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Original Research Article

Radiological Assessments of Farm Soil and Yam Tubers Grown in Ika North East Local Government Area of Delta State, Nigeria

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KEYWORDS

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Radiological health risk.

ABSTRACT

^{40}K, ^{238}U and ^{232}Th are natural radionuclides found in soil and may migrate into plants through their root. Yam is a food crop that is commonly produced and widely ingested in the study area. Therefore, it is important to assess the concentration levels of soil and yam radionuclides in order to evaluate the associated radiological risk factors. This study evaluated the activity concentration, transfer factor, and radiological risk associated with natural radionuclides in farm soils and yam tubers cultivated in Ika North East Local Government Area, Delta State, Nigeria. Ten soil and ten yam samples were collected from selected farms and analyzed using a NaI(Tl) gamma-ray spectrometry system. The activity concentrations of ^{40}K, ^{238}U and ^{232}Th were determined along with the estimation of transfer factors (TFs), absorbed dose rate, annual effective dose, ingestion dose, and excess lifetime cancer risk (ELCR) associated with studied samples. The mean activity concentrations in soil were 353.75 ± 4.43, 4.01 ± 0.08, and 1.95± 0.05 Bq kg^{-1} for ^{40}K, ^{238}U, and ^{232}Th, respectively, while the corresponding mean values in the yam sample were 366.04 ± 4.38, 4.57 ± 0.07, and 1.64 ± 0.05 Bq kg^{-1}. The radionuclide concentrations is in order of $^{40}K > ^{238}U > ^{232}Th$ in both soil and yam samples. Mean transfer factors were 1.05, 1.20, and 0.96 for ^{40}K, ^{238}U, and ^{232}Th, respectively, indicating appreciable soil-to-yam transfer. The mean absorbed dose rate and outdoor annual effective dose were 19.38 nGy h^{-1} and 21.42 μSv y^{-1}, respectively, both were below the recommended global averages. The mean annual ingestion dose from yam consumption was 0.21 mSv y^{-1}, which is below the public dose limit of 1 mSv y^{-1}. However, the mean excess lifetime cancer risk was 1.38 × 10^{-3}, which is higher than the recommended value of 0.29 × 10^{-3}. The study concludes that although most of the current external and ingestion radiation doses are within acceptable limits, continuous monitoring of radionuclide levels in yam and agricultural soils is necessary to minimize potential long-term radiological health risks.

CITATION

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INTRODUCTION

Natural radionuclides are radioactive elements that are naturally found in rocks, soils, water, and air. The major naturally occurring radionuclides present in soils are ^{238}U, ^{232}Th, ^{226}Ra, and ^{40}K. These radionuclides are products of geological formations and weathering processes, which may be enhanced in the environment through natural and artificial activities such as mining, oil exploration, industrial activities, and fertilizer application (Adesiji and Ademola, 2019). Fertilizer is applied to crops to improve crop yield and can cause redistribution of soil radionuclides at trace level, making it a source of soil radioactivity (Ononugbo, 2019). Farm soils act as reservoir of natural radionuclides, which move into crops that are grown on such soils through their roots system. This soil to crop uptake of radionuclides commonly referred as transfer factor (TF), represents the ratio of radionuclide concentration in the plant to that in the soil. Transfer factor is used in environmental radioactivity studies and radiological risk assessment since they are used in estimating the potential radiation dose which humans receive through food ingestion (Bello et al., 2025).

While soil radioactivity levels can show the degree of contamination in food crops, it cannot be used to describe the health implications associate with ingestion of the contaminated food. Hence dose estimation is usually carried out to determine the health risk for persons exposed to radiation through food intake. The concentrations of radionuclide that enter man through food ingestions is proportional to the level of concentration of radionuclide in food and the food consumption rates (Ononugbo et al., 2016; Ononugbo et al., 2019). Radionuclides in the body deliver doses to the body and therefore determine the risk associated with radionuclide ingestion (Long et al., 2017).

Humans are constantly exposed to ionizing radiations when they consume crops such as yam. These natural radionuclides in the crops release radiation when they disintegrate and contribute to total absorbed dose (Ode and Agee, 2022). The presence and accumulation of these radionuclides in the body can lead to health conditions such as sterility, weakening of the immune system, cancer and increase in mortality rate. Therefore, it is pertinent to know the level of radiation exposure mankind is exposed to and evaluate its risk impacts to him (Ononugbo et al., 2019).

