.50 ± 0.35
E	*Anacardium occidentale*	184.71 ± 5.40	5.06 ± 0.08	9.51 ± 0.59
F	*Persea americana*	146.59 ± 4.81	5.21 ± 0.25	4.97 ± 0.19
	Min	146.59 ± 4.81	2.25 ± 0.06	4.50 ± 0.35
	Max	296.08 ± 3.42	5.57 ± 0.15	12.07 ± 0.57
	Mean	209.43 ± 5.14	4.73 ± 0.15	8.00 ± 0.40

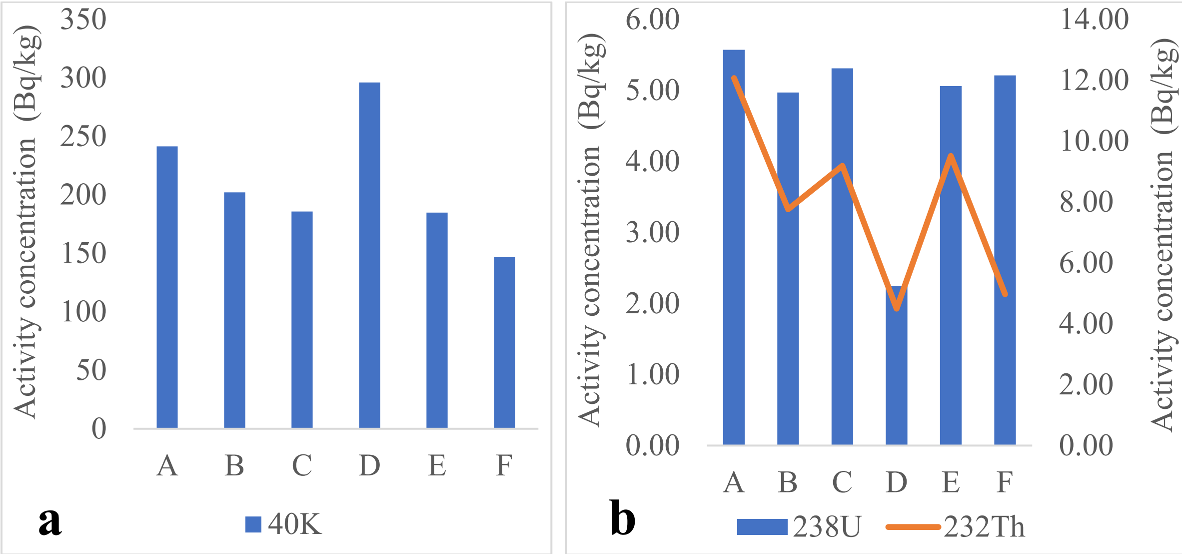

Fig. 2. Activity concentration in selected samples of medicinal plants.

activity concentrations of ^{238}U and ^{232}Th were found in *Mangifera indica* and *Cymbopogon citratus,* respectively. Notably, radionuclides were present in all the examined samples, though at varying concentrations. Differences in the location and radiochemical composition of the soils where medicinal plants grow lead to fluctuations in the concentrations of natural radionuclide activity (Tettey-larbi *et al.*, 2013).

The mean concentrations of ^{40}K, ^{238}U, and ^{232}Th radionuclides in the examined medicinal plants are lower than the worldwide average of 420 Bq/kg for ^{40}K, 33 Bq/kg for ^{238}U, and 45 Bq/kg for ^{232}Th (UNSCEAR, 2000). The activity concentration of ^{40}K was the highest of all the samples (Fig. 2).

According to their metabolic needs and potential regional differences, plants may absorb varied amounts of potassium from soil (Kolapo & Omoboyede, 2018). The radionuclide concentrations in the soil of higher education institutions in Ogwa and Igueben are of 57.80 ± 1.7 Bq/kg and 30.19 ± 1.22 Bq/kg, respectively (Popoola *et al.,* 2019). The ^{40}K results in this study imply that the area under study has experienced some ^{40}K enrichment. These plants have a high potassium concentration because they can absorb potassium from the soil more readily than other elements (Tettey-larbi *et al.*, 2013), possibly because fertilizer application by farmers increases agricultural yields. Compared to the concentrations reported by (Oni *et al.*, 2011) for Ugheli and Ogbomoso, the ^{40}K concentrations for *Cymbopogon citratus* obtained in this study were significantly greater. Similarly, *Terminalia catappa* had ^{40}K concentrations greater than the 145.59 ± 7.19 Bq/kg reported by (Njinga *et al.*, 2015) but with an elevated concentration of ^{232}Th. The activity concentration of ^{40}K in *Mangifera indica* in this study was lower than the 389.63 ± 34.42 Bq/kg reported by (Alade *et al.*, 2020). The high activity concentration of ^{40}K in leaves may be due to the significant function that potassium plays in plant photosynthesis, which causes it to accumulate more in leaves where photosynthesis occurs most frequently (Saenboonruang *et al.*, 2018).

