Determination of Radionuclides Concentration and Transfer Factor in Selected Crops in Ganye Local Government Area of Adamawa State, Nigeria

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ABSTRACT

The activity concentrations of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) in the food crops grown in Ganye Local Government Area of Adamawa State with their corresponding soil samples were measured using gamma-ray spectroscopy. The research was to determine the concentration of radionuclides in selected crops and their Transfer factor. The activity concentrations of eight (8) maize samples, eight (8) groundnut samples and four (4) yam samples with their corresponding soil samples were determined using gamma spectroscopy with a 3" x 3" NaI (Tl) detector. Soil radioactivity exceeded UNSCEAR recommended values for ^{238}U and ^{40}K, while ^{232}Th generally remained within safe limits. In crops, ^{40}K showed the highest activity (ranging 88.38 ± 5.02 Bq/kg -148.42 ± 8.07 Bq/kg), followed by ^{238}U ($12.62 \pm 2.52 – 25.12 \pm 3.90$ Bq/kg) and ^{232}Th ($3.95 \pm 0.33 - 15.19 \pm 0.42$ Bq/kg). Transfer factors for all crops were below 1, indicating low soil-to-plant transfer. Radiological hazard indices including absorbed dose rate, radium equivalent, hazard indices, annual effective dose, and gamma index were all below international safety limits. However, the excess lifetime cancer risk (ELCR) exceeded the recommended threshold of 1E-4 to 1E-6 across all crops. This suggests a potential long-term cancer risk from continual consumption, despite the minimal transfer of radionuclides into crops. The findings indicate that while soils in the study area have elevated natural radioactivity, crop contamination remains low and does not pose an immediate health threat. Continuous monitoring and soil management are advised to ensure sustainable agricultural safety.

Keywords:
Radionuclides,
Activity concentration,
Transfer factor,
Soil,
Crops.

INTRODUCTION

Natural radioactive elements exist widely across the environment, permeating soil, sediment, water, plants, and air (Issa *et al*., 2014). Scientists have extensively investigated the integration of these radioactive elements, which are found in soil, due to the crucial role soil plays as the main conduit for transferring these elements to plants. The extent to which plants can take up long-lasting radioactive elements is determined by their chemical accessibility and proximity to the roots. However, the speed at which these radioactive elements move through different types of soil under varying pH and moisture conditions remains uncertain. Plants absorb these elements through their roots or leaves, and animals consume these plants, ultimately leading to human exposure through the consumption of animal products such as meat, dairy, and fat (Al-Hamarneh *et al*., 2016).

Soil around the world contains varying amounts of uranium, thorium, and their decay products, which expose people to both internal and external radiation. This type of soil-based radiation is the largest source of natural radiation humans are exposed to (Olabimtan, *et al.,* 2024). The exposure of humans to radiation from naturally occurring radioactive elements like those from the ^{238}U, ^{232}Th series, and ^{40}K has raised concerns among radiation health experts worldwide. The diverse activities of these elements in soil, influenced by local geology, contribute to varying levels of external human exposure globally (Agbalagba & Onoja, 2011). These radioactive elements have entered the food chain and water over time, resulting in internal human exposure, in addition to direct external exposure (Khandaker *et al*., 2017). Natural radioactive elements and their by-products are detectable in all food items (UNSCEAR, 2000). Notably, significant amounts of ^{40}K, ^{232}Th, ^{238}U, and ^{226}Ra have

been identified in various food crops consumed by humans (Ugbede & Akpolile, 2020). As food is an essential part of human life, habitual consumption can lead to the accumulation of radioactive elements in internal organs, potentially causing radiation-related damage proportional to the organ's radiation dose. (Jibiri *et al*., 2007).

The process of transferring radioactive elements to plants, along with the nutrients they absorb during mineral uptake, results in accumulation within different plant parts, including the edible portions. This often leads to contamination of agricultural products with these radioactive elements. Consumption of contaminated plants can pose significant health risks, including weakened immune defences, stunted fatal growth, impaired behaviour, and malnutrition-related disabilities. Therefore, assessing radioactive elements in our food is a crucial method for managing radiation exposure to humans.

Additionally, the transfer factor (TF) of radioactive elements can significantly vary based on factors such as location, time, season, chemical form of the elements, soil properties, and environmental conditions (Shayeb *et al.,* 2016). The widespread and persistent presence of natural radioactive elements in soil initiates food contamination, with the content in the food chain directly correlating with that in the soil (Hu *et al*., 2014). While natural processes introduce radioactive elements into the soil, agricultural practices contribute significantly to the levels of these elements in cultivated soil, subsequently leading to higher levels in plants.

Over the years the presence of radionuclides in the human environment has been of serious concern to research community. Much like the global trend, Nigeria is witnessing a rise in its population, creating a need to enhance food availability by increasing food production rates through the application of chemical fertilizers. The primary constituents necessary for crafting these fertilizers must, as a result, provide the fundamental nutrients essential for fostering plant growth specifically, nitrogen, phosphorus, and potassium. The presence of natural radioactivity, predominantly attributed to Uranium-238 (^{238}U), Thorium-232 (^{232}Th), and Potassium-40 (^{40}K), within phosphate fertilizers stems from the phosphate ore. This occurrence is driven by geological factors, with the phosphate ore serving as the central raw material in the production of phosphate fertilizers (Ei-Taher & Abbady, 2012).

