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Research Paper

Radionuclides proportion and the assessment of radiological risks of soil and cassava in ika land, delta state, nigeria

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ABSTRACT

This paper examines the levels of radionuclides and radiological risks of soil and cassava grown in Ika land (Delta State, Nigeria). A total of 20 farm samples were sampled and both cassava and soil samples were sampled, mixed and analyzed using a calibrated NaI (Tl) gamma-ray spectrometer. The soil activity concentrations were 447.39 ug/kg (00K), 6.29 ug/kg (238U), and 3.23 ug/kg (^{232}Th). The values in cassava were 400.30 ± 4.46 Bq/kg (40K), 5.18 +0.13 Bq /kg (238U) and 3.03 + 0.04 Bq/kg (^{232}Th). The approximate mean absorbed dose rate was 23.51 nGy/h, an effective dose of 0.4 -1/y and a cancer risk of 2.55 x 10 -3 on cassava consumption. Doses that were associated with soil were a little more. In the region, there is no serious radiological health risk in the intake of soil or cassava because all values are less than the recommended safety limits.

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1. INTRODUCTION

Radionuclides are radioactive isotopes, which have unstable states that radiate off spontaneously as alpha, beta particles, and gamma rays. These ion radiations have the ability to damage tissues and change body chemistry [1]. Radionuclides are natural and exist in the environment, water, air and in human bodies and human activities such as industrial processes, mining and medical procedures [2], [3].

Radionuclides with half-life of more than 24 hours, e.g. 238 U, 232 Th, and 40 K, have chronic exposure. Because these radionuclides may be absorbed by humans majorly through food, it is mandatory to determine their concentrations in foodstuffs such as cassava, which is the major source of carbohydrates in Nigeria and sub Saharan Africa [4]. Radionuclides are taken up by plants through roots and its translocation depends on the characteristics of the soil and the environmental factors as well as the mobility of the radionuclides [5], [6].

Previous studies have reported varying radionuclide concentrations in cassava. For example, [7] observed activity levels of 19.3 ± 5.0, 11.4 ± 3.3, and 426.9 ± 33.8 Bq/kg for ^{238}U, ^{232}Th, and ^{40}K in Onne, River State. In Delta State, [8] reported 565.31 ± 13.17 Bq/kg (^{40}K), 21.89 ± 5.94 Bq/kg (^{226}Ra), and 817.28 ± 2.52 Bq/kg (^{232}Th).

1.1. Mechanisms of Soil Dynamics and Transfer

The Soil-to-Plant Transfer Factor (TF) mainly controls the accretion of these radionuclides in the cassava tubers. This ratio is affected by the physical and chemical characteristics of the soil such as pH levels, organic matter and cation exchange capacity. [6] In the Niger Delta tropical soils, high precipitation and humidity may increase the weathering of parent rocks and they may release naturally occurring radioactive materials (NORM) into the topsoil where cassava roots grow. Cassava being a root tuber has direct and extensive contact with the soil matrix and therefore has a high chance of uptaking radionuclides over surface growing crops.

1.2. Radiological Health Risk Assessment

Not just in detection, the radiological risk indices also should be assessed to identify the potential effects of the radiology on the long-term health of the local population. Internal exposure may occur as a result of chronic low-level radiation intake in staples such as "Garri" or "Akpu" which may result in mutation of DNA or other types of cancer throughout life. The Annual Effective Dose Equivalent (AEDE) and the Excess Lifetime Cancer Risk (ELCR) are the most important measurements used by health physicists to measure these threats. Evaluation of these risks will help in ensuring that the food intake of the people in the Ika Land is within the safety levels of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

1.3. The Significance of Ika Land

Ika Land which consists of Ika South and Ika North-East Local Government Areas is an agricultural hub of Delta State. Cassava crop is a very important part of the economy of the region. Nevertheless, the fact that the area is close to the industrial activity and due to the geologic peculiarities of Agbor the locality, the special radiologic survey is needed. Although there are general studies on Niger Delta, there is a need of site specific data on Ika Land to give it local assurances on safety. In this study, the researcher seeks to bridge this gap in data by estimating the percentage of radionuclides in the soil and their consequent bioaccumulation in cassava as an indicator of environmental safety and policy of the health of the people in the area.

2. RELATED WORK

Recent studies on the transfer of natural radionuclides (^{238}U, ^{232}Th, and ^{40}K) from soil to food crops have gained increasing attention due to their implications for human health, especially in areas with elevated natural background radiation or industrial activity. Understanding how these radionuclides move through the soil-plant pathway is crucial for assessing potential radiological risks associated with food consumption. Various studies have been conducted in Nigeria to give information on the patterns of radionuclide transfer. [9] Studied cassava in Ethiope East, Delta State whereby transfer factors were 1.55, 0.99, and 1.69 of ^{0}K, ^{238}U, and ^{232}Th respectively. Their results hinted at the fact that cassava accumulates thorium isotopes in preference, whereby the transfer factors are greater than unity in the case of 232 Th.