A comparison of the mean activity concentrations of the ^{40}K, ^{238}U, and ^{232}Th radionuclides in the examined medicinal plant to those in other studies in other parts of the world is presented in Table 3. This table indicates that ^{40}K is prevalent in medicinal plants around the world. In this investigation, the ^{40}K activity concentration surpassed the levels documented by Njinga *et al.* (2015) in Lapai, Niger State, Nigeria, yet remained lower than those reported by Alade *et*

Table 3. Comparison of natural radionuclide activity concentrations (Bq/kg) in medicinal plant samples.

Country	Activity concentration (Bq/kg)			References
	^{40}K	^{238}U	^{232}Th	
Nigeria	209.43	4.73	8.00	This study
Bangladesh	661.10	12.65	7.38	Sultana *et al.*, 2020
Iraq	219.1	4.68	2.91	Kareem et al., 2016
Turkey	1910	-	5.67	Cengiz & Çağlar, 2019
Egypt	471.4	7.25	7.78	Saudi *et al.*, 2022
India	230.00	-	36.00	Monica *et al.*, 2020
Uganda	359.59	-	9.65	Biira *et al.*, 2021
Nigeria	171.72	-	35.09	Njinga *et al.*, 2015
Nigeria	630.02	5.79	4.13	Alade *et al.*, 2020
Ghana	839.80	31.78	56.16	Tettey-larbi *et al.*, 2013
World	420	33	45	UNSCEAR, 2000

al. (2020) in Ibadan. The ^{238}U concentration was found to be lower compared to Alade *et al.* (2020). In contrast, the ^{232}Th concentration exceeded the levels reported by Alade *et al.* (2020) but fell below those observed in Lapai, Nigeria, according to Njinga *et al.* (2015).

Activity concentration in relation to other global regions showed that ^{40}K in this study was slightly lower than that reported in Iraq (Kareem *et al.*, 2016) and India (Monica *et al.*, 2020). However, this value is more than nine times lower than that found in Turkey (Cengiz & Çağlar, 2019) and four times lower than that recorded in Ghana (Tettey-larbi *et al.*, 2013). This value is lower than that of Uganda (Biira *et al.*, 2021) and is more than three times lower than that recorded in Bangladesh (Sultana *et al.*, 2020) but more than twice as low as that obtained in Egypt (Saudi *et al.*, 2022). Our results demonstrate that the level of ^{238}U in medicinal plant samples is comparable to that reported by Kareem *et al.* (2016) in Iraq but lower than that reported by Saudi *et al.* (2022) in Egypt and Sultana *et al.* (2020) in Bangladesh, and Tettey-larbi *et al.* (2013) in Ghana.

The findings of the ^{232}Th study demonstrate that our findings are comparable with investigations carried out in Egypt (Saudi *et al.*, 2022) as well as Bangladesh (Sultana *et al.*, 2020). Furthermore, the ^{232}Th concentration is higher than that documented in Iraq (Kareem *et al.*, 2016), and Turkey (Cengiz & Çağlar, 2019) and lower than the levels reported in India (Monica *et al.*, 2020), Uganda (Biira *et al.*, 2021), and Ghana (Tettey-Larbi *et al.*, 2013). Variations in geography, geology, and the mineral makeup of different sample locations may account for the discrepancy in natural radioactivity concentrations across the various sampling sites.

Radiological hazard indices for medicinal plants

The calculated average annual committed effective dose E_{CED} for the examined medicinal plants is presented in Table 4. The values varied from 2.29 ± 0.085 to 4.52 ± 0.176 μSv/yr, with 3.35 ± 0.130 μSv/yr as the mean. Compared to the comparable global value of 1 mSv/yr, the E_{CED} values are less significant. Approximately 0.3 mSv/yr of NORM are received annually by the general population from medicinal plants (UNSCEAR, 2000). Furthermore, ^{232}Th contributes 54.91% to the total average annual committed equivalent dose E_{CED}, followed