According to Britannica, (2023) maize, groundnut and yam are part of the major crops produced in Adamawa State and are consumed almost daily in meals. Ganye Local Government Area of Adamawa State fall under the four classification of agricultural zones in Adamawa State. (Mohammed *et al.*, 2021). This implies that, this local government is hub for agriculture yet nothing has been done on accessing the concentration and transfer factor of radionuclide from soil to plant. Hence, this research is aimed at determining the transfer factor and dose rate of radionuclides and also identifies areas with higher concentration and their effect on man in Ganye Local Government Areas of Adamawa State.

MATERIALS AND METHODS

The major materials utilised in carrying out the research include the following: Global positioning system (GPS), Mortar and Pestle, Sieve (2mm mesh), Knife, Weighing balance, Plastic Containers, Masking Tape, Polythene bag and Na (TI) gamma detector system.

Study Area

Ganye Local Government Area occupies the Southern part of the State between latitude 8º 451 and 8º 261 N, and longitude 12º 091 and   12º 031 E, It is bounded by Jada to the North, Mayo-Belwa and Taraba State to the West, Toungo to the South and to the East Cameroon Republic (Adebayo, 2010). It has a land mass of about 2291.42 km^2 and a population of 164,087. The mean annual temperature is 26.7°C and the mean annual rainfall ranges between 1000mm and 1600mm with a distinct dry season which begins in November, and ends in April and the wet season begins in April and ends in October or sometimes in November. The area is located within the Guinea Savannah zone of the Nigeria's vegetation Zones. The major economic activity in the area is agriculture, food crops grown in the area includes maize, sorghum, cowpea, cassava and potatoes. While Cash crops such as ground nuts, rice, yam and sugarcane are produced in large quantities. The famers are also engaged in collection and processing of non-timber forest such as Shea nuts. Major livestock reared in the zones are cattle, sheep, and goats.
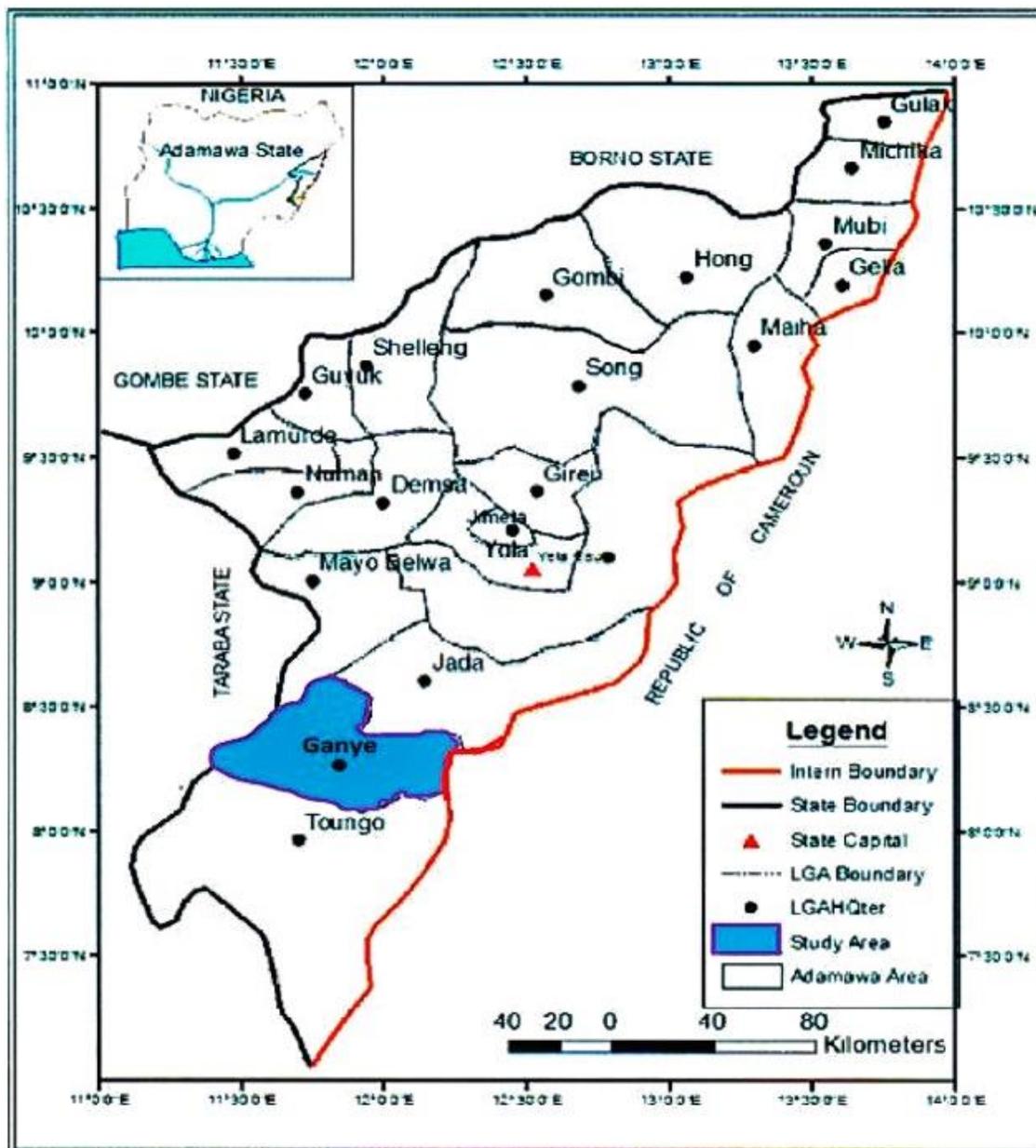
Figure 1: Map of Ganye Local Government Area (Adebayo, 2020)