On the same note, [10] analyzed yam tubers in north-central Nigeria, where the activity concentrations of 29.23 + 4.0 Bq/kg of 238U, 13.10 + 0.72 Bq/kg of 238Th and 445.10 + 27.20 Bq/kg of 40K were found. Their findings revealed that there were low radiological health risks associated with yam intake and the annual effective doses were much low than the safety levels.

Transfer of radionuclides is largely affected by environmental conditions. In the study of cassava in the coal mining regions of Enugu State, Nigeria, [11] determined that there were high levels of-00K (mean of 523.4 Bq/kg) as a result of the industrial activity. Their research placed emphasis on local geology and industrial effects on uptake of radionuclides. On the same parliament, [12] ascertained soil to leaf vegetable transfer in the Akwa Ibom State, and reported transfer factor values of 0.82 of 40K, 1.15 of 238U, and 0.94 of ^{232}Th of fluted pumpkin meaning moderate to high transfer efficiency, particularly of uranium isotopes.

Studies in other areas highlight differences that are caused by the soil type and environmental factors. [13] Found greater transfer of radionuclides in the sandy soils than in clay soils in Nasarawa State, Nigeria. Wider ecological investigations like [14] also revealed that marine animals can bioaccumulate the radionuclides in seawater by uptake and incorporation into food chain processes and transferred to a wider context of soil by terrestrial ecosystem.The recent methodological progress, such as advanced gamma spectrometry and statistical modeling methods also led to improvements in the precision of the transfer factor measurements and risk assessments. Research always indicates that radiological risks produced out of the consumption of local grown crops does not exceed international safety levels and the estimated amounts of effective dose is usually between 0.1 and 1.5 mSv/year [15]. However, continuous monitoring is highlighted particularly in such areas that have industrial processes or that have intense natural background radiations as a measure to guarantee food safety.

In general, although the radionuclide uptake is observed in different crops and surroundings, existing evidence has indicated that there is little health risk in normal circumstances. There should be future research which aims at developing crop-specific transfer models, exploring seasonal differences and developing regional transfer factor databases to enhance risk assessment localization [16], [17].

3. METHODOLOGY

3.1. Study Area

This research was conducted in two local government areas of Ika South and Ika North-East Local Government Areas of Delta State, Nigeria, as indicated in Figure 1 below. The area indicates fertile land, a favorable climate (annual rainfall ~1909 mm, humidity 70%, temperature 37°C), and extensive cassava cultivation by the indigenes. The population exceeds 200,000, with agriculture being the primary livelihood. Coordinates are approximately 06°22'–06°27'N latitude and 07°25'–07°30'E longitude.

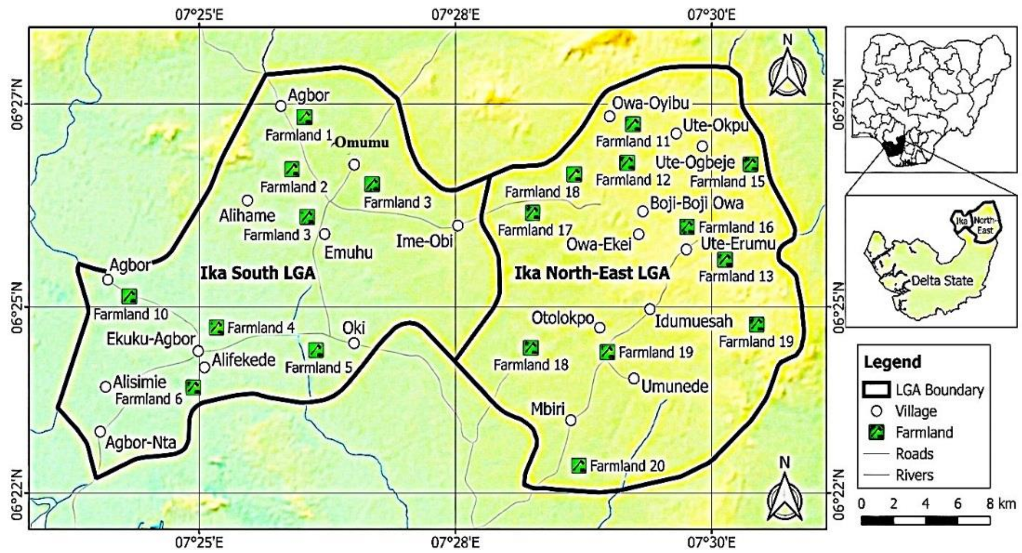

Figure 1. Map Showing the Study Area with Village and Farmland Site Locations

3.2. Sample Collection and Preparation

Twenty farms lands across fifteen villages were sampled. Soil and cassava samples were collected from the locations, combined to form representative samples, and prepared as follows:

Soil: ~2 kg collected, air-dried, ground, and sieved.

Cassava: Edible portions peeled, sliced, air-dried for four months, ground into fine powder, and sieved through a 0.2 mm mesh.

Samples (200 g) were sealed in plastic containers for 30 days to achieve secular equilibrium before gamma spectrometry analysis [18], [19].

