

The Nigerian Association of Mathematical Physics

Journal homepage: <https://nampjournals.org.ng>



Natural Radionuclide Concentrations, Soil to Yam Transfer Factors and Radiological Risk Evaluation of Yam in Fertilized Farms of Agbor, Delta State

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ARTICLE INFO

Article history:

Received xxxxx

Revised xxxxx

Accepted xxxxx

Available online xxxxx

Keywords:

Radionuclide,
fertilized farm soil,
spectrometric system,
radiological health risk

ABSTRACT

This study assessed the activity concentrations of naturally occurring radionuclides (^{40}K , ^{238}U , and ^{232}Th) in fertilized farm soils and yam tubers from Agbor and environs, Delta State, Nigeria, and evaluated the associated radiological health risks. Ten soil and ten yam samples were collected using stratified random sampling and analyzed with a NaI(Tl) gamma spectrometry system. Mean activity concentrations in soils were 590.77, 4.82, and 2.72 Bq kg⁻¹ for ^{40}K , ^{238}U , and ^{232}Th , respectively, while corresponding values in yam were 444.55, 5.04, and 2.76 Bq kg⁻¹. Mean transfer factors were 0.75, 1.15, and 1.06, indicating the highest soil-to-yam transfer for uranium. Yam consumption hazards were significantly low except for excess lifetime cancer risk. Although fertilizer application contributed to radionuclide levels, current concentrations pose no significant radiological risk. Continuous environmental monitoring is recommended to detect long-term radionuclide accumulation.

1. Introduction

Natural radioactivity is naturally found in the environment due to naturally occurring radioactive materials (NORMs) present in rocks, soils, water, air, and living organisms. The principal primordial radionuclides are uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K). Their distribution in the environment is influenced by both natural processes, such as weathering, and anthropogenic activities including mining, industrial operations, waste disposal, and agriculture. The application of phosphate-based fertilizers is of particular concern because these fertilizers often contain appreciable amounts of uranium, thorium, and potassium, which may increase radionuclide concentrations in agricultural soils following prolonged use [1].

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DOI: <https://doi.org/10.60787/jnamp.vol73no.740>

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Agricultural soils serve as reservoirs for radionuclides, which may be transferred to crops through root uptake. This soil-to-plant transfer is a major pathway by which radionuclides enter the human food chain [19]. The extent of radionuclide uptake depends on soil characteristics, radionuclide bioavailability, climatic conditions, and crop species [2], [12]. The transfer factor (TF), defined as the ratio of radionuclide concentration in the plant to that in the corresponding soil, is widely used to assess radionuclide mobility, estimate internal radiation doses, and evaluate radiological risks associated with food consumption [2].

Yam (*Dioscorea* spp.) is one of the most important staple crops in Nigeria, the world's largest producer of yam. In Delta State, particularly Agbor and its environs, yam cultivation is widespread because of favourable climatic conditions and fertile soils. To improve productivity, farmers frequently apply NPK fertilizers, which may contribute to radionuclide accumulation in soils and subsequent uptake by yam tubers. Since yam is consumed extensively, the presence of elevated radionuclide concentrations could increase internal radiation exposure and associated health risks through long-term dietary intake.

Assessment of radiological hazards associated with agricultural products commonly involves the determination of activity concentrations and the estimation of indices such as radium equivalent activity (Ra_{eq}), absorbed dose rate, annual effective dose equivalent (AEDE), hazard indices, and excess lifetime cancer risk (ELCR). These parameters are widely used to evaluate compliance with internationally accepted safety limits established by organizations such as the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the World Health Organization (WHO).

Several studies have investigated radionuclide concentrations and soil-to-plant transfer in agricultural environments. Studies conducted in Rivers, Ondo, Benue, and southwestern Nigeria reported that prolonged fertilizer application can increase radionuclide concentrations in soils and food crops, with yam frequently exhibiting relatively high transfer factors for ⁴⁰K and other naturally occurring radionuclides [1], [2], [14], [17], [18]. Although radionuclide concentrations and estimated ingestion doses were generally below recommended safety limits, these studies emphasized the need for continuous environmental monitoring because of increasing agricultural intensification and the cumulative effects of long-term fertilizer application.