Sample Collection

Sampling was conducted in the Ganye Local Government Areas of Adamawa State. Maize, groundnut and yam crops with their corresponding soil samples were collected from farmlands at depth of 5cm-10cm during the harvest period in September, 2023. The emphasis was on gathering the edible portions of the crops for analysis, considering the cost and time constraints associated with analysis. A total of twenty (22) samples were collected from farmlands within the study area. Four (4) maize, groundnut and yam samples were collected within Ganye Local Government Areas of Adamawa State with their corresponding soil samples. To ensure proper identification, each of the crops and their corresponding soil samples were carefully packaged in nylon bags and labelled as $MZ_1 - MZ_4$ for maize, GN_1- GN_4 for groundnut and $YM_1 - YM_4$ for yam. The reading and location of these samples are shown in Table 1 and Figure 2 respectively. These points of collection were marked out using a Global Positioning System (GPS).

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Table 1: Samples and Locations for Ganye LGA

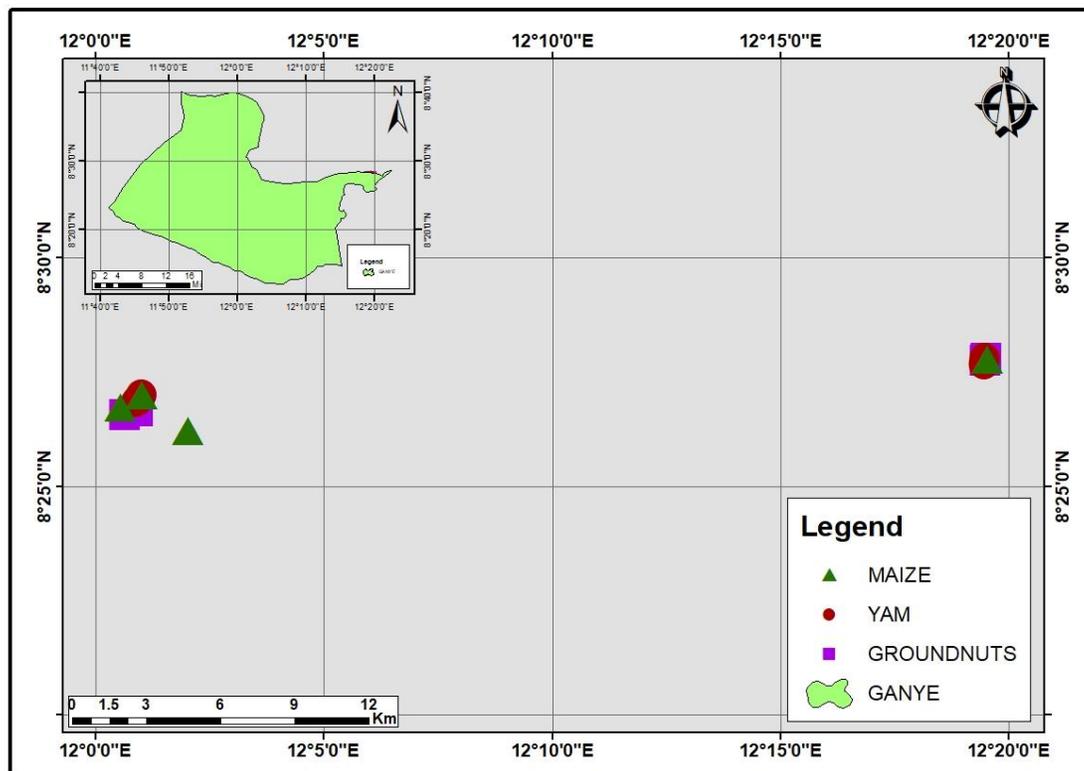| Sample Site	Sample Code	Latitude (N)	Longitude (E)	Elevation(m)
Gangkoen	YM1	08^0 26.850	012^0 00.911	1676
	YM2	080 26.997	012^0 00.997	1699
	MZ1	08^0 26.974	012^0 00.995	1696
	GN1	08^0 26.655	012^0 00.926	1687
Sansiri	MZ2	08^0 26.711	012^0 00.541	1698
	GN2	08^0 26.568	012^0 00.632	1690
Dabora	GN3	08^0 27.530	011^0 59.488	1717
	GN4	08^0 27.478	011^0 59.464	1702
	MZ3	08^0 27.478	011^0 59.495	1715
	YM3	08^0 27.533	011^0 59.454	1720
	YM4	08^0 27.414	011^0 59.447	1699
Santasa	MZ4	08^0 26.209	012^0 02.017	1650

Figure 2: Maize, Groundnut and Yam Sample Locations at Ganye (GIS Map)

Sample Preparation

The outer layer of the maize, groundnut and yam samples were removed and the yam was sliced, these samples (maize, groundnut and yam) were sun-dried until a constant weight was attained. Each sample was crushed using a mortar and pestle and sieved using sieve mesh (2mm), kept in air-tight containers, and sealed. The crushing and sieving were necessary for achieving a homogeneous state of the sample. The samples were later scaled in 100g each in a plastic container for a minimum of 28 days to reach secular equilibrium between radon and its daughter nuclides before radiometric counting.

Soil samples were well mixed after removing extraneous materials such as roots, pieces of stones and gravel. Samples were dried at room temperature for three days until a constant dry weight was obtained. The dried samples were then crushed into powder using a mortar and pestle. After crushing and mixing thoroughly, soil samples were shaken in a sieve shaker using a 2 mm mesh size. The samples were later scaled in 100g each in a plastic container for a minimum of 28 days to reach secular equilibrium between radon and its daughter nuclides before radiometric counting.

