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Soil to Cassava Transfer Factors of Natural Radionuclides in Farms in Ini Local Government Area, Akwa Ibom State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Knowledge of activity concentration of radionuclides in soil of our farmlands and the consequent transfer factors of the radionuclide to plants are necessary to estimate the contamination level of the soil, plants and food. The activity concentration of ^{40}K, ^{238}U and ^{232}Th in soils and cassava in Ini Local Government Area, Akwa Ibom State, Nigeria were measured using gamma spectrometry. Activity concentrations of radionuclides in soils in the locations ranged from BDL (below detectable limit) to 298.76 ± 21.40 Bq/Kg for ^{40}K; BDL to 7.95 ± 1.88 Bq/Kg for ^{238}U and 2.59 ± 0.25 to 16.56 ± 1.61 Bq/Kg for ^{232}Th. Activity concentration of the radionuclides in cassava in all locations ranged from 213.96 ± 15.38 Bq/kg to 520.58 ± 37.25 Bq//Kg for ^{40}K; BDL to 33.02 ± 8.91 Bg/Kg for ^{238}U and BDL to 16.34 ± 1.59 Bq/kg for ^{232}Th. The activity concentrations of all the radionuclides were lower than the world standard. Transfer factors obtained ranged between 3.21 to 4.18 for ^{40}K; 0.93 to 12.64 for ^{238}U and 0.75 to 1.01 for ^{232}Th. Effective ingestion dose due to the consumption of cassava from the studied area obtained ranged between 1.31 to 1.74 mSv/yr and 3.52 to 4.69 mSv/yr for children and adult respectively. These values are above the 1.0 mSv/yr recommended dose limit for general public, therefore the consumption of this food stuff could pose a radiological health effect on humans. However the risk could be minimized when the cassava is cooked.

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Keywords: Soil; cassava; radionuclides; transfer factors; effective ingestion dose.

1. INTRODUCTION

Natural radioactivity occurs everywhere in our environment. The activities of these radionuclides produce ionizing radiations which irradiate human beings and its environment with its attendant detrimental health effect. There is an abundance of work found in the literatures showing the presence of naturally radioactive materials (NORMS) in the different media especially soils and the potential health risk associated with their exposures [1,2]. It is known that these natural occurring radioactive materials (NORM) in the soil contaminate the soil, environment and plant grown on these soils [3,4].

Ingestion of the food material contaminated by these radionuclides deposit these radionuclides in certain organs of the body causing chemical and radiotoxicities [5,6,7]. In a previous study conducted by the authors in a government owned farmland [8], it was observed that cassava contributed 20% of the background ionizing radiation (BIR) of the total BIR of the farmland.

Cassava is the most stable food of people of the southern part of Nigeria and other communities which could be eaten raw or cooked in form of garri, tapioca. Soil – to – plant transfer factors (TF) of radionuclides is the parameter used in measuring the quantity of radionuclides expected to enter a plant from soil [9], and the TF is also referred to as the plant / substrate concentration ratio (CR) or transfer coefficient (TC) that estimates the transport of radionuclides from soil to the food chain under equilibrium conditions [10, 11].

It is reported that many factors both natural and physicochemical, affect the accumulation of radionuclides in plant and are identified to include; concentration of radionuclides in the soil, soil PH, climate, speciation of radionuclide in soil solution, organic content of the soil, soil type and time [12]. This study is therefore set up to measure the activity concentration of NORM deposit in the soil and as well estimate the TF of the radionuclides from soil to cassava in the respective farmlands. Consequently the effective ingestion dose due to the consumption of the contaminated cassava will be determined.

2. MATERIALS AND METHODS

2.1 Location and Geology of the Study Area

The farms used for this study are located in Uta and Mba, Ini local Government Area, Akwa Ibom State, Nigeria. Ini is located about latitude 5°20’ and 5°31’ N and longitude 7°38’E and 7°53’E [13]. The area is underlain by two main rock types which are clay/shale and sandstone [14]. Carbonized streaks of plants remains are present in the dark gray portion of the shale predominantly in the area towards boundary between Akwa Ibom State and Abia state. Ini has a tropical climate with a maximum annual rainfall of 2000 mm; monthly temperatures range between 26°C and 28°C. The area is characterized by deep sandy loam soil with pH of 4.5 – 5.2. The soil is well drained with an undulating relief. The vegetation of the area is that of a typical tropical rain forest. Its natural resources include limestone, clay, gravel, fine sand, crude oil and iron ore. The population of the study areas are estimated to be 435,429. . The people are mainly farmers, producing food items such as garri, rice, palm produce, cocoa, plantain and banana.

2.2 Sample Collection, Preparation and Analysis

Two cassava farms were selected for this study. Interaction with the farm owners to find out their knowledge of ionizing radiation and its biological effects was conducted. Also, permission to use their farms for this study was obtained. The farms were divided into evenly spaced sites with a distance of 20 m between each site for larger coverage of the farm [15]. At each sampling location, the soil surface was cleared of stones, pebbles, vegetation and roots. A soil sample of 2.0 kg (wet weight) was collected from each position with shovel at a depth of 30 cm and corresponding cassava samples were collected in three different directions. At each sampling site, about 2 kg cassava (fresh weight) samples were collected. The samples were thoroughly washed with tap water and then in distilled water to remove surface sand. The two sets of samples were each placed into separate polyethylene bags [2].