Despite the importance of yam cultivation in Delta State, information on radionuclide concentrations, soil-to-yam transfer, and associated radiological risks in fertilized farms within Agbor and its environs remains limited. Most Nigerian studies have focused on other crops or different geographical locations, leaving a significant knowledge gap regarding environmental radioactivity in the Ika region. Furthermore, baseline radiological data for agricultural soils in the area are scarce despite intensive farming and increasing fertilizer use.

Therefore, this study determined the activity concentrations of ⁴⁰K, ²³⁸U, and ²³²Th in fertilized farm soils and yam tubers cultivated in Agbor and its environs, evaluated their soil-to-yam transfer factors, and assessed the associated radiological health risks. The findings provide baseline environmental radioactivity data that will support future environmental monitoring, food safety assessment, agricultural management, and radiological protection in the study area.

MATERIALS AND METHODS

Study Area

The study area, shown in Figure 1, is located in Agbor and surrounding farming communities in the northern part of Delta State, Nigeria. It lies between latitudes 6.20°N–6.30°N and longitudes 6.10°E–6.30°E, covering approximately 650 km² with an estimated population of 240,000 [16]. The area experiences a tropical rainforest climate with wet (April–October) and dry (November–March) seasons, annual temperatures of 25–32°C, high rainfall, and fertile soils that support intensive agriculture [19]. Farming is the major economic activity, with yam, cassava, maize, oil palm, and vegetables commonly and widely grown in the area. Agricultural communities such as Agbor-Obi, Oki, Alihame, Owanta, Agbor-Nta, Aliokpu, Idumesa, Umunede, Owa-Aliero, and Owa-Oyibo with their coordinates shown in Table 1 were selected for soil and yam sampling because of their active farming practices and suitability

for radionuclide transfer assessment. The study area is known to use different types of NPK fertilizers at different rate in order to replenish lost nutrients, and as such enhances crop productivity



Figure 1. Geological map of the study area

Table 1. Studied Communities and their Geographical Locations

Farming Community	Latitude (N)	Longitude (E)
Agbor-Obi	6.26	6.20
Oki	6.24	6.18
Alihame	6.27	6.21
Owanta	6.30	6.24
Agbon-nta	6.25	6.19
Aliokpo	6.23	6.17
Idumuesa	6.29	6.22
Umunede	6.31	6.26
Owa-Alero	6.28	6.18
Owa-Oyibo	6.27	6.16

Sample Collection and Preparation

Ten yam and ten soil samples were collected from ten fertilized farms across ten farming communities within the study area. Each farm was assigned a sampling code (F1–F10) for easy identification. At each farm, seven yam tubers were randomly selected, washed thoroughly with distilled water to remove adhering soil and contaminants, peeled, and cut into small pieces. Equal portions were taken from each tuber, mixed to produce a representative composite sample, thereby minimizing location bias and improving statistical representativeness. The composite sample was oven-dried and ground into powder. Sampling from ten farms provided adequate baseline information on radionuclide distribution and ensured spatial coverage of major yam-producing communities.

Soil samples were collected directly from the yam uprooting points using a stainless steel auger. Equal quantities from each point were mixed to obtain a representative composite sample, reducing variability associated with heterogeneous soil composition. Foreign materials were removed before the samples were crushed, ground, sieved through a 2 mm mesh for homogeneity, and sun-dried for 14 days to attain constant mass and remove residual moisture.

Each yam and soil sample was packed into a sealed plastic container and weighed to 200 g. The samples were stored undisturbed for 28 days to establish secular equilibrium between ^{226}Ra and its short-lived progenies (^{214}Pb at 351.9 keV and ^{214}Bi at 609.3 keV), used as proxy gamma emitters for ^{226}Ra quantification. This ensured accurate measurement of radionuclides in the ^{238}U and ^{232}Th decay series.