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Sample Analysis
The plant and soil samples were analysed using the sodium iodide NaI (Ti) detector to determine activity concentration of radionuclides at LAUTECH Research Institute Ogbomosho, Oyo State, Nigeria.

Calculation of Radiation Hazard Parameters
The evaluation of radiation hazard parameters for natural radionuclides within the environment and food crops will entail the computation of radiation dose and risk indicators. This calculation will provide insights into whether the concentration of natural radionuclides and radiation dose fall within acceptable thresholds. Key risk parameters computed in this research encompass: Absorbed dose rate (D_R), Transfer Factor (TF), Radium Equivalent Activity (Ra_{eq}), Internal radiation hazard index (H_{in}), External radiation hazard index (H_{ex}), Annual Effective Dose Equivalent (AEDE), Excess lifetime cancer risk (ELCR), Gamma Index ($I\gamma$) and Annual Effective Dose due to Ingestion.

Absorbed dose rate (D_R)
The absorbed dose rate for the collected samples is calculated using the equation (1) (Alausa *et al*, 2017).
$$D_R(nGyh^{-1}) = 0.462A_U + 0.604A_{Th} + 0.0417 A_K \quad (1)$$
where, A_U, A_{Th}, and A_k are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K of the samples, respectively, and conversion factors of $0.462 nGyh^{-1}/Bq\cdot kg^{-1}$, $0.604 nGyh^{-1}/Bq\cdot kg^{-1}$ and $0.0417 nGyh^{-1}/Bq\cdot kg^{-1}$ for ^{238}U, ^{232}Th, and ^{40}K respectively (Alausa *et al*, 2017).

Transfer Factor (TF)
The soil to plant transfer factors was determined using equation (2). (Alharbi, 2013)
$$TF = \frac{A_p \,(Bq.kg^{-1})}{A_s \,(Bq.kg^{-1})} \quad (2)$$
where A_p is the activity concentration of radionuclides in plant and A_s is the activity concentration of radionuclides in soil.

Radium Equivalent Activity (Ra_{eq})
Radium equivalent activity is calculated using equation (3) (Ekhaguere *et al*, 2019)
$$Ra_{eq}(Bq/kg) = 0.077 A_k + A_{Ra} + 1.43A_{Th} \quad (3)$$
where A_{Ra} is the activity concentration of ^{226}Ra or ^{238}U in $Bq\cdot kg^{-1}$, ^{238}U and ^{226}Ra produce the same gamma dose, hence their activity concentration can used interchangeably (Ocheje and Tyovenda, 2020), A_{Th} is the activity concentration of ^{232}Th in $Bq\cdot kg^{-1}$ and A_K is the activity concentration of ^{40}K in $Bq\cdot kg^{-1}$.

Internal radiation hazard index (H_{in})
The H_{in} was calculated using the equation (4). (Harb *et al*, 2014)
$$H_{in} = \frac{A_k}{4810} + \frac{A_u}{185} + \frac{A_{Th}}{259} \quad (4)$$

where A_U, A_{Th}, and A_K are the specific activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in $Bq\cdot kg^{-1}$, respectively.

External radiation hazard index (H_{ex})
The external hazard index of electromagnetic (gamma) radiation was estimated using equation (5) (Harb *et al*, 2014).
$$H_{ext} = \frac{A_k}{4810} + \frac{A_u}{370} + \frac{A_{Th}}{259} \quad (5)$$
where A_U, A_{Th}, and A_K are the specific activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in $Bq\cdot kg^{-1}$, respectively.

Annual Effective Dose Equivalent (AEDE)
The outdoor annual effective dose in $mSvy^{-1}$ was calculated using equation (6).
$$AEDE(mSvy^{-1}) = D_R(nGyh^{-1}) \text{x } 8760\, h \text{ x } 0.2 \text{ x } 0.7 \text{ Sv.} G^{-1} \text{ x } 10^{-6} \quad (6)$$
Where D_R ($nGyh^{-1}$) is the absorbed dose rate in air, 8760 is the total hours in a year; 0.7 is the dose conversion factor from absorbed dose in the air to the effective dose and 0.2 is the occupancy factor for outdoor exposure as recommended by UNSCEAR (2000).

Excess lifetime cancer risk (ELCR)
The excess lifetime cancer risk (ELCR) was estimated based on the computed values of AEDE, using the equation (7) (Rafique *et al, 2014*, Taskin, 2009).
ELCR ($mSvy^{-1}$) = AEDE × average duration of life (DL) × risk factor (RF)   (7)
where, AEDE signifies the yearly effective dose equivalent, DL stands for the average duration of life 56.05 years (Macrotrends, 2024), and RF represents the risk coefficient for fatal cancer (0.05 Sv^{-1})

Gamma Index ($I\gamma$)
The gamma representative index associated with ^{238}U, ^{232}Th and ^{40}K in the samples was calculated using the equation (8) (Reda *et al,* 2018).
$$I_\gamma = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (8)$$
where A_U, A_{Th}, and A_k are the concentration of ^{238}U, ^{232}Th and ^{40}K, respectively

Annual Effective Dose due to Ingestion ($H_{T,R}$) :
The annual ingestion dose ($H_{T,R}$) for human was calculated using the equation (9) (Abojassim *et al*, 2014).
$$H_{T,R} = \sum(U^i C_r^i)\, g_{T,r} \quad (9)$$
where, i denotes a food group, U^i and C_r^i denote the activity concentration of the radionuclide r of interest ($Bq\cdot kg^{-1}$) and consumption rate ($kg.y^1$) respectively, and $g_{T,r}$ is the dose conversion coefficient for ingestion of radionuclide r ($Sv\cdot Bq^{-1}$) in tissue T. For adult members of the public, the recommended dose conversion

coefficient r $g_{T,r}$ for ^{40}K, ^{238}U, ^{234}Th are 6.2 × 10–9 Sv·Bq⁻¹, 2.8 × 10⁻⁷ Sv·Bq⁻¹, 2. 2 × 10⁻⁷ Sv·Bq⁻¹ respectively. (Abojassim *et al*, 2014). There are no specific consumption rate data for the study areas and as such adopted the Nigeria mean annual consumption rate per capita values as shown in Table 5 to enable us calculate the effective dose due to intake of the food crops.