Yam is a staple food in Nigeria (Kolo *et al,* 2023) and a major source of carbohydrate. In Nigeria, the government has developed strong desire towards yam production, processing and exportation in order to boost forest exchange earnings (Kolo *et al.,* 2023). Different types of yam are grown in Nigeria, including white yam (*Discorea rotundata*) and water yam (*Discorea alata*). White yam is the most commonly grown variety in the country (Adeleke and Ojediran, 2019). Its production faces problem of pests and diseases, limited access to improved seed and technology, and inadequate storage facility. These constraints negatively affect its productivity, quality and marketability (Adekiya and Aboyeji, 2021). The crop is also widely grown in Delta State, including Ika North East. Since it has direct contact with soil during growth, yam may easily absorb natural radionuclides present in the soils. Consistent consumption of the radionuclide contaminated yam by man may therefore expose him to internal radiation hazards over time. (Adesiji and Ademola, 2019)

Ika North East is predominantly a rural region where yam production is a major economic activity. The area is characterized by fertile agricultural lands and favorable climatic conditions suitable for large yam crop production. However, the geological nature of the soil, coupled with agricultural related practices such as fertilization application and possible oil-related activities in the area, may lead to enhanced levels of natural radionuclides in the study area (Ononugbo, 2019).

Several studies have investigated radionuclide contents in soil and food crops in Nigeria and other parts of the world. Adesiji and Ademola (2019) studied the transfer factors of ^{238}U and ^{232}Th from soil to cassava plants in mining-impacted soils in Nigeria. The study reported that cassava leaves generally accumulated higher radionuclide concentrations than stems and tubers. The researchers also observed that transfer factors varied depending on soil composition and contamination levels.

Bello et al. (2025) investigated soil-to-cassava transfer factors of radionuclides around a cement factory in Kogi State, Nigeria. The study reported average transfer factors of 0.428 for ^^{226}Ra, 0.531 for ^{232}Th, and 0.398 for ^{40}K. The researchers concluded that the radionuclide transfer levels were below international safety limits and of radiological threat to the public for now.

Adebayo et al. (2026) evaluated the transfer of natural radionuclides from soil to crops including yam in southwestern Nigeria. The study emphasized the scarcity of transfer factor data for tropical ecosystems in Africa and highlighted the importance of environmental radioactivity studies in food crops commonly consumed by local populations.

A study carried outby Adesiji and Ademola, 2019in Ondo State, Nigeria, investigated the activity concentrations and transfer of ^{226}Ra, ^{232}Th, and ^{40}K from soil to crops such as yam. They observed measurable radionuclide transfer from soil to crops and concluded that ^{40}K generally showed comparable higher activity concentrations to other radionuclides.

Although several studies have been conducted on radionuclide transfer in agricultural produce in Nigeria, there is still limited published information specifically concerning the transfer of natural radionuclides from soil to yam in Ika North East. Therefore, the study seeks to determine the radionuclide concentrations in soil and yam samples, evaluate transfer factors, and assess possible radiological implications associated with the consumption of yam grown in the study area

MATERIALS AND METHODS

Study Area

Ika North East is a Local Government Areas in Delta State, located in the south-southern region of Nigeria, with headquarters at Owa-Oyibu. The LGA land area size of about 463 km^2 with a population of approximately 183,657 according to the 2006 national census, with more recent projections indicating significant population growth.

The people of Ika North East are predominantly Christians with Ika, which is closely related to the Igbo language, as their main language that is widely spoken in the area. The area has a rich culture and is known for traditional festivals such as the Iwa-Ji (New Yam Festival), which reflects the agricultural lifestyle of the people.

Agriculture is the major occupation of the inhabitants of Ika North East. The fertile soils and favorable climatic conditions support the cultivation of crops such as cassava, yam, maize, oil palm, and vegetables. Farming activities are largely practiced, though at small-scale commercial levels, this makes the study area an important agricultural zone. Ika North East experiences tropical climatic conditions characterized by wet and dry seasons, with relatively high annual rainfall and average temperatures suitable for crops production.

The Local Government Area contains several farming and residential communities including Otolokpo, Mbiri, Umunede, Owa-Alero, Owa-Ofie, Owa-Oyibu, Owanta, and Ute-Uremo. These, among other studied sampling farms and their geographical coordinates are shown in Figure 1.