Radioactivity Measurement

Radioactivity analysis was carried out using a high-purity Sodium Iodide detector activated with Thallium, NaI(Tl), coupled to a multichannel analyzer (MCA). The detector was shielded with thick lead and lined internally with 1 mm cadmium and 1 mm copper to reduce background radiation. It had 2.0 energy resolution, 33% efficiency at the 1.33 MeV ^{60}Co gamma peak, and a counting time of 36,000 s. Detector geometry was maintained throughout the analysis [7].

Activity concentrations were determined from characteristic gamma-ray photopeaks: 1460 keV for ^{40}K , 1764.5 keV (^{214}Bi) for ^{238}U , and 583.9 keV (^{208}Tl) for ^{232}Th [11]. Samples were counted for 36,000 s, while background counts obtained using an empty sealed container were subtracted from sample counts. Activity concentration (Bq kg^{-1}) was calculated using [6]:

$$C \left(\frac{\text{Bq}}{\text{Kg}} \right) = \frac{C_n}{\varepsilon P_{YMS}} \quad (1)$$

where C_n is 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 [15]. The detection limit estimates the minimum detection level for appropriate determination of radionuclides in the studied samples, this was obtained using the relation [15].

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

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

RESULTS AND DISCUSSION

Activity Concentration in Soil

Table 2 presents activity concentrations of naturally occurring radionuclides (^{40}K , ^{238}U , ^{232}Th) measured in ten farm locations. The values are expressed in Bq kg^{-1} , with associated measurement uncertainties. The mean activity concentrations obtained are: $^{40}\text{K} = 590.77 \pm 5.09 \text{ Bq kg}^{-1}$, $^{238}\text{U} = 4.82 \pm 0.096 \text{ Bq kg}^{-1}$ and $^{232}\text{Th} = 2.72 \pm 0.05 \text{ Bq kg}^{-1}$. ^{40}K recorded the highest activity concentration in all farms, while ^{232}Th had the lowest average concentration among the three radionuclides detected. The activity concentration of ^{40}K ranged from $558.71 \pm 5.30 \text{ Bq kg}^{-1}$ (F7) to $634.23 \pm 5.52 \text{ Bq kg}^{-1}$ (F1). The relatively high concentration of ^{40}K across all farms suggests that ^{40}K bearing minerals is in abundance in the soil. This is expected because ^{40}K is a naturally occurring element essential for plant growth and is commonly present in agricultural soils. The ^{40}K elevation may also have been influenced by the enhanced use of potassium based fertilizer in the study area [19]. The variation of ^{40}K among farms is moderate; this shows fairly uniform distribution of the radionuclide across the study area. The ^{238}U concentrations varied between $3.45 \pm 0.08 \text{ Bq kg}^{-1}$ (F8) and $10.02 \pm 0.20 \text{ Bq kg}^{-1}$ (F4). Most farms recorded low uranium concentrations between 3–5 Bq kg^{-1} . Farms 3 and 4 exhibited noticeably elevated values, suggesting possible localized enrichment of ^{238}U bearing substances in those farms. The overall mean value of 4.82 Bq kg^{-1} indicates low uranium activity concentration within the study area. The ^{232}Th activity concentration ranged from $1.44 \pm 0.04 \text{ Bq kg}^{-1}$ (F3) to $3.98 \pm 0.07 \text{ Bq kg}^{-1}$ (F2) with mean value of $2.72 \pm 0.05 \text{ Bq kg}^{-1}$. Concentrations are generally low across all farms, low thorium levels suggest limited presence of thorium-rich substances in the area. With the exception ^{40}K the radioactivity levels in the farm soils from the study area were tremendously lower than 34.90 ± 12.91 for ^{238}U and 13.54 ± 4.30 for ^{232}Th reported by [17]. The mean value of 4.82 Bq kg^{-1} for ^{238}U and $2.72 \pm 0.05 \text{ Bq kg}^{-1}$ for ^{232}Th were significantly lower than the world average value of 35 and 30 for ^{238}U and ^{232}Th respectively. The higher mean value of $634.23 \pm 5.52 \text{ Bq kg}^{-1}$ for ^{40}K compared to the world average value of 420 Bq kg^{-1} according to UNCCLEAR, 2000 may be due to the application of potassium based fertilizer to farm soil to recover lost nutrients caused by continuous farming and erosion that plagued the study area