Table 2: Consumption rate for different Food Crops (Source: FAOSTAT, 2021)

S/N	Food Crop	Consumption Rate in kg/yr
1	Maize	33.79
2	Yam	88.1
3	Groundnut	9.15

RESULTS AND DISCUSSION

Activity concentration in Maize

The activity concentration of radionuclide (238U, 232Th and 40K) in maize in Ganye Local Government Area of Adamawa State is shown in Table 3.

Table 3: Activity concentration in Maize

Sample Code	^{238}U	^{232}Th	^{40}K
MZ1	25.89±3.79	15.29±0.51	136.26±11.26
MZ2	42.88±4.45	13.78±0.58	141.06±12.70
MZ3	14.78±2.61	14.03±0.37	145.80±13.09
MZ4	16.92±4.76	14.15±0.60	134.08±19.31
Mean	25.12±3.90	14.31±0.52	139.30±14.09
Min	14.78±2.61	13.78±0.58	134.08±19.31
Max	42.88±4.45	15.29±0.51	145.80±13.09

The activity concentration in Maize at Ganye Farm of the radionuclides ranged as shown in Table 3 together with their mean values respectively.

The activity concentration value of ^{40}K is higher than that of ^{238}U and ^{232}Th in the samples owing to the fact that potassium is an essential nutrient required for various physiological processes in plant such as photosynthesis and osmoregulation. Plants actively uptake potassium from soil through their roots, while on the other hand uranium and thorium are non-essential for plant growth hence their uptake by plant is generally low.

The mean activity of ^{238}U, ^{232}Th and ^{40}K in Maize at Ganye were higher than that of activity of maize in Abeoukuta, South Western Nigeria which were reported to be 10.4 ± 3.60 Bq/kg, 11.83 ± 2.59 Bq/kg , 831.92 ± 73.11 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively (Jibiri and Abiodun, 2012). The mean activity of ^{238}U, ^{232}Th and ^{40}K in Maize at Ganye Farm were also higher than the activity of maize in Jalingo, Taraba State, Nigeria with mean values reported as 11.51 ±   2.33 Bq/kg, 12.67 ± 1.50 Bq/kg and 306.17 ± 83.86 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively (Tyovenda *et al*, 2023). The difference between the radionuclide activities may be attributed to variation in the geological composition of the soil, as well as differences in soil properties that influence radionuclide uptake by crops.

Activity Concentration in Groundnut

The activity concentration of radionuclide (^{238}U, ^{232}Th and ^{40}K) in Groundnut at Ganye Local Government Area of Adamawa State is shown in Table 4.

Table 4: Activity Concentration in Groundnut

Sample Code	^{238}U	^{232}Th	^{40}K
GN1	13.09±2.51	15.05±0.36	143.24±7.75
GN2	15.86±2.25	17.49±0.35	123.87±9.29
GN3	12.58±4.11	13.59±0.54	168.13±5.65
GN4	18.62±3.00	14.63±0.43	158.42±9.57
Mean	15.04±2.97	15.19±0.42	148.42±8.07
Min	12.58±4.11	13.59±0.54	123.87±9.29
Max	18.62±3.00	17.49±0.35	168.13±5.65

The activity concentration in Groundnut at Ganye farm of ^{238}U, ^{232}Th, and ^{40}K are ranged as shown in Table 4 together with their mean values respectively. The mean average of ^{232}Th and ^{40}K in the groundnut samples were greater than that of maize samples with exception of ^{238}U. This might be as a result of groundnut being a root crop and grows in the soil hence will have higher concentration of radionuclides than maize.

The measured mean values of ^{238}U, ^{232}Th and ^{40}K for groundnut from Ganye farm were lower than that obtained from Niger Delta region of Nigeria which were 22.73±5.20 Bq/kg, 20.18±5.46 Bq/kg and 84.73±7.10 Bq/kg respectively with exception of ^{40}K. The oil mining

activities going on in this region might contribute to the high concentration of radionuclides (Avwiri *et al*, 2021). It was also higher than the mean activity values from the southwestern part of Nigeria which were 159.77 ± 37.01 Bq/kg, 6.28 ± 1.58 Bq/kg and 12.42 ± 2.40 Bq/kg for ^{40}K, ^{232}Th and ^{226}Ra with exception of ^{232}Th that was lower. (Oladele *et al*, 2023), and this may be due to regional difference in soil composition and farming practices.

Activity Concentration in Yam
The activity concentration of radionuclide (^{238}U, ^{232}Th and ^{40}K) in Yam at Ganye Local Government Area of Adamawa State is shown in Table 5 and Figure 4.