3.3. Activity Concentration Measurement

Samples were measured using a calibrated NaI (Tl) gamma-ray spectrometer shielded with lead, cadmium, and copper. The detector's efficiency was 33% at 1.33 MeV, with a resolution of 2.0 keV. Gamma peaks at 1460 keV (^{40}K), 1764.5 keV (^{214}Bi from ^{238}U), and 2614.5 keV (^{208}Tl from ^{232}Th) were used for activity determination.

The activity concentration (C) was calculated using:

$$C\left(\frac{Bq}{Kg}\right) = \frac{C_n}{\varepsilon P_Y M_S} \qquad 1$$

Where C_n is the count rate under the corresponding photopeak, *P*_Y is the absolute transition probability of the specific gamma ray, ε is the detection efficiency at the energy line, and *M*_s is the mass of the sample.

4. RESULTS AND DISCUSSION

Table 1 shows the radionuclide activity concentrations that were measured in the soil and cassava samples. With a mean value of 447.36, the activity concentration of ^{40}K varied from 275.46 ± 2.28 in Farm 19 to 602.46 ± 5.77 in Farm 3. With a mean value of 6.29 ± 0.13, the activity concentration of ^{238}U ranged from 1.70 ± 0.02 in Farm 18 to 20.70 ± 0.29 in Farm 17. With a mean value of 3.25 ± 0.17, the ^{232}Th activity varied from 1.40 ± 0.04 in Farm 11 to 12.00 ± 2.07 in Farm 19.

When compared to the corresponding values of ^{238}U and ^{232}Th in the entire samples measured, the activity concentration of ^{40}K in the soil samples was extremely high. This is strongly at odds with the report [11], but it is in line with studies by [9], [20]. The activity concentrations of ^{40}K and ^{232}Th were either marginally higher or lower than one another in their reports.

The farm soil radioactivity levels were marginally higher than those determined by [9]. The corresponding mean values of soil and cassava radioactivity found in this study were substantially lower than those found in the work of [8]. They ascribed this observed difference to the increased use of fertiliser. According to the study's findings, the mean activity concentrations of ^{232}Th and ^{238}U were lower than the global averages of 32 and 40 Bq kg^{-1}, respectively. The current work's mean value for ^{40}K was greater than the 420 Bq kg^{-1} global mean value of [21].

The activity consentrations of soil and cassava crops in farmlands are shown in Table 1, while the Activity concentrations against sampling sites are shown in Figure 2 and Figure 3 respectively. The concentration of ^{40}K in the cassava samples ranged from 486.91 ± 4.32 Bq kg^{-1} in Farm 1 to 295.52 Bq kg^{-1} in Farm 19, with a mean value of 400.30 ± 4.46 Bq kg^{-1}. The mean value for ^{238}U was 5.18 ± 0.13 Bq kg^{-1}, with a range of 7.65 ± 0.12 in Farm 8 to 2.75 ± 0.12 in Farm 18. The mean activity concentration of ^{232}Th was 3.03 ± 0.04 Bq kg^{-1}, with a range of 5.82 ± 0.06 Bq kg^{-1} (Farm 5) to 1.24 ± 0.04 Bq kg^{-1} (Farm 11).

The mean activity of ^{238}U radioisotope was significantly greater than the corresponding value obtained for ^{232}Th. A similar observation was recorded in the work [4]. This observation could be attributable to the much higher mobility of ^{238}U than ^{232}Th in the soil, resulting in its higher absorption by the cassava crop.

Table 1. Activity Concentrations of Soils and Cassava Crops in Farmlands

Farm No	Concentration in Soils (Bq kg^{-1})			Concentration in Cassava (Bq kg^{-1})		
	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th