Activity Concentration in Yam

Table 3 shows the activity concentrations natural radionuclides in the yam samples measured across ten farms, with values expressed in Bq kg⁻¹ and their associated uncertainties. The activity concentration of ⁴⁰K varied from 414.91 ± 4.00 Bq kg⁻¹ (F6) to 478.24 ± 5.07 Bq kg⁻¹ (F10), with mean value of 444.55 ± 4.58 Bq kg⁻¹. The results show that most farm measured results fall within the range of 420–460 Bq kg⁻¹, an indication of relatively uniform potassium distribution across farms. The ²³⁸U concentration ranged between 2.29 ± 0.06 Bq kg⁻¹ (F2) and 9.39 ± 0.13 Bq kg⁻¹ (F4), with mean value of 5.04 ± 0.09 Bq kg⁻¹. The mean concentration of 5.04 Bq kg⁻¹ indicated generally low uranium activity. The activity concentration of ²³²Th ranged from 1.27 ± 0.04 Bq kg⁻¹ (F3) to 3.99 ± 0.07 Bq kg⁻¹ (F1), with mean value of 2.76 ± 0.06 Bq kg⁻¹. The mean thorium concentration of 2.76 Bq kg⁻¹ is low, suggesting minimal thorium enrichment in the studied farms.

The results obtained from this study showed that the mean values of ⁴⁰K, ²³⁸U and ²³²Th was slightly lower than their corresponding values of 456.2 ± 126.0, 46.9 ± 9.6 and 29.5 ± 12.8 reported by [8].

Radiological Health Parameters in Yam Sample

The table 3 presents several radiological hazard parameters calculated from the activity concentrations of naturally occurring radionuclides that migrated into our body during food ingestion. These parameters help to evaluating the potential radiation exposure and health risks associated with the ingested radionuclides. The assessed parameters include

i). Absorbed dose (D_R).

The absorbed dose rate quantifies the amount of energy deposited by ionising radiation per unit mass in a medium. The D_R in nGyh⁻¹ was calculated by applying conversion factor of 0.462, 0.604 and 0.0417 for ²³⁸U, ²³²Th and ⁴⁰K respectively as in equation 3 [20].

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

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

The absorbed dose ranged from 20.13 (F2) to 23.91 nGyh⁻¹ (F4) with mean value of 22.53 nGyh⁻¹. It was observed that the calculated mean value was lower than the global permissible limits, suggesting the radiological safety of the study area.

ii). Annual effective dose (AED) due to consumption of yam

The AED is given by and [7].

$$AEDE = \sum (U^i \times C_r^i) g \quad (4)$$

Uⁱ is the consumption rate per year, C_rⁱ, the activity concentration of the radionuclide and g is the dose coefficient for ingestion of radionuclide. The values for g in SvBq⁻¹ for ⁴⁰K is 5.9 × 10⁻⁹, ²³⁸U is 4.8 × 10⁻⁸ and ²³²Th is 2.3 × 10⁻⁷ for adult member of the public [7]. The Σ is the summation for all the radionuclides under consideration in the sample [13]. According to [7] 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 the consumption rate for yam is 75.15.