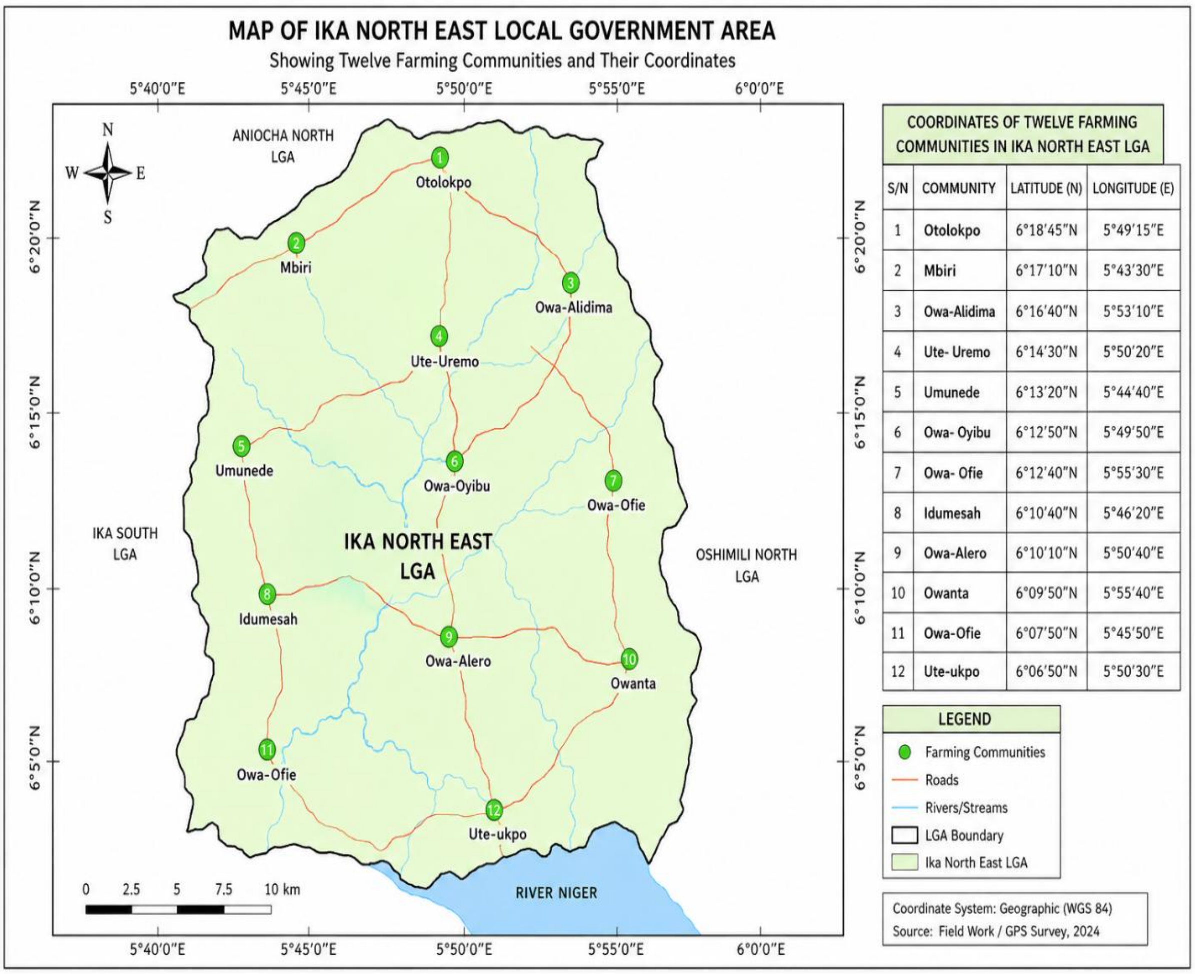

Figure 1: Geological map of the study area and their coordinates

Samples Collection and Preparation

Ten yam samples and ten soil samples were collected from ten selected farms located across ten farming communities in Ika North East Local Government Area for this study. Each sampling farm was assigned a sampling code represented by the word Farm 1 for ease of identification, where Farm1 denotes the first farm, Farm 2 the second farm, and so on.

At each sampling farm, seven yam tubers were randomly selected and were thoroughly washed with distilled water to remove soil particles and other contaminants. Since the edible part was required for analysis, the tubers were peeled and sliced into smaller pieces. Equal portions were taken from each of the seven yam tubers to ensure that no single yam sample disproportionately influenced the overall composition of the final sample. This helped to enhance the representativeness of the samples. The portions obtained were then combined in a clean container to produce a representative composite sample for each farm. The composite yam samples were oven-dried and grounded into fine powder form.

The ten farms selected across the ten farming communities were considered to be enough generating representative baseline data on radionuclide distribution within the region. The sampling was done to ensure adequate spatial coverage of communities actively involved in the farming of yam in the study area.

Soil samples were collected directly from the locations where the yam tubers were uprooted using a stainless-steel auger. The soil obtained from each sampling point was thoroughly mixed in equal proportion to produce a representative composite sample for each farm, thereby reducing variability arising from heterogeneous soil composition. Stones, roots, and plant debris were removed before the soil samples were crushed and ground into powder form. The powdered soil samples were sieved using a 2 mm mesh sieve to achieve homogeneity and then sun-dried for fourteen days to attain constant mass and eliminate residual moisture.

Each prepared and soil sample was weighed to 200 g and sealed in a plastic container. The samples were stored undisturbed for approximately 28 days to establish secular equilibrium between ^{226}Ra and its short-lived decay products, particularly ^{214}Pb (351.9 keV) and ^{214}Bi (609.3 keV), which served as proxy gamma emitters for the quantification of ^{226}Ra. This process ensured accurate determination of radionuclides associated with the ^{238}U and ^{232}Th decay series.