1	543.46 ± 3.93	5.55 ± 0.10	1.86 ± 0.05	486.91 ± 4.32	5.60 ± 0.10	1.32 ± 0.04
2	581.96 ± 5.27	2.45 ± 0.06	2.86 ± 0.06	411.2 ± 5.12	3.65 ± 0.12	2.87 ± 0.06
3	602.46 ± 5.77	3.65 ± 0.08	2.96 ± 0.05	401.5 ± 4.22	2.82 ± 0.18	5.27 ± 0.08
4	583.26 ± 3.87	4.59 ± 0.12	1.88 ± 0.08	426.95 ± 4.82	4.90 ± 0.12	2.27 ± 0.04
5	538.45 ± 5.93	7.65 ± 0.10	1.56 ± 0.05	456.93 ± 4.32	6.65 ± 0.14	5.82 ± 0.06
6	443.46 ± 3.93	5.85 ± 0.11	2.26 ± 0.05	405.91 ± 4.32	5.86 ± 0.10	3.12 ± 0.06
7	508.44 ± 4.93	8.66 ± 0.15	3.56 ± 0.05	422.92 ± 4.10	6.80 ± 0.11	2.52 ± 0.04
8	564.67 ± 3.53	9.55 ± 0.12	1.46 ± 0.05	456.98 ± 5.35	7.65 ± 0.12	2.72 ± 0.04
9	548.86 ± 5.99	4.85 ± 0.20	2.46 ± 0.05	406.98 ± 4.52	7.26 ± 0.12	3.15 ± 0.06
10	583.26 ± 5.93	4.55 ± 0.10	2.52 ± 0.05	456.54 ± 3.92	3.86 ± 0.14	2.18 ± 0.06
11	326.11 ± 4.43	3.53 ± 0.08	1.40 ± 0.04	347.15 ± 4.56	3.16 ± 0.12	1.24 ± 0.04
12	350.21 ± 4.23	5.10 ± 0.09	2.00 ± 0.08	395.67 ± 4.25	5.55 ± 0.10	2.11 ± 0.05
13	426.44 ± 4.49	4.63 ± 0.06	1.74 ± 0.08	447.15 ± 4.26	5.26 ± 0.12	1.54 ± 0.04
14	305.4 ± 2.43	3.23 ± 0.10	5.40 ± 0.14	327.25 ± 2.84	5.18 ± 0.20	4.24 ± 0.04
15	360.24 ± 2.62	3.73 ± 0.25	2.44 ± 0.04	387.17 ± 6.54	5.48 ± 0.12	3.24 ± 0.02
16	305.55 ± 2.28	12.52 ± 0.49	4.05 ± 0.18	295.67 ± 4.18	4.55 ± 0.10	2.56 ± 0.05
17	378.28 ± 5.25	20.70 ± 0.29	7.10 ± 0.08	425.67 ± 7.42	5.85 ± 0.18	2.21 ± 0.04
18	405.26 ± 5.62	1.70 ± 0.02	3.20 ± 0.08	385.62 ± 3.29	2.75 ± 0.12	5.52 ± 0.05
19	275.46 ± 2.28	8.40 ± 0.02	12.00 ± 2.08	295.52 ± 2.25	6.52 ± 0.14	2.54 ± 0.05
20	316.52 ± 4.48	4.82 ± 0.08	1.90 ± 0.04	367.15 ± 4.56	4.16 ± 0.12	4.24 ± 0.06
MEAN	447.39 ± 4.36	6.29 ± 0.13	3.23 ± 0.17	400.30 ± 4.46	5.18 ± 0.13	3.03 ± 0.04

The histogram of Table 1 is illustrated in Figure 2.