Table 5: Activity concentration in Yam

Sample Code	^{238}U	^{232}Th	^{40}K
YM1	12.95±1.71	2.56±0.25	86.18±4.97
YM2	10.23±1.26	3.81±0.10	83.66±4.24
YM3	14.30±2.82	4.97±0.38	99.18±6.30
YM4	12.99±4.28	4.47±0.57	84.50±4.58
Mean	12.62±2.52	3.95±0.33	88.38±5.02
Min	10.23±1.26	2.56±0.25	83.66±4.24
Max	14.30±2.82	4.97±0.38	99.18±6.30

The activity concentration in Yam at Ganye Farm of the radionuclides as shown in Table 5 together with their mean values respectively. The mean activity of yam samples being a root crop was lower than that of maize that grows outside the soil. These could be due to could be due to differences in soil type, pH, organic matter and other related factor (Ocheje and Tyovenda, 2020).
The mean specific activities of ^{238}U, ^{232}Th and ^{40}K in yam samples at Ganye farm were lower than that obtained from North central Nigeria which were 31.11 ± 4.00, 11.82 ± 0.72, 466.96 ± 27.20 Bqkg^{-1} respectively. (Kolo *et al,* 2021). The mean specific activities of ^{238}U, ^{232}Th

and ^{40}K in yam samples at Ganye farm were all lower than that of the tin mining area in Jos Plateau State, Nigeria which were 85.5 ± 10.2 Bq/kg, 89.8 ± 6.2 Bq/kg and 684.5 ± 40.6 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. This high concentration of radionuclide may be owing to the effect of mining activities. (Jibiri *et al*, 2006).

Activity concentration in Maize Soils
The activity concentration of radionuclide (^{238}U, ^{232}Th and ^{40}K) in Maize soil at Ganye Local Government Area of Adamawa State is shown in Table 6.

Table 6: Activity concentration in Maize Soils

Sample Code	^{238}U	^{232}Th	^{40}K
MZ1	79.58±4.33	56.61±3.16	442.51±23.49
MZ2	71.42±4.10	53.59±3.08	411.55±22.73
MZ3	50.76±2.31	17.68±1.77	333.10±24.31
MZ4	21.07±2.23	18.50±1.81	560.61±18.23
Mean	55.71±3.24	36.60±2.46	436.94±22.19
Min	21.07±2.23	17.68±1.77	333.10±24.31
Max	79.58±4.33	56.61±3.16	560.61±18.23

The activity concentration in maize soil at Ganye Farm of ^{238}U, ^{232}Th and ^{40}K as shown in Table 6 together with their mean values respectively. The mean activity of ^{238}U, ^{232}Th and ^{40}K in maize soil in Ganye Farm were all higher than the recommended value of 35 Bq/kg for ^{238}U, 30 Bq/kg for ^{232}Th and 400 Bq/kg for ^{40}K by UNSCEAR

(Ocheje and Tyovenda, 2020). This high concentration might be from the use of phosphate fertilizer.

Activity Concentration in Groundnut Soils
The activity concentration of radionuclide (^{238}U, ^{232}Th and ^{40}K) in Groundnut soil at Ganye Local Government Area of Adamawa State is shown in Table 7.

Table 7: Activity Concentration in Groundnut Soils

Sample Code	^{238}U	^{232}Th	^{40}K
GN1	35.66±1.93	21.75±1.96	529.28 ±7.64
GN2	92.04±4.66	66.09±3.42	460.44±17.77
GN3	70.04±4.06	55.43±3.13	407.76±20.82
GN4	64.01±5.56	20.31±3.60	498.47±53.14
Mean	65.44±4.05	40.90±3.03	473.99±24.84
Min	35.66±1.93	20.31±3.60	407.76±20.82
Max	92.04±4.66	66.09±3.42	529.28 ±7.64

The activity concentration in Groundnut soil at Ganye Farm of ^{238}U, ^{232}Th and ^{40}Kas shown in Table 7 together with their mean values respectively. The mean activity of ^{238}U, ^{232}Th and ^{40}K in groundnut soil at Ganye Farm were all higher than the recommended value of 35 Bq/kg for ^{238}U, 30 Bq/kg for ^{232}Th and 400 Bq/kg for ^{40}K

(UNSCEAR, 2000). This may be due to the soil type which is rich in clay and organic matter.

Activity Concentration in Yam Soil
The activity concentration of radionuclide (^{238}U, ^{232}Th and ^{40}K) in Yam Soil at Ganye Local Government Areas of Adamawa State is shown in Table 8 and Figure 7.

Table 8: Activity concentration in Yam Soils for Ganye Farm

Sample Code	^{238}U	^{232}Th	^{40}K
YM1	75.78±6.05	24.29±3.94	675.73±42.75
YM2	43.98±4.94	13.77±3.18	357.03±23.13
YM3	48.49±4.84	16.49±3.24	455.68±31.09
YM4	53.19±5.06	17.01±3.29	339.99±18.41
Mean	55.36±5.22	17.89±3.41	457.11±28.85
Min	43.98±4.94	13.77±3.18	339.99±18.41
Max	75.78±6.05	24.29±3.94	675.73±42.75

The activity concentration in Yam Soil at Ganye farm of ^{238}U, ^{232}Th and ^{40}Kas shown in Table 7 together with their mean values respectively. The mean activity concentration of ^{238}U and ^{40}K in yam soil were all higher than the recommended value of 35 Bq/kg for ^{238}U, and 400 Bq/kg for ^{40}K, ^{232}Th fell within the safe limit of 30 Bq/kg. (UNSCEAR, 2000). These result were higher

than the mean activity of ^{238}U, ^{232}Th and ^{40}K in soil from Ishiagu and Ezillo, Ebonyi State Nigeria which were 22.5, 13.7, 141.3 Bq/kg and 15.7, 11.9, 128.2 Bq/kg respectively. (Nduka *et al*, 2022). This attributed due to difference in geological formations and soil types.
Radiological Interpretations