Radioactivity Measurement

The prepared samples were analyzed using a thallium-activated Sodium Iodide detector, NaI(Tl), coupled to a multichannel analyzer (MCA) for gamma spectral acquisition. The detector assembly was adequately shielded with thick lead on the sides and top, lined internally with 1 mm cadmium and 1 mm copper sheets to reduce effect of background ionizing radiation within the laboratory environment. The detector possessed an energy resolution of 2.0 and an efficiency of 33% at the 1.33 MeV gamma-ray peak of ^{60}Co. The Standard International Atomic Energy Agency (IAEA) was used for the calibration of the detector as explain by Orosun and Lawal (2016). A counting time of 36,000 seconds was adopted in order to reduce statistical counting errors. Throughout the analysis, the sample geometry and detector configuration were kept constant in accordance with the procedure described by Alausa and Ogunsanwo (2019).

The detector measured radionuclide activity concentrations based on their characteristic gamma-ray energies (Doung et al., 2020). The gamma-ray peak at 1460 keV was used for the determination of ^{40}K, while the 1764.5 keV peak of ^{214}Bi was used for estimating ^{238}U activity concentration. Similarly, the 583.9 keV gamma peak of ^{208}Tl was employed for the determination of ^{232}Th. These characteristic photopeaks formed the basis for evaluating radionuclide activity levels in the samples.

For the measurement procedure, each sealed sample container was placed on the detector inside the lead shielding and counted for 36,000 seconds to obtain reliable statistical accuracy. Background radiation counts were also measured under identical experimental conditions using an empty sealed container of the same dimension as those containing the samples and the resulting background counts were subtracted from the sample counts. To reduce uncertainty associated with sample measurements and ensure reliability the measurement of the sample was done twice and background correction was strictly maintained. The activity concentration of radionuclides, expressed in Bqkg^{-1}, was calculated using the relation provided by Alausa et al. (2017):

$$C\left(\frac{\mathrm{Bq}}{\mathrm{Kg}}\right) = \frac{\mathrm{C_n}}{\varepsilon \mathrm{P_{Y}} \mathrm{M_S}} \quad (1)$$

where C_n represents the count rate under the corresponding photopeak is, P_y is the absolute transition probability of the specific gamma ray, ε is the detection efficiency at the energy line; M_s is the mass of the sample.

The gamma ray detection system's detection limit DL refers to the ability of the detector to operate without the influence of the sample (Naven and Ilori, 2024). The detection limit estimates the minimum detection level for appropriate determination of radionuclides in the studied samples, this was obtained using the relation (Ilori and Chetty, 2021; Naven and Ilori, 2024).

$$D_L\ (\mathrm{Bqkg})^{-1} = \frac{F\sqrt{B}}{E.T.m.T_y} \quad (2)$$

Where F is the factor which converts counting per seconds to Bq given as 1.96 at 95 % confidence level, B is the net background count rate at the region of interest of radionuclide of interest, E is the counting photo-peak efficiency, T is the measurement time in seconds, m is the mass of the studied sample in Kg. T_y is the probability of gamma emission.

Activity Concentrations in Soil and Cassava Samples

The results of the measured activity concentrations of the detected radionuclides in the soil and the yam samples from the studied area along with their uncertainties are presented in Table 1 and Table 2 respectively. The results show that in all the samples measured, the value of the activity concentrations of ^{40}K was tremendously higher than the values of the activity concentrations of ^{238}U and ^{232}Th. This comparatively higher value of ^{40}K is in trend with most studies. The relatively high concentrations of ^{40}K observed in the soil and yam samples may be attributed to the natural abundance of potassium-bearing minerals in the soil. Since plants largely depend on essential nutrient such as potassium for their healthy growth and production, large quantity of it moved into the yam crop to facilitate food development in their root tubers (Emumejaye, 2015; Alausa and Ogunsanwo, 2019). The radionuclide abundance in the samples followed the pattern: ^{40}K > ^{238}U > ^{232}Th. Figures 2 and 3 show the distribution ^{40}K, ^{238}U and ^{232}Th in the soil and yam samples. The results in Table 1 show the activity concentrations of naturally occurring radionuclides (^{40}K, ^{238}U, and ^{232}Th) measured in soil samples collected from ten farms in the study area. The activity concentration of ^{40}K ranged from 278.27 ± 4.73 Bqkg^{-1}to 425.27 ± 4.43 Bqkg^{-1} in, with an average value of 353.75 ± 4.43 Bqkg^{-1}.The mean value obtained for ^{40}K was slightly higher than the global value of 420 Bq/kg for natural soils reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The activity concentration of ^{238}U varied between 3.26 ± 0.08 Bqkg^{-1} and 5.54 ± 0.10 Bqkg^{-1}, with a mean value of 4.01 ± 0.08 Bqkg^{-1}. The study shows low ^{238}U concentration, indicating moderate uranium presence in the soils of the study area. The observed variations of ^{238}U across the studied farms may be due to geological formations, soil texture, organic matter content, and possible farming activities. The overall mean value remains relatively low compared to world recommended limits of 30 Bqkg^{-1} for agricultural soils. The activity concentration of ^{232}Th ranged from 1.13 ± 0.04 Bqkg^{-1} to 3.99 ± 0.07 Bqkg^{-1}, with a mean value of 1.95 ±0.05 Bqkg^{-1}.The highest ^{232}Th concentration was found in Farm 7 and this is attributed to localized thorium-bearing minerals such as clay (Ononugbo, 2019) within this farm soil location. However, the average activity concentration of ^{232}Th in the studied farms was still within acceptable limit of 35 Bqkg^{-1}. Except for ^{40}K, the mean activity concentrations of ^{238}U and ^{232}Th from the study area were significantly lower than the values of 34.90 ± 12.91 for ^{238}U and 13.54 ± 4.30 for ^{232}Th reported by Alausa and Ogunsanwo, (2019).