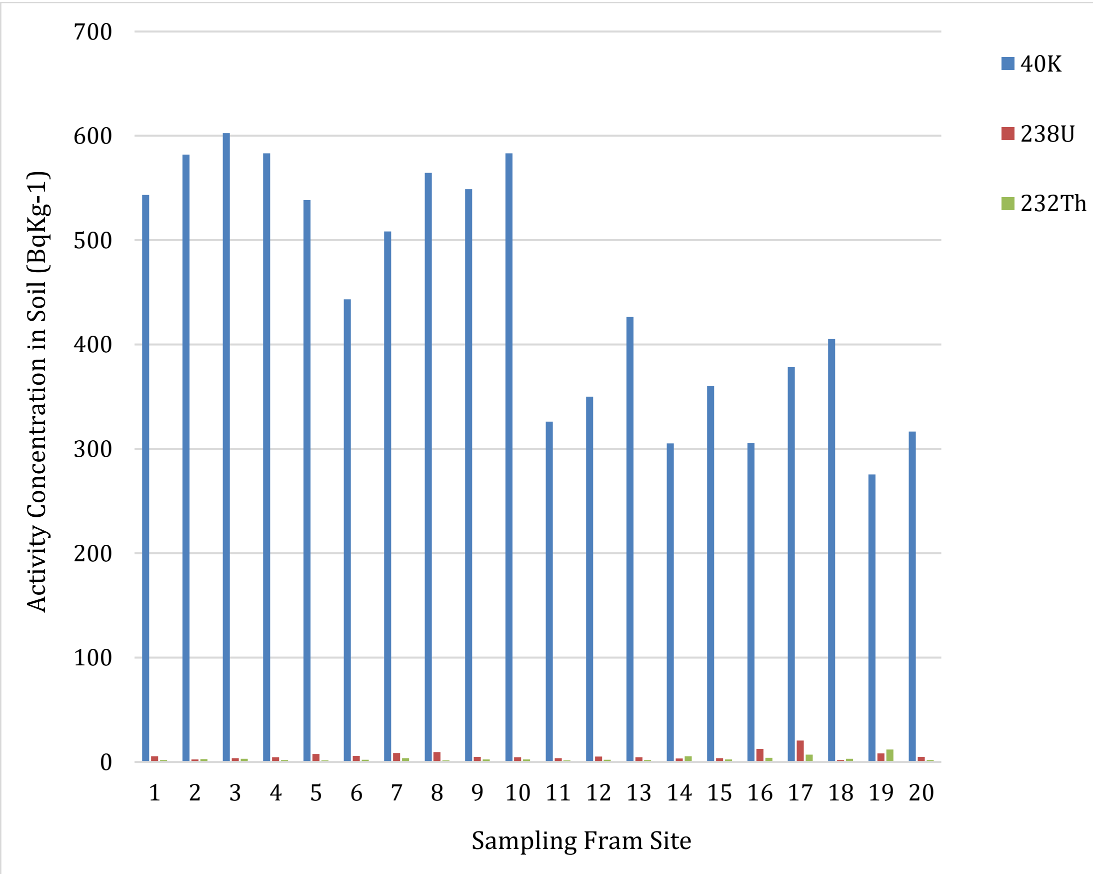

Figure 2. Activity Concentrations against Sampling Sites

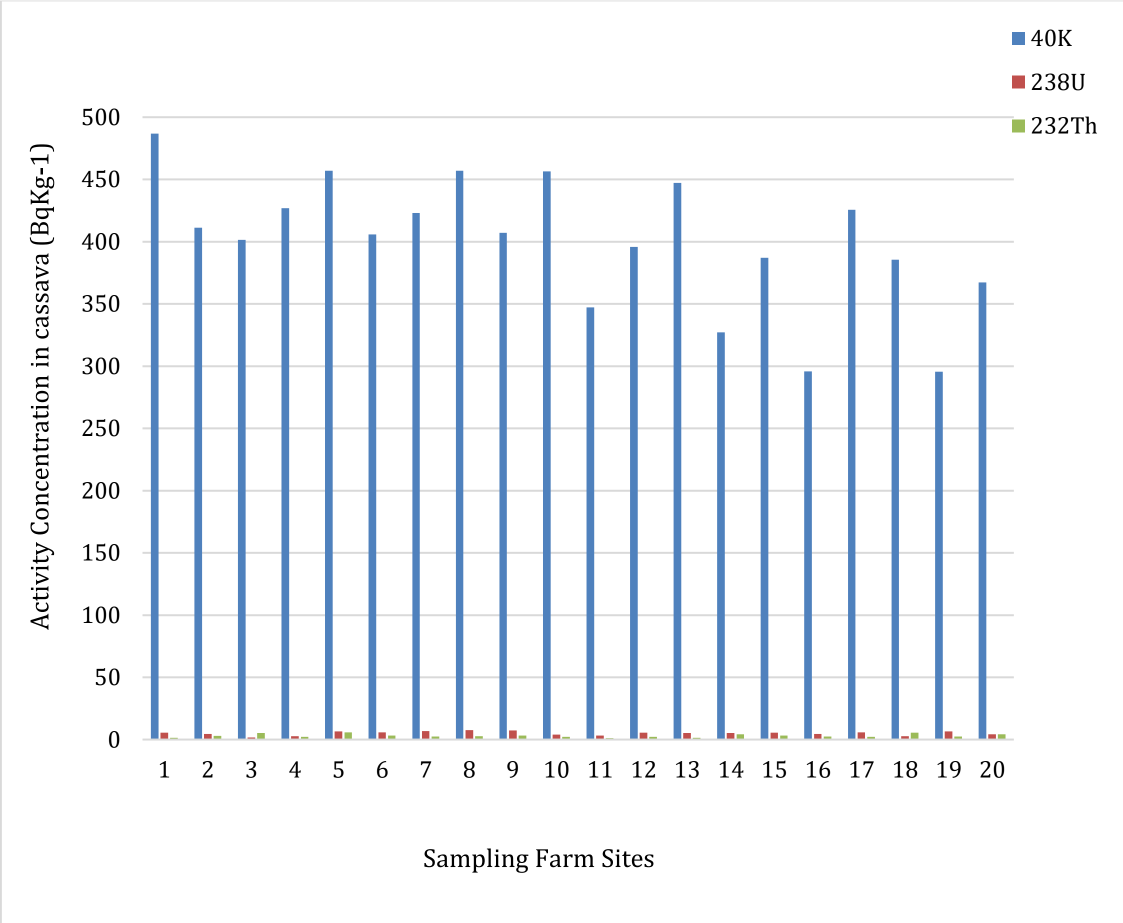

Figure 3. Activity Concentrations against Sampling Sites

4.1. Radiological Health Risk Parameters

To assess the effects of the radionuclides' activity levels in the samples on humans and the environment, health risk parameters were calculated from the activity concentrations of the radionuclides in the cassava soils. The results are displayed in Table 2, while Figure 3 depicted the bar chart. No farm site's recorded value for any radiological parameter was found to be higher than the corresponding globally acceptable value.

The annual effective dose rate varied from 36.33 μSv y^{-1} to 19.71 μSv y^{-1} with a mean value of 28.83 μSv y^{-1}, while the absorbed dose rate ranged from 16.07 nGy h^{-1} to 29.63 nGy h^{-1} with a mean value of 23.51 nGy h^{-1}. With a mean value of 0.1×10^{-3}, the cancer risk values varied from 0.127×10^{-3} to 0.069×10^{-3}.

The current study's mean values for radium equivalent activity (Ra), absorbed dose rate (*D*), annual effective dose rate, excess life cancer risks, internal health risks (IHR), and external health risks (EHR) were 45.35, 23.51 nGy h^{-1}, 28.83 μSv y^{-1}, 0.1×10^{-3}, 0.14, and 0.12, respectively. The corresponding global allowable values of 370, 55 nGy h^{-1}, 1.0 mSv y^{-1}, 0.29×10^{-3}, 1, and 1 were all higher than these computed average values. The world-permissible limit of 300 mSv/y was exceeded by the estimated mean gonad dose of 173.40 per year. According to the findings, using soils from the study area does not significantly endanger the health of the local population.