Table 9: Radiological Parameters due to NORM in Maize

Sample Code	D_R (nGyh^{-1})	Ra_{eq} Bq/kg	(H_{in})	(H_{ex})	AEDE mSv/yr	ELCR	I_y
MZ1	26.87838	58.24672	0.22731	0.15734	0.03296	0.09238	0.41634
MZ2	34.01588	73.44702	0.31432	0.19842	0.04172	0.11691	0.51771
MZ3	21.38234	46.0695	0.16437	0.12443	0.02622	0.07349	0.33603
MZ4	21.95478	47.47866	0.17397	0.12824	0.02693	0.07546	0.34369
Mean	26.05785	56.31048	0.21999	0.15211	0.03196	0.08956	0.40344
Min	21.38234	46.0695	0.16437	0.12443	0.02622	0.07349	0.33603
Max	35.81478	77.47866	0.33613	0.20932	0.04392	0.11691	0.54369

Absorbed Dose (D_R)
The radiological assessment of crops cultivated in Ganye Local Government showed that the absorbed dose rate for maize, groundnut, and yam fell well below the global safety benchmark of 58 nGy/h. Specifically, maize recorded absorbed dose values ranging between 21.38 and 34.02 nGy/h with a mean of 26.06 nGy/h, groundnut

recorded between 21.11 and 24.05 nGy/h with a mean of 22.31 nGy/h, while yam recorded values between 10.52 and 12.22 nGy/h with a mean of 11.90 nGy/h. These results indicate that all crops from Ganye produce radiation levels that do not pose any immediate radiological hazard.

Table 10: Radiological Parameters due to NORM in Groundnut for Ganye Farm

Sample Code	D_R (nG_yh^{-1})	Raeq (Bq/kg)	(Hin)	(Hex)	AEDE (mSv/yr)	ELCR	I_y
GN1	21.11089	45.64098	0.158644	0.123266	0.02589	0.07256	0.33326
GN2	23.05666	50.40869	0.179011	0.136146	0.028277	0.07925	0.363213
GN3	21.03134	44.95971	0.155425	0.121425	0.025793	0.07228	0.331853
GN4	24.04507	51.73924	0.190071	0.139746	0.029489	0.08264	0.376047
Mean	22.31099	48.18716	0.170788	0.130146	0.027362	0.07668	0.351093
Min	21.11089	44.95971	0.155425	0.121425	0.025793	0.07228	0.331853
Max	24.04507	51.73924	0.190071	0.139746	0.029489	0.08264	0.376047

Radium Equivalent Activity (Ra$_{eq}$)

The radium equivalent activity (Raeq) for all crops in Ganye was also below the international limit of 370 Bq/kg. Maize samples showed values between 46.07 and 77.48 Bq/kg with a mean of 56.31 Bq/kg, groundnut ranged from 44.96 to 51.74 Bq/kg with a mean of 48.19 Bq/kg, while yam values fell between 22.12 and 29.04 Bq/kg with a mean of 25.07 Bq/kg. These findings confirm that the radiological content of these crops is within safe limits for consumption and agricultural use.

Table 11: Radiological Parameters due to NORM in Yam for Ganye Farm

Sample Code	D_R (nG_yh^{-1})	Raeq (Bq/kg)	(Hin)	(Hex)	AEDE (mSv/yr)	ELCR	I_y
YM1	11.12285	23.24666	0.097801	0.062801	0.013641	0.03823	0.169387
YM2	10.51612	22.12012	0.087401	0.059752	0.012897	0.03614	0.162073
YM3	13.74429	29.04396	0.117106	0.078457	0.016856	0.04724	0.211153
YM4	12.22491	25.8886	0.105042	0.069934	0.014993	0.04202	0.187633
Mean	11.90204	25.07484	0.101838	0.067736	0.014597	0.04091	0.182562
Min	10.51612	22.12012	0.087401	0.059752	0.012897	0.03614	0.162073
Max	12.22491	29.04396	0.117106	0.078457	0.016856	0.04724	0.211153

Internal Radiation Hazard (H$_{in}$)

The internal hazard index (Hin) values for Ganye crops were all below the maximum recommended value of 1. Maize exhibited Hin values ranging from 0.164 to 0.336 with a mean of 0.220, groundnut values ranged from 0.155 to 0.190 with a mean of 0.171, and yam ranged from 0.087 to 0.117 with a mean of 0.102. These results indicate that internal exposure risks associated with radionuclides in these crops remain negligible.

External Radiation Hazard (H$_{ex}$)

Similarly, the external hazard index (Hex) for all crop samples was below unity, further confirming their safety. The Hex values for maize ranged from 0.124 to 0.198 with a mean of 0.152, for groundnut ranged from 0.121 to 0.140 with a mean of 0.130, and for yam ranged from 0.060 to 0.078 with a mean of 0.068. These values fall within acceptable limits, suggesting that external radiation hazards from these crops are minimal.

Annual effective dose equivalent (AEDE)

The annual effective dose equivalent (AEDE) for the crops in Ganye also complied with international safety limits. Maize showed AEDE values between 0.02622 and 0.04392 mSv/yr with a mean of 0.03196 mSv/yr, groundnut ranged from 0.02579 to 0.02949 mSv/yr with a mean of 0.02736 mSv/yr, while yam values ranged from 0.01290 to 0.01686 mSv/yr with a mean of 0.01460 mSv/yr. These values are well below the recommended limit of 1 mSv/yr, indicating that ingestion of these crops contributes minimally to annual radiation exposure.