The annual effective dose equivalent (AEDE) arising from the consumption of the studied yam samples ranged from 0.23 to 0.29 mSv y⁻¹, with a mean value of 0.26 mSv y⁻¹. The highest AEDE was observed in Farm F8 (0.29 mSv y⁻¹), whereas the lowest value was recorded in Farm F2 (0.23 mSv y⁻¹). The mean AEDE was below the recommended annual dose limit of 1 mSv y⁻¹ for people resident in the area, indicating that the consumption of yam from the study area does not pose significant radiological health concerns to the populace.

iii). 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

$$\text{ELCR} = \sum r_i A_i C T \quad (5)$$

where r_i is the cancer risk coefficient for the i th radionuclide with $r = 9.56 \times 10^{-9} \text{ Bq Kg}^{-1}$ for ^{238}U , $r = 2.45 \times 10^{-9} \text{ Bq kg}^{-1}$ for ^{232}Th and $5.89 \times 10^{-10} \text{ Bq kg}^{-1}$ for ^{40}K , A_i is the activity concentration of the i th radionuclide, C is the food consumption rate which is equal 75.15 and T is the average life expectancy according to (FAO, 2006) obtained from Federal Office of Statistics (FOS) which is 70 years in Nigeria [10].

The ELCR due to the consumption of yam from the study area ranged from 1.49×10^{-3} (F2) to 1.82×10^{-3} (F4) with mean value of 1.66×10^{-3} . The calculated mean value was higher than the global permissible limit of 0.29×10^{-3} . United Nations Scientific Committee on the Effects of Atomic Radiation [23]. The observed results showed that long term ingestion of yam crop from the study area may pose cancer risk to the general public. Therefore constant monitoring of the study area is highly recommended.

Table 2: Activity Concentration of Radionuclide in Soil Samples [12].

Farm Number	^{40}K (Bq kg $^{-1}$)	^{238}U (Bqkg $^{-1}$)	^{232}Th (Bqkg $^{-1}$)
F1	634.23±5.52	3.57± 0.08	2.59±0.06
F2	578.25±5.25	3.54±0.08	3.98±0.07
F3	565.59±5.18	8.00±0.12	1.44±0.04
F4	572.34±3.21	10.02±0.20	3.50± 0.22
F5	615.34±5.43	3.96±0.08	1.74±0.04
F6	559.13±4.62	3.50±0.08	2.82±0.06
F7	558.71±5.30	3.88±0.08	2.83±0.06
F8	624.52±5.22	3.45±0.08	2.65±0.05
F9	587.39±5.24	4.52±0.09	2.75±0.07
F10	612.24±5.84	3.75±0.07	2.85±0.06
MEAN	590.77 ± 5.09	4.82 ±0.096	2.72 ± 0.05

Table 3. Activity concentrations of natural radionuclides, absorbed dose, effective dose and excess life cancer risks in yam samples.

Farm Number	^{40}K (Bqkg $^{-1}$)	^{238}U (Bqkg $^{-1}$)	^{232}Th (Bqkg $^{-1}$)	D (nGhy $^{-1}$)	AED (mSvy $^{-1}$)	ELCR $\times 10^{-3}$
F1	457.98 ± 4.62	3.54 ± 0.08	3.99 ± 0.07	23.14	0.28	1.64
F2	436.27 ± 5.53	2.29 ± 0.06	1.46 ± 0.04	20.13	0.23	1.49
F3	442.98 ± 3.92	3.26 ±0.07	1.27 ± 0.04	20.75	0.23	1.55
F4	421.12 ± 4.58	9.39 ± 0.13	3.33 ±0.06	23.91	0.28	1.82

F5	446.86 ± 5.09	3.93 ± 0.08	2.58 ± 0.06	22.01	0.26	1.61
F6	414.91 ± 4.00	7.21 ± 0.11	2.62 ± 0.06	22.22	0.26	1.68
F7	453.89 ± 4.59	3.24 ± 0.07	2.59 ± 0.07	21.99	0.26	1.60
F8	449.82 ± 4.54	6.52 ± 0.09	3.94 ± 0.07	24.15	0.29	1.77
F9	443.45 ± 3.85	7.10 ± 0.12	2.59 ± 0.07	23.34	0.27	1.76
F10	478.24 ± 5.07	3.87 ± 0.08	3.24 ± 0.06	23.69	0.28	1.72
MEAN	444.55 ± 4.58	5.04 ± 0.09	2.76 ± 0.06	22.53	0.26	1.66