With the exception of ^{232}Th, the radionuclide concentrations of ^{40}K and ^{238}U in yam samples were higher than their corresponding values in the soil samples. ^{40}K varied from 326.00 ± 4.68 to 407.39 ± 4.32, with a mean value of 366.04±4.38. The activity concentration of ^{238}U ranged from 2.63 ± 0.06 to 9.66±0.13, with mean value of 4.57 ± 0.07. ^{232}Th varied from 1.26± 0.04 to 2.05 ± 0.05 Bqkg^{-1} with mean value of 1.64 ± 0.05. The similarity between the present findings and previous Nigerian studies shows that the measured natural radionuclide concentrations are largely controlled by natural geological conditions and agricultural practices, particularly fertilizer application

Risk Parameters associated with the Farm Soil

Absorbed dose rate (D_R).

The absorbed dose rate is the amount of energy deposited by ionising radiation per unit mass in a medium. This was calculated by using the conversion factor of 0.462, 0.604 and 0.0417 for ^{238}U, ^{232}Th and ^{40}K respectively as in equation 3.7 (Popoola *et al.,* 2019).

$$D_{\mathrm{R}} = 0.462A_{\mathrm{U}} + 0.604A_{\mathrm{Th}} + 0.0417A_{\mathrm{K}} \quad (3)$$

where A_U, A_{Th} and A_K are the activity concentration of ^{238}U, ^{232}Th and ^{40}K respectively.

The computed value of the absorbed dose rate varied from 14.73 to 33.22 nGy h^{-1}, with a mean value of 19.38 nGy h^{-1}. The global permissible limit of absorbed dose rate is approximately 59 nGy h^{-1} according to UNSCEAR, making the mean dose rate obtained in this study significantly less than half the global average. This showed that external gamma exposure from naturally occurring radionuclides in the study area is relatively low and does not pose major radiological hazard to the public.

Outdoor annual effective dose (AED) in soil samples

The Annual effective dose is the measure of radiation risk relative to the air absorbed dose rate, which represents the dose quantity of the stochastic health impact of low-level radiation on human tissue, which was determined using the following relations (Popoola *et al.,* 2019)

$$\text{Outdoor AED } (\mu\text{Svy}^{-1}) = D_R\ (\text{nGyh}^{-1}) \times 8760\ (\text{hy}^{-1}) \times 0.7 (\text{SvGy}^{-1}) \times 0.2\times10^{-3} \quad (4)$$

Where AED is the annual effective dose inμSvy^{-1}, D_R is the dose rate in nGyh^{-1}, the constant 0.7 (SvGy^{-1}) is the conversion coefficient from the absorbed dose in the air to the effective dose received by adult, or is the conversion factor which converts Gy to Sv. It represents the biological effectiveness of the dose to cause damage to human tissue. 0.2 is the outdoor occupancy factor (since it is assumed that people spent 20 % of their time outside the house on the average (Bai *et al.,* 2017; Alausa, 2020).

The value of the outdoor annual effective dose ranged from 17.28 to 25.00 µSv y^{-1}, with a mean value of 21.42 µSv y^{-1}. The obtained mean value is considerably lower than the world average value of 1 mSv y^{-1}, therefore that farmers working on those farms receive relatively low external radiation exposure from the soil radionuclides

Risk Parameters due to the Ingestion of Yam

The ingestion dose due to consumption of yam

The ingestion was calculated using the equation 5 (Alausa and Ogunsanwo, 2019).

$$\text{AEDE} = \sum (U^{i} \times C_r^{i})\ g \quad (5)$$

U^i is the consumption rate per year, C_r^i, the activity concentration of the radionuclide and g is the dose coefficient for ingestion of radionuclide. The values for g in $SvBq^{-1}$ for ^{40}K is 5.9×10^{-9}, ^{238}U is 4.8×10^{-8} and ^{232}Th is 2.3×10^{-7} for adult member of the public (Alausa and Ogunsanwo, 2019). The Σ is the summation for all the radionuclides under consideration in the sample (Essien *et al.,* 2021). According to Alausa (2012) the food annual consumption rate statistics used for the different food crops in Nigeria, got from Food Agriculture of Organisation (FAO, 2006) at the Federal Office of Statistics (FOS) shows that yam consumption rate annually 75.5 (Alausa, 2012).