The average values of radium equivalent activity (Ra), absorbed dose rate (*D*), annual effective dose rate, excess life cancer risks, internal health risks (IHR), and external health risks (EHR) in the current study were 40.32, 20.92, 0.40, 2.55×10^{-3}, 0.12, and 0.10, respectively, based on the risk parameters of the cassava crop that were calculated in Table 3. The recommended corresponding values of 370, 55, 1.0, 0.29×10^{-3}, 1, and 1 were all much higher than the actual values. As a result, the residents are not at risk for any radiological health issues from eating cassava.

Table 2. The Radiological Health Risk Parameters for Cassava Farm Soils

Farm No	Raeg (Bqkg-1)	D (nGhy-1)	Outdoor AEB µSvy-1	Indoor AED µSvy-1	ELCR×10-3	AGED	1Yr	Hin
1	50.05	26.35	32.32	129.26	0.113	195.57	0.15	0.14
2	51.35	27.13	33.27	133.07	0.116	202.26	0.14	0.14
3	54.27	28.60	35.07	140.28	0.122	212.82	0.16	0.15
4	52.19	27.58	33.82	135.29	0.118	205.19	0.15	0.14
5	51.34	26.93	33.03	132.10	0.115	199.23	0.16	0.14
6	43.23	22.56	27.67	110.67	0.096	166.77	0.13	0.12
7	52.90	27.35	33.55	134.18	0.117	201.29	0.17	0.14
8	55.12	28.84	35.37	141.48	0.123	212.92	0.17	0.15
9	50.63	26.61	32.64	130.56	0.114	197.61	0.15	0.14
10	53.06	27.95	34.27	137.09	0.120	207.74	0.16	0.14
11	30.64	16.07	19.71	78.86	0.069	119.15	0.09	0.08
12	34.93	18.17	22.28	89.12	0.078	134.08	0.11	0.09
13	39.95	20.97	25.72	102.88	0.090	155.48	0.12	0.11
14	34.48	17.49	21.45	85.80	0.075	128.45	0.10	0.09
15	34.96	18.22	22.34	89.36	0.078	134.84	0.10	0.09
16	41.84	20.97	25.72	102.88	0.090	151.56	0.15	0.11
17	59.98	29.63	36.33	145.33	0.127	212.42	0.22	0.16
18	37.48	19.62	24.06	96.24	0.084	145.88	0.11	0.10
19	46.77	22.62	27.74	110.94	0.097	162.61	0.15	0.13
20	31.91	16.57	20.33	81.30	0.071	122.22	0.10	0.09
Mean	45.35	23.51	28.83	115.33	0.10	173.40	0.14	0.12

Table 3. The Radiological Health Risk Parameters Due to Consumption of Cassava

Farm No	Raeg (Bqkg-1)	D (nGhy-1)	AEB µSvy-1	ELCR ×10-3	AGED	1Yr	Hin
1	44.98	23.69	0.43	2.99	175.71	0.14	0.12
2	39.42	20.55	0.40	2.47	152.25	0.12	0.11
3	41.28	21.22	0.46	2.40	156.78	0.12	0.11
4	41.03	21.43	0.41	2.64	158.70	0.12	0.11
5	50.15	25.61	0.54	3.01	188.20	0.15	0.14
6	41.58	21.52	0.42	2.63	158.60	0.13	0.11
7	42.96	22.30	0.42	2.78	164.34	0.13	0.15
8	46.73	24.23	0.46	3.03	178.50	0.15	0.13
9	43.10	22.23	0.43	2.75	163.40	0.14	0.12
10	42.13	22.14	0.42	2.71	164.40	0.12	0.11
11	31.66	16.69	0.31	2.07	123.95	0.09	0.09
12	39.03	20.34	0.38	2.53	150.21	0.12	0.11
13	41.89	22.01	0.04	2.76	163.10	0.13	0.11
14	36.44	18.60	0.39	2.20	136.49	0.11	0.10
15	39.93	20.63	0.41	2.51	152.05	0.12	0.11
16	30.98	15.98	0.32	1.95	117.60	0.10	0.08
17	41.79	21.79	0.41	2.71	160.97	0.13	0.11
18	40.34	20.68	0.46	2.32	152.66	0.13	0.12
19	32.90	16.87	0.33	2.11	123.56	0.11	0.09
20	38.49	19.79	0.41	2.32	145.86	0.12	0.10
Mean	40.32	20.92	0.40	2.55	154.37	0.12	0.10