Statistical Analysis

The **Pearson correlation coefficient (r)** was used to determine the strength and direction of the relationship between the two variables, such as radionuclide concentrations in soil and yam. The results in Table 5 show the relationship between radionuclide concentrations in soil and yam samples. The results show that the correlation coefficient $r = 0.597$ for ^{40}K , $r = 0.434$ for ^{232}U and $r = 0.112$ for ^{232}Th . The observed moderate positive correlation for ^{40}K indicated that its concentration in yam was largely controlled by its abundant concentrations in the soil. The correlation coefficient of ^{238}U was slightly lower than r of ^{40}K , indicating that ^{238}U concentration in yam was not affected by only ^{238}U concentrations in the soil, but other factors such as physiochemical properties and radionuclide bioavailability. However ^{232}Th had very weak positive correlation coefficient suggesting that ^{232}Th concentration in yam did not largely depend on its concentration on the soil, other factors may influence its transfer. This may be due to low ^{232}Th mobility and bioavailability in farm soils.

Analysis of Variance (ANOVA) was conducted to evaluate differences among the mean activity concentrations of ^{40}K , ^{238}U and ^{232}Th in both soil and yam samples collected from the ten fertilized farms. The analysis revealed a highly significant difference among the radionuclides in soil samples ($F = 4239.56$, $p < 0.0001$). Similarly, a highly significant difference was observed among the radionuclides in yam samples ($F = 5841.32$, $p < 0.0001$). These results indicate that the measured radionuclides were not uniformly distributed within either the soil or yam matrices.

Table 4: Transfer Factor from Soil to Yam in Fertilized Farms

Farms (Locations)		^{40}K (Bq /kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
1	Soil to yam	0.72	0.99	1.54
2		0.75	0.65	0.37
3		0.78	0.41	0.88
4		0.74	0.94	0.95
5		0.73	0.99	1.48
6		0.74	2.21	0.93
7		0.81	0.84	0.92
8		0.72	1.89	1.47
9				

	0.75	1.57	0.94
10			
	0.78	1.03	1.14
MEAN			
	0.75	1.15	1.06

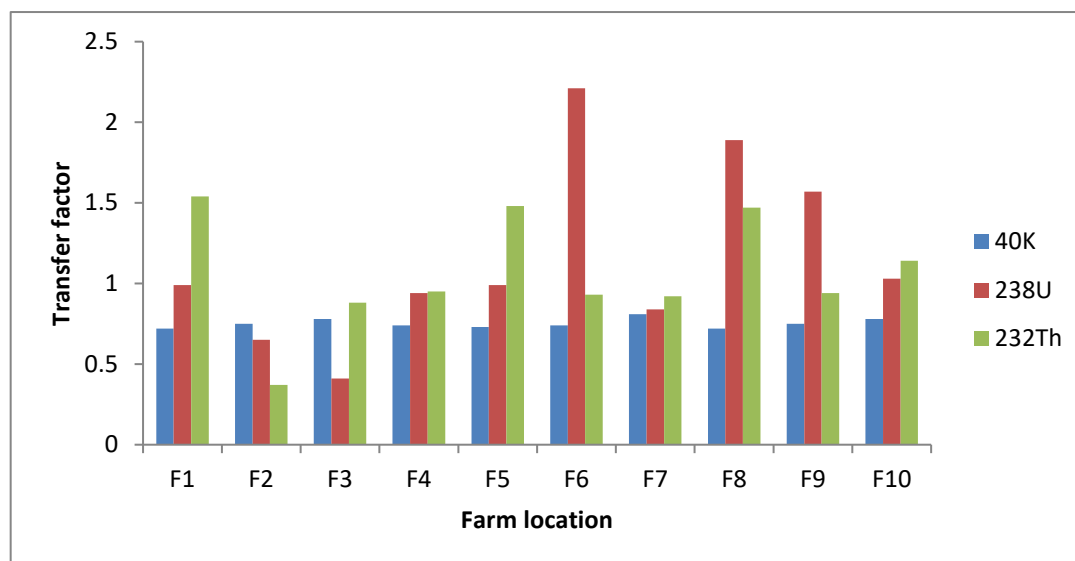


Figure 2. Variation of transfer factor against farm location

Table 5. Pearson correlation table

Radionuclide	Pearson (r)	Interpretation
⁴⁰ K	0.597	Moderate positive correlation
²³⁸ U	0.434	Weak to moderate positive correlation
²³² Th	0.112	Very weak positive correlation