The mean annual ingestion dose due to ingestion of yam was 0.21Sv y^{-1}, with individual farm values ranging from0.17 to 0.24 mSv y^{-1}. This value remains below the public dose limit of 1 mSv y^{-1} recommended by the International Commission on Radiological Protection (ICRP). Therefore, consumption of yam from the study area is not likely to pose significant radiological health risk

Excess life cancer risk due to consumption of yam (ELCR)

The excess life cancer risks due to ingestion of the yam crop was calculated using the relation

$$ELCR = \Sigma r_i A_i CT \quad (6)$$

where r_i is the cancer risk coefficient for the ith radionuclide with r = 9.56×10^{-9} $Bqkg^{-i}$ for ^{238}U, r = 2.45×10^{-9} $Bqkg^{-i}$ for ^{232}Th and 5.89×10^{-10} $Bqkg^{-i}$ for ^{40}K, A_i is the activity concentration of the ith radionuclide, C is the food consumption rate which is equal 75.5 and T is the average life expectancy according to (FAO, 2006) obtained from Federal Office of Statistics (FOS) which is 70 years in Nigeria (Poopola et al., 2019).

The calculated mean values of excess lifetime cancer risk of cassava cultivated in the study area ranged from 1.14×10^{-3} to 1.77×10^{-3} with obtained mean cancer risk value of:1.38×10^{-3}. The mean value is above the global permissible radiological cancer risk of 0.29×10^{-3}. Therefore, long-term consumption of yam from the studied farms may contribute to a slightly elevated lifetime cancer risk. There is, therefore, need for continuous monitoring of food crops grown in this area.

Table 1: Activity concentration of the natural radionuclides, absorbed dose and effective dose in the soil samples

Farm Number	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	D ($nGhy^{-1}$)	Outdoor AED (μSvy^{-1})
1	425.96±4.43	3.93±0.08	1.29±0.04	20.36	24.97
2	365.51±4.66	5.54±0.10	2.59±0.06	19.37	23.75
3	332.89±3.86	4.93±0.08	1.86±0.05	33.22	17.28
4	400.43±4.28	3.26±0.08	1.13±0.04	18.89	23.16
5	278.27±4.73	3.55±0.08	3.99±0.07	15.66	19.20
6	335.27±4.42	3.85±0.08	1.74±0.05	16.81	20.62
7	415.72±4.62	4.22±0.07	1.82±0.04	20.38	25.00
8	352.23±4.85	3.48±0.08	1.64±0.04	17.29	21.20
9	342.89±3.75	3.83±0.08	1.65±0.06	17.06	20.92
10	288.27±4.65	3.53±0.08	1.79±0.07	14.73	18.07
MEAN	**353.75±4.43**	**4.01± 0.08**	**1.95± 0.05**	**19.38**	**21.42**

Table 2: Activity concentrations of natural radionuclides, ingestion dose and excess cancer risks in yam samples

Farm Number	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	Ingestion dose ($mSvy^{-1}$)	Cancer risk (× 10^{-3}
1	352.85±4.59	3.54±0.08	2.09±0.05	0.21	1.30
2	378.56±4.15	2.63±0.06	1.26±0.04	0.20	1.32
3	401.11±4.29	5.68±2.68	1.82±0.05	0.23	1.55
4	407.39±4.32	9.66±0.13	1.43±0.04	0.24	1.77
5	306.00±4.88	3.54±3.54	1.29±0.04	0.17	1.14
6	327.54±3.85	4.42±0.09	1.73±0.05	0.19	1.26
7	387.85±4.28	4.17±0.08	1.32±0.04	0.21	1.40
8	372.86±4.58	4.05±0.06	2.05±0.05	0.22	1.38
9	400.21±4.22	4.52±0.07	1.87±0.05	0.23	1.49
10	326.00±4.68	3.48±0.08	1.49±0.04	0.18	1.20
MEAN	**366.04±4.38**	**4.57±0.07**	**1.64±0.05**	**0.21**	**1.38**