Excess lifetime cancer risk (ELCR)

However, the excess lifetime cancer risk (ELCR) for crops in Ganye exceeded the recommended safety threshold of 1.0×10^{-6} to 1.0×10^{-4} (USEPA, 1991). Maize showed ELCR values between 0.07349 and 0.11691 with a mean of 0.08956, groundnut ranged from 0.07228 to 0.08264 with a mean of 0.07668, and yam ranged from 0.03614 to 0.04724 with a mean of 0.04091. Although these values are above the global guideline, they represent long-term risks and do not imply immediate health concerns.

Gamma Index (Iγ)

The gamma index (Iγ) for maize, groundnut, and yam samples from Ganye remained below the acceptable limit of 1, confirming environmental safety with respect to gamma emissions. Maize exhibited gamma index values between 0.336 and 0.544 with a mean of 0.403, groundnut ranged from 0.332 to 0.376 with a mean of 0.351, and yam values ranged from 0.162 to 0.211 with a mean of 0.183.

Transfer Factor
Table 12: Maize transfer Factor

Sample code	^{238}U	^{232}Th	^{40}K
MZ1	0.325333	0.270094	0.307925
MZ2	0.600392	0.257138	0.342753
MZ3	0.291174	0.793552	0.437706
MZ4	0.803037	0.764865	0.239168
Mean	0.504984	0.521412	0.331888
Min	0.291174	0.257138	0.239168
Max	0.600392	0.793552	0.437706

Table 13: Groundnut transfer Factor

Sample code	^{238}U	^{232}Th	^{40}K
GN1	0.367078	0.691954	0.270632
GN2	0.172316	0.264639	0.269025
GN3	0.179612	0.245174	0.412326
GN4	0.290892	0.720335	0.317813
Mean	0.252475	0.480526	0.317449
Min	0.172316	0.245174	0.269025
Max	0.367078	0.720335	0.412326

Table 14: Yam transfer Factor, Ganye Farm

Sample code	^{238}U	^{232}Th	^{40}K
YM1	0.170889	0.105393	0.127536
YM2	0.232606	0.276688	0.234322
YM3	0.294906	0.301395	0.217653
YM4	0.244219	0.262787	0.248537
Mean	0.235655	0.236566	0.207012
Min	0.170889	0.105393	0.127536
Max	0.294906	0.301395	0.248537

The transfer factor (TF) results for maize, groundnut and yam as shown from Tables 12, 13 and 14 further demonstrate that the movement of radionuclides from soil to crops in Ganye is generally low. For maize, TF values ranged from 0.291 to 0.803 for 238U, 0.257 to 0.794 for 232Th, and 0.239 to 0.438 for 40K, all with mean values well below unity. Groundnut samples showed TF ranges of 0.172 to 0.367 for 238U, 0.245 to 0.720 for 232Th, and 0.269 to 0.412 for 40K, while yam samples ranged from 0.171 to 0.295 for 238U, 0.105 to 0.301 for 232Th, and 0.128 to 0.249 for 40K. These values being below unity indicate that radionuclide uptake by the crops is minimal and poses no threat to consumers.

Annual Effective Dose due to Ingestion
The values for the Annual Effective dose due to ingestion for maize, groundnut and yam were shown in Table 15.

Table 15: Annual Effective Dose due to ingestion of Maize, Yam and Groundnut

Sample Code	Annual Effective Dose (mSv/yr)	Sample Code	Annual Effective Dose (mSv/yr)	Sample Code	Annual Effective Dose (mSv/yr)
MZ1	0.000387159	GN1	7.19582E-05	YM1	0.000416142
MZ2	0.000537686	GN2	8.28678E-05	YM2	0.000371896
MZ3	0.000274678	GN3	6.91246E-05	YM3	0.000503255
MZ4	0.000293361	GN4	8.61418E-05	YM4	0.00045323
Mean	0.000373221	Mean	7.75231E-05	Mean	0.000436131
Min	0.000274678	Min	6.91246E-05	Min	0.000371896
Max	0.000537686	Max	8.61418E-05	Max	0.000503255

The annual effective dose due to ingestion in Ganye remained below the international limit of 1 mSv/yr for all crops. For maize, ingestion dose values ranged from 0.000274678 to 0.000537686 mSv/yr with a mean of 0.000373221 mSv/yr. Groundnut showed ingestion doses between 6.91×10^{-5} and 8.61×10^{-5} mSv/yr with a mean of

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7.75×10⁻⁵ mSv/yr, while yam values ranged from 0.000371896 to 0.000503255 mSv/yr with a mean of 0.000436131 mSv/yr. These findings confirm that ingestion-related radiation exposure from these crops is extremely low and within safe limits of 1mSv/yr (UNSCEAR, 2000).

CONCLUSION

The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in maize, groundnut and yam samples from Ganye were significantly lower than those found in the corresponding soil. This indicates that the soil in Ganye may pose a radiological risk. Although most hazard parameters were below their standard limits, the Excess Lifetime Cancer Risk (ELCR) exceeded the recommended safety level, suggesting a potential cancer risk from long-term consumption of crops grown in the area. The results also confirm that radionuclide transfer factors are not linearly dependent on soil concentrations, meaning that while transfer to crops is generally low, lifetime consumption can still contribute to cancer risk. In this area farmers are advice to adopt soil management practices that reduce radionuclide availability such as maintaining optimal soil pH, increasing organic matter content, and using fertilizer judiciously.

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