Table 4. Radiological hazard indices in medicinal plant samples

Sample Code	Scientific Name	E_{CED} (mSv/yr)	E_{CED} (μSv/yr)	ELCR ($\times 10^{-3}$)
A	*Mangifera indica*	0.00452 ± 0.00018	4.52 ± 0.176	0.01233 ± 0.00048
B	*Dacryodes edulis*	0.00326 ± 0.00009	3.26 ± 0.089	0.00889 ± 0.00024
C	*Terminalia catappa*	0.00350 ± 0.00015	3.50 ± 0.153	0.00955 ± 0.00024
D	*Cymbopogon citratus*	0.00297 ± 0.00010	2.97 ± 0.104	0.00810 ± 0.00028
E	*Anacardium occidentale*	0.00356 ± 0.00017	3.56 ± 0.173	0.00970 ± 0.00047
F	*Persea americana*	0.00229 ± 0.00009	2.29 ± 0.085	0.00623 ± 0.00023
	Minimum	0.00229 ± 0.00009	2.29 ± 0.085	0.00623 ± 0.00023
	Maximum	0.00452 ± 0.00018	4.52 ± 0.176	0.01233 ± 0.00048
	Mean	0.00335 ± 0.00013	3.35 ± 0.130	0.00913 ± 0.00035

Table 5. Correlation coefficient matrix for all the radiological variables

	^{40}K	^{238}U	^{232}Th	E_{CED}	ELCR
^{40}K	1				
^{238}U	-0.75*	1			
^{232}Th	-0.06	0.66	1		
E_{CED}	0.33	0.34	0.92**	1	
ELCR	0.33	0.34	0.92**	1.00**	1

r-values significant *p<0.1; **p<0.05

by ^{40}K, with 38.75%, while ^{238}U has the least impact on E_{CED}. Our findings for E_{CED} are not of greater significance than those found by (Alade *et al.,* 2020; Njinga *et al.,* 2015; Tettey-larbi *et al.,* 2013). Consumers' health may not be affected by the yearly effective dosage of the therapeutic herbs in this investigation.

The minimum, maximum, and mean values of the estimated ELCR for ingestion of the medicinal plants were 0.00623 ± 0.00023 ($\times 10^{-3}$), 0.01233 ± 0.00048 ($\times 10^{-3}$), and 0.00913 ± 0.00035 ($\times 10^{-3}$), respectively. These results are lower than the acceptable global average, and there is extremely little probability of acquiring stomach cancer when these plant samples are used as medications.

Overall, Sample D, *Cymbopogon citratus*, had the greatest value of all the medicinal plants under examination (^{40}K), whereas Sample A, *Mangifera indica*, had the highest value of all the hazard indices. This is because *Mangifera indica* contains the greatest concentrations of ^{232}Th and ^{238}U out of all the samples, and ^{232}Th mostly contributes to the estimated radiological risk.

Correlation analysis

Pearson's correlation analysis was also conducted to determine the associations between the examined radiological parameters and the medicinal plants. The matrix of the established correlation coefficients (r values) is shown in Table 5. Some of the highest correlations observed are discussed. The analysis findings showed that ^{238}U exhibited a significantly strong negative relationship with ^{40}K content (*r* = -0.75*, p= 0.0859). This result shows that a decrease in ^{238}U leads to an increase in the concentration of ^{40}K. The association between ^{238}U and ^{232}Th was strong and not statistically significant according to the data. The correlation matrix showed that ^{232}Th exhibited a very strong and significant positive correlation with E_{CED} (*r*= 0.92**, p=

0.0087) and ELCR (r= 0.92**, p= 0.0087) in the medicinal plants. This could be because ^{232}Th accounts for the majority of the committed effective dose. The E_{CED} is perfectly connected to the ELCR. This finding implies that there is a direct relationship between E_{CED} and the ELCR.

CONCLUSION

The natural radionuclide activity concentrations of six different samples of medicinal plants used in the manufacture of herbal products were examined using the gamma spectrometric method. ^{40}K, ^{238}U, and ^{232}Th were detected in all the samples. The average concentrations of 209.43 ± 5.14 Bq/kg, 4.73 ± 0.15 Bq/kg, and 8.00 ± 0.40 Bq/kg for ^{40}K, ^{238}U, and ^{232}Th, respectively, are below the global recommended limit set by UNSCEAR (2000), and all the predicted radiological hazards fall within the boundaries that have been established globally. The relationships between ^{232}Th and E_{CED} and between ^{232}Th and the ELCR were shown to be extremely strong, positive, and significant. This indicates that the ^{232}Th radionuclide has a significant role in both the increased lifetime cancer risk caused by ingesting the studied herbal plant and the average annual committed effective dose E_{CED}. Therefore, there is no radiological risk to consumers' health from ingesting these therapeutic plants. This study can therefore be used as a baseline reference for determining the radioactivity of medicinal plants in Esan Land, Edo State, Nigeria, and may help develop standards and guidelines for medicinal plants as well as radiation protection rules and regulations.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission and redundancy have been completely observed by the authors. We would like to extend our sincere appreciation to Dr. Paul Ayanlola of the Radiation and Health Laboratory at LAUTECH, Ogbomoso. Thank you for your expertise and support.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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