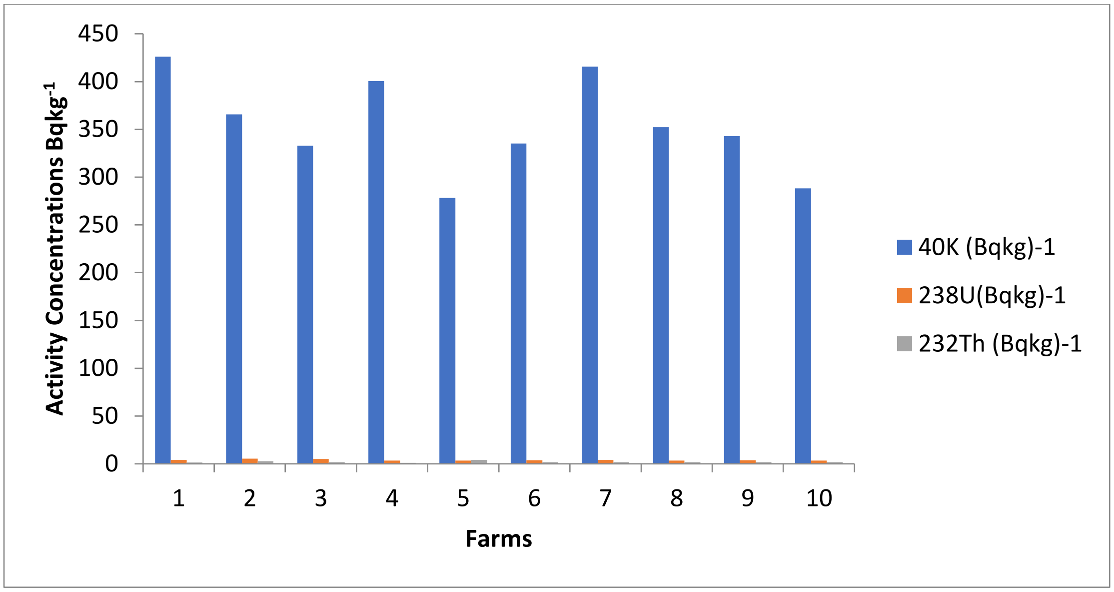

Figure 2: Distribution of radionuclides in soils samples

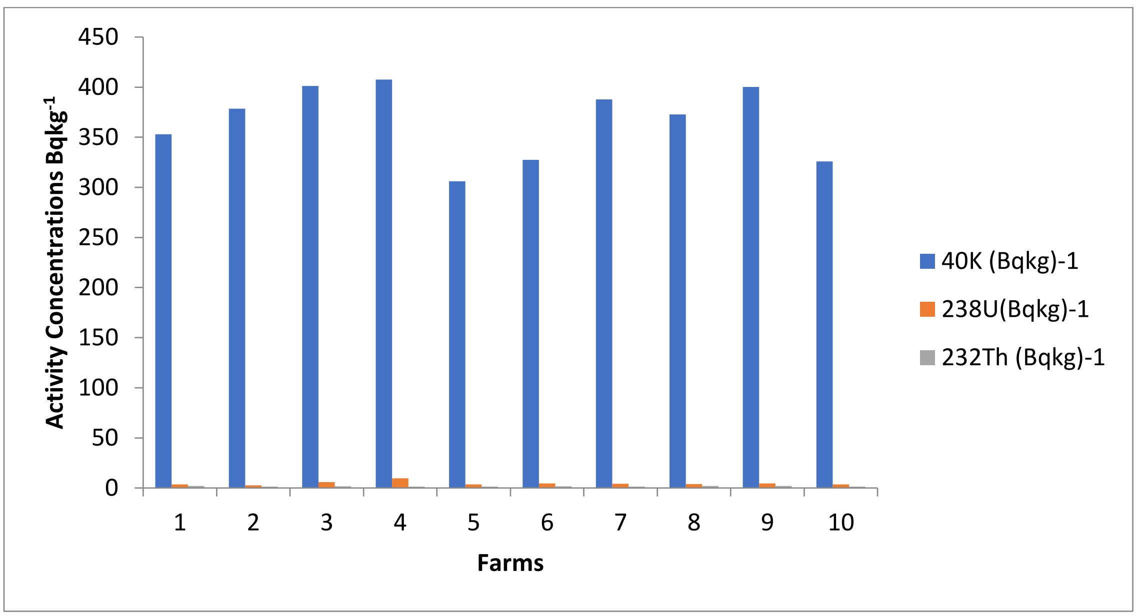

Figure 3: Distribution of radionuclides in yam samples

Transfer Factor

Transfer factor refers to the movement of radionuclides into food crops (Akpolile, 2021), and was calculated using the relation 7 (Adesiji and Ademola, 2019).

$$TF = \frac{\text{Activityconcentrationinfoodsamples (Bq/Kg)}}{\text{Activityconcentrationinsoilsamples(Bq /Kg)}} \quad (7)$$

TF could vary across farms, for example TF Table 3 shows varying values of TF within the study region. This distribution as shown in Figure may have been influenced by. According to Ononugbo et al., 2019, the variations of TF across farms may be influenced by soil mineral composition organic matter content, pH, moisture conditions, fertilizer application, and local geology Ononugbo et al., 2019; Egheneji et al., 2026).