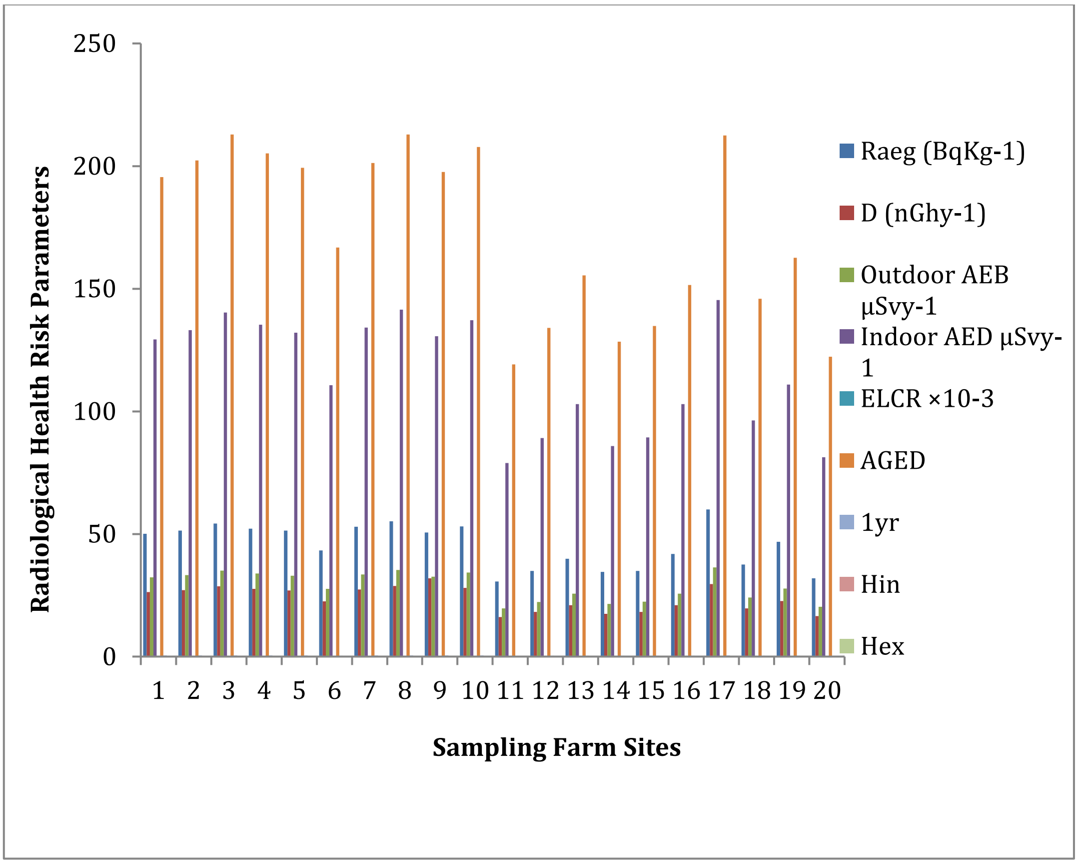

Figure 4. Radiological Health Risk Parameters in Cassava Farm Soil

Table 2 shows the Radiological Health Risk Parameters for Cassava Farm Soils Wile Figure 4 is its graphical representation. Similarly, Table 3 indicates Parameters Due to Consumption of cassava.

4.2. Transfer Factor (TF)

According to [22], [8], TF quantifies the quantity of radionuclides transferred from the soil to the crop through the plant's roots. The transfer factor for the detected radionuclides was calculated using the activity concentration of the radionuclide in the plant and the corresponding soil, as per Equation (2) [23], and is shown in Table 4 and is depicted graphically by Figure 4.

$$TF = \frac{Activity\ concentration\ in\ food\ samples\ (Bq/Kg}{)\ Activity\ concentration\ in\ soil\ samples\ (Bq\ /Kg} \quad 2$$

Table 4. TF for Radionuclides from Soil to Cassava Samples

Farms	^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)
1	0.90	1.01	0.71
2	0.71	1.49	1.00
3	0.67	0.77	1.78
4	0.73	1.07	1.21
5	0.85	0.87	3.73
6	0.91	1.00	1.38
7	0.83	0.79	0.71
8	0.81	0.80	1.86
9	0.74	1.59	1.28
10	0.78	0.85	0.87
11	1.06	0.90	0.89
12	1.13	1.09	1.06

13	1.05	1.14	0.91
14	1.07	1.60	0.79
15	1.07	1.47	1.33
16	0.97	0.36	0.63
17	1.13	0.28	0.31
18	0.95	1.62	1.73
19	1.07	0.78	0.21
20	1.16	0.86	2.23
MEAN	0.93	1.02	1.23

TF for Radionuclides from Soil to Cassava Samples are shown on Table 4. This study found that the accumulation of radionuclides in the crops varied, which was consistent with the findings of the majority of studies. ^{238}U ranged from 1.62 in Farm 18 to 0.28 in Farm 17, with an average value of 1.02, ^{40}K varied from 1.16 in Farm 20 to 0.67 in Farm 3. In contrast, ^{232}Th had a mean value of 1.21 and ranged from 0.21 in Farm 19 to 3.73 in Farm 5.