Transfer Factor

This describes the ease with which radionuclides migrate into food crops [5], it is calculated using the relation 14 [4].

$$TF = \frac{\text{Activity concentration in food samples (Bq/Kg)}}{\text{Activity concentration in soil samples (Bq/Kg)}} \quad (6)$$

The values on Table 4 show how much radionuclide moves from the soil into the yam tuber in the ten farms. A higher value means greater movement and accumulation of the radionuclides in the yam tuber. The TF values for ⁴⁰K varied from 0.72 and 0.81, meaning that the TFs of ⁴⁰K across farms were relatively uniform. This could be attributed to the importance of ⁴⁰K to plant healthy growth which makes its absorption by plant uniform and controlled. ²³⁸U showed the widest spread among farms with values ranging from 0.41 to 2.21 meaning that ²³⁸U mobility across farms was not uniform. This may be due to the soil characteristics or geological formations of the study area. The TF values of ²³²Th were between 0.37 and 1.54 showing moderate uniformity. According to Table 5, ²³⁸U average TF into yam samples was greatest, indicating that ²³⁸U showed the greatest readiness to migration into yam samples from soil among all the natural radionuclides present in the studied farms. This was followed by ²³²Th which showed moderate uptake and ⁴⁰K showed the lowest mean TF of 0.75. Although thorium is usually less mobile in soil, certain farm conditions may increase ²³²Th bioavailability and mobility to crops. With the

exception of ^{40}K which mean TF of 0.75 is slightly lower than the world standard limits of 0.2 -0.8 [3], the mean TFs of ^{238}U , and ^{232}Th of 1.15 and 1.06 respectively were higher than their corresponding world standard limits of 0.2- 0.8 and 0.01 - 0.15 [3].

TF could vary from one farm location to another, for example TF across the sampled farms were of different values (Figure 2). According to [19], the variations of TF across farms may be influenced by soil mineral composition organic matter content, pH, moisture conditions, fertilizer application, and local geology. Higher transfer factors could enhance radionuclide concentration in food crops and may lead to internal radiation exposure through food ingestion if concentrations elevated.

Limitation and Future Research Directions

In this work some limitation was acknowledged, the ten farms size considered makes it difficult to generalize the results to the entire agricultural zone. Larger number of farms and sampling locations should be considered in future studies concerning the study area. Similarly, there was no enough information on the energy-efficiency calibration of the detector and its uncertainty was not calculated. Future studies should ensure that certified reference source and calculations of uncertainty were done. Periodic monitoring of farms in the study area to notice possible elevation of radionuclide concentrations occasioned by prolong use of fertilizer should be carried out.

Conclusion

The study evaluated the activity concentrations of ^{40}K , ^{238}U , and ^{232}Th in fertilized farm soils and yam cultivated in Agbor and its environs, Delta State, Nigeria, together with soil-to-yam transfer factors and radiological health risks. ^{40}K recorded the highest activity concentration in both soil and yam, while ^{232}Th had the lowest, likely due to potassium-based fertilizer application. Transfer factors followed the order $^{238}\text{U} > ^{232}\text{Th} > ^{40}\text{K}$, indicating greater mobility of uranium. Variations reflected differences in soil properties, fertilizer use, moisture, organic matter, and geology. Radiological indices (Raeq, absorbed dose, AEDE, ELCR, Hin, Hex, AGED, and gamma index) were generally below UNSCEAR, IAEA, and WHO safety limits, although ELCR from yam ingestion exceeded the global reference value. Continuous environmental monitoring and controlled fertilizer application are therefore recommended.

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