^{40}K mean factor was 1.05 suggesting efficient migration of ^{40}K into yam tuber. Potassium is an essential plant nutrient and is readily absorbed from soil through root systems. Similarly, the mean transfer factor of 1.20 for ^{238}U showed high transfer of ^{238}U radionuclide from soil to yam crop. The mean transfer factor of ^{232}Th was 0.96, this indicates relatively weak migration. Soil pH, organic matter, clay content, and bioavailability other than the ^{238}U in the soil might have influence ^{238}U migration into the tuber.

Table 3: Transfer factors of natural radionuclides for yam

Farm	TF (^{40}K)	TF (^{238}U)	TF (^{232}Th).
1	0.83	0.90	1.62
2	1.04	0.48	0.49
3	1.21	1.15	0.98
4	1.02	2.96	1.27
5	1.10	1.00	0.32
6	0.98	1.15	0.99
7	0.93	0.99	0.73
8	1.06	1.16	1.25
9	1.17	1.18	1.13
10	1.13	0.99	0.83
MEAN	1.05	1.20	0.96

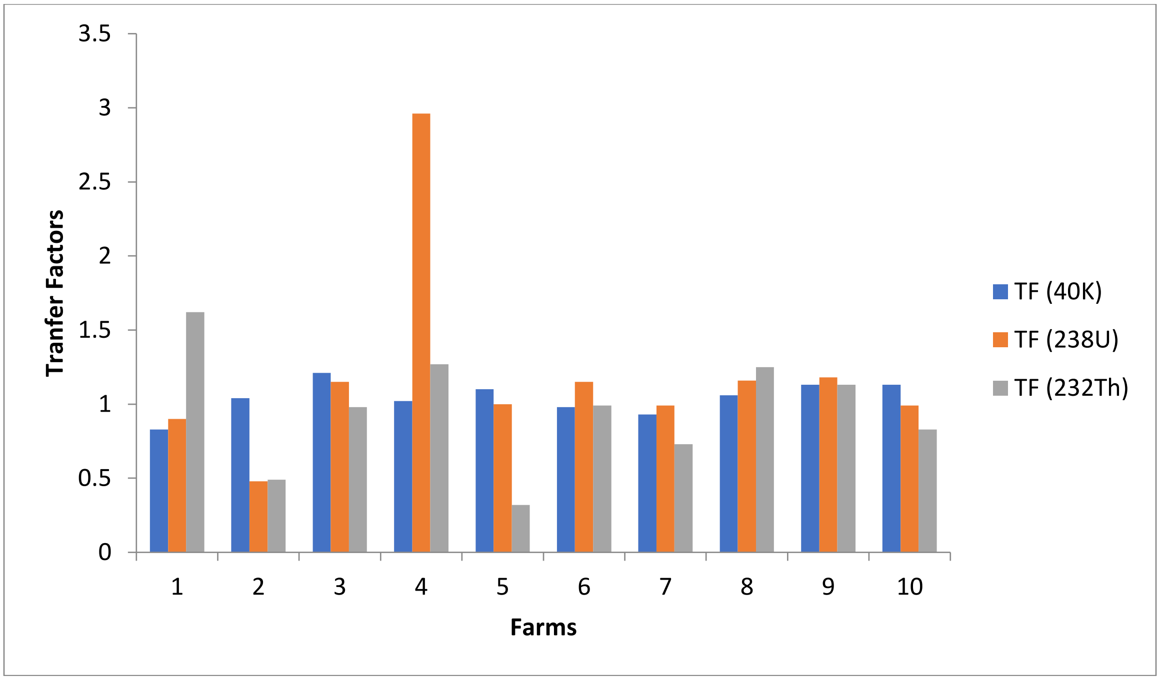

Figure 4: Transfer factors across farms

CONCLUSION

This study assessed the distribution of naturally occurring radionuclides (^{40}K, ^{238}U, and ^{232}Th) in farm soils and yam tubers cultivated in Ika North East Local Government Area of Delta State, Nigeria, and evaluated the associated radiological implications. The results showed that ^{40}K was the dominant radionuclide in both soil and yam samples, while the activity concentrations of ^{238}U and ^{232}Th remained relatively low and within internationally accepted limits. The estimated absorbed dose rate and outdoor annual effective dose were below the global average values recommended by UNSCEAR, indicating low external radiation exposure to farmers and residents within the study area. Similarly, the annual ingestion dose resulting from yam consumption was below the recommended public dose limit of 1 mSv y^{-1}, suggesting that the consumption of yam cultivated in the area does not presently pose significant radiological health concerns. Transfer factor analysis revealed effective migration of radionuclides from soil to yam, particularly for ^{238}U and ^{40}K, highlighting the influence of soil characteristics and agricultural practices on radionuclide uptake. Although the measured dose parameters indicate a generally safe radiological environment, the calculated excess lifetime cancer risk were higher than the permissible value, suggesting the possibility of cumulative long-term health effects associated with prolonged consumption. Therefore, continuous environmental monitoring, periodic assessment of food crops, and proper management of agricultural practices are recommended to ensure sustainable food safety and radiological protection of the population in the study area.

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