The average values of 0.93 for ^{40}K, 1.02 for ^{238}U, and 1.23 for ^{232}Th indicate that the cassava crop absorbs natural radionuclides from the soil at a moderate rate. The arithmetic mode of IAEA recommended 0.089 and 0.0082 as the International Atomic Energy Agency (IAEA) recommended values of ^{232}Th and 238U, respectively. Their relocation to the cassava food could have been influenced by the importance of ¯40K and other radionuclides to the cassava crop, the capacity of the crop to survive environmental stress, and physiochemical properties [23]. These could have contributed to the worth of radionuclides which are taken up by the plant [8], [23].

The results of the work disproved the hypothesis that there is an increasing absorption of radioisotopes in the soil related to the concentration of the soil. An example of this is that Table 3 was 40K on Farm 1, which was measured as 543.46 3.93 Bq kg-1 with a transfer factor of 0.90. The same table provided a concentration of 0.67, 602.46 ± 5.77 Bq kg of 40K concentration (T.F 0.67) in Farm 3. This aligns with the research conducted by [8].

The mean transfer factor from the study area, as indicated in Figure 5 was lower for ^{40}K and ^{232}Th, except for ^{238}U, which was marginally higher when comparing the findings of this work with those of [8]. Additionally, it was found to be inferior to the outcomes of the research conducted by [23]. Numerous variables, including plant species, soil pH and fertility, and fertiliser, may affect how well plants absorb radionuclides.

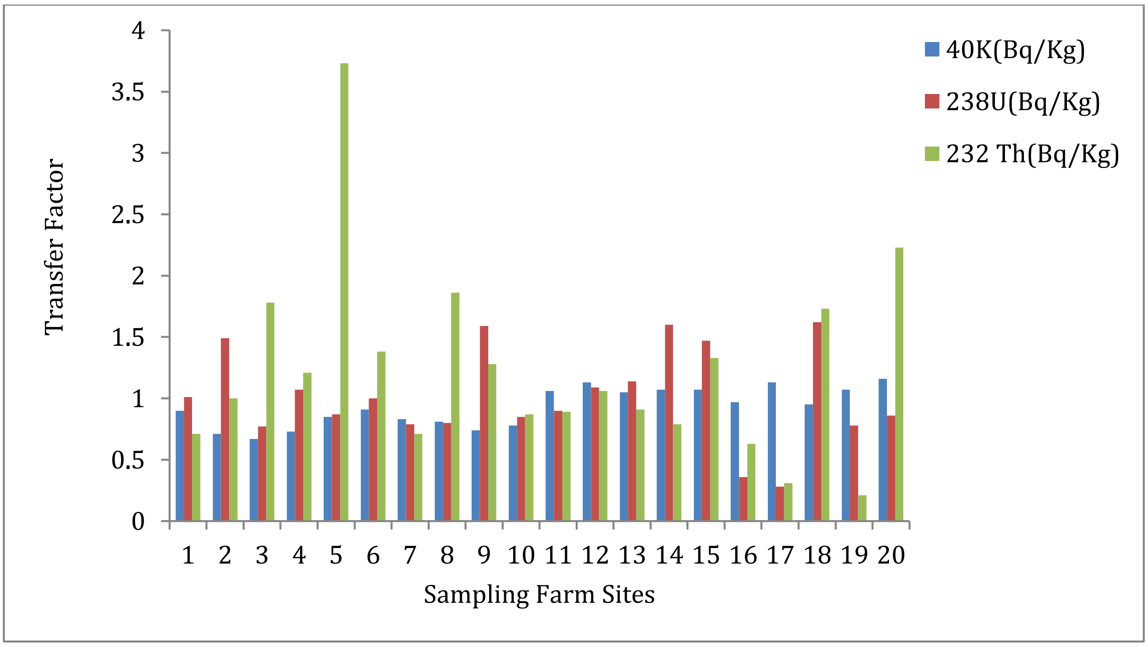

Figure 5. Bar Chart for the Soil to Radionuclide Transfer Factor

5. CONCLUSION

Based on the average mean values of the activity concentrations and radiological health risk parameters of the cassava foodstuff, consuming radionuclide-contaminated cassava from the study area poses no health risks to the local population. It is therefore safe for ingestion because the radiological health risk parameters and activity concentration did not exceed their respective allowable limits. The project was deemed safe.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Egheneji A. Anthony	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
Mokobia E. C	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓	✓
Eseka Kenneth	✓		✓	✓		✓			✓		✓		✓	✓
Ilugo N. Theresa	✓	✓		✓	✓	✓	✓		✓	✓		✓	✓	
Onojake Lawson	✓		✓	✓		✓	✓		✓	✓	✓		✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

The authors confirm that there are no conflicts of interest associated with this research, its results, or its publication in any form.

Informed Consent

Official approvals were obtained from the relevant authorities prior to conducting the study. All research procedures were carried out in accordance with the ethical and professional standards approved for environmental studies, and in compliance with national and international guidelines related to the collection and analysis of samples.

Ethical Approval

Ethical approval was obtained from the Ethics Committee at the University of Delta Agbor to conduct this study. All ethical guidelines and approved scientific standards were followed to ensure the accuracy of the results and the integrity of the procedures used in the collection and analysis of samples.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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