The collected soil samples were dried, crushed, grounded and passed through a sieve of 1.0mm mesh size. The fine-grained powder of each sample obtained was dried in an oven at a temperature of 110°C for 3 days to ensure total removal of moisture. 300 g of each dried prepared sample was sealed in a cylindrical plastic container and properly labeled for easy identification. The prepared samples were stored for a period of 30 days to ensure secular radioactivity equilibrium between Ra -226 and its short lived daughters. The cuticles of the cassava were removed with a stainless steel knife and the edible parts were cut into pieces and put in polyethylene materials for refrigeration. The cassava samples were freeze-dried for three days and crushed into powder form (flour) using a blender and kept separately in their respective containers. The samples were further screened in 110µm mesh sieve to obtain fine grained powder –sized particles before they were subjected to radioactivity measurement. Samples codification was done for easy identification. Soils in Uta farms were coded W_{11} to W_{66} and Cassava W_1 to W_6 while in Mba farm codes as X_{11} to X_{55} and X_1 to X_5 were given to soils and cassava samples respectively.

These samples were sent to National Institute of Radiation Protection and Research (NIRPR) an affiliate of Nigerian Nuclear Regulatory Authority (NNRA). In the laboratory, the activity concentrations of Uranium–238, Thorium–232 and Potassium–40 were measured using gamma spectrometry system [2].

2.3 Activity Concentration in the Soil Sample

Activity concentration of the radionuclides in the analyzed sample is being estimated using equation 1 below [2].

$$c = \frac{N}{\xi t \gamma M} \tag{1}$$

Where M is the mass of the samples measured in Kg, ξ the detector energy dependent efficiency, t is the counting time 36,000 s (10 hrs), γ is the gamma ray yield per disintegration of the nuclides and N is the net peak area of the nuclide. The 1.460 MeV photopeak was used for the measurement of ^{40}K, the 1.760 MeV photopeak was used for the measurement of ^{238}U, while the 2.614 MeV photopeak was used for the measurement of ^{232}Th.

2.4 Transfer Factor (TF)

The soil to plant transfer factor depends on the activity concentration of the radionuclides in soil and plant and is calculated according to equation 2 [16].

$$TF = \frac{A_p}{A_s} \tag{2}$$

where A_p is the activity concentration of radionuclides in plant (Bq/Kg dry weight) and A_s is the activity concentration of radionuclides in soil (Bq/Kg dry weight)

2.5 Effective Dose Due to Consumption of Radionuclide in Food Stuff

Effective dose E(Sv/y) due to intake of radionuclide contaminated material is calculated using equation 3 [17].

$$E(Sv/year) = C \sum A_i DCF_i \tag{3}$$

Where C (Kg/year) is the mean annual consumption of the contaminated food stuff, A_i (Bq/ Kg) is the activity concentration of radionuclide (i) in the ingested material and DCF (Sv/Bq) is the dose coefficient for radionuclide i while the summation is for all the radionuclide considered in the sample material under study. Evaluation of the ingested dose estimates the radiation induced deleterious health effects associated with consumption of radionuclides. This is because the ingested dose in the body is proportional to the total dose delivered by the radionuclides into the body. This effective radiation doses from the consumption of contaminated food are obtained by measuring radionuclide activities concentration in the material and multiplying the activities by dose conversion factors and the mean annual consumption of food stuffs. The dose conversion coefficients for the respective radionuclides are given as 2.8 × 10^{-4}, 6.9 ×10^{-4} and 6.2× 10^{-6} mSv/Bq for ^{238}U, ^{232}Th and ^{40}K respectively.

3. RESULTS AND DISCUSSION

3.1 Activity Concentration of Radionuclides in Soil in the Studied Areas

Results for activity concentrations (AC) of the radionuclides determined in Soils in the respective farms are presented in Tables 1 and 2. In Uta farm the AC in Soils (Table 1) ranged between BDL- 298.76 ± 40.0 with mean of 105.39 ± 7.56Bq/Kg for ^{40}K, ^{238}U ranged between BDL -7.95 ± 1.88 with a mean of 4.44 ± 1.05 Bq/Kg while the AC of ^{232}Th ranged between 2.59 ±0.25 – 13.95 ± 1.36 with mean of 9.12 ± 0.89 Bq/Kg. In Mba farm (Table 2), the AC in soils ranged between 29.94 ± 2.15 to 190.67 ± 13.70 with mean of 119.11 ± 7.12 Bq/Kg for ^{40}K, ^{238}U ranged between BDL to 5.25 ± 1.12 with a mean of 1.65 ± 0.36 Bq/Kg, while the AC of ^{232}Th ranged between 5.40 ± 0.53 to 11.79 ± 1.01 with mean of 10.63 ± 1.04 Bq/Kg.

It is observed that potassium has the highest activity concentration in the soil, these could be due to the application of fertilizer to the soil to enhance growth yield [18]. However the mean activity concentration values of the measured radionuclides are lower than the mean world value.

Comparison of the obtained values of activity concentration of the measured radionuclides in the study area with previous studies in different parts of Akwa Ibom State, Nigeria as presented in Table 3 shows that ^{40}K is a dominant radionuclide in the area with activity concentration value ranging between 33.96 ± 1.76 Bq/Kg in Odiok Itam to 238.10 ± 22.47 Bq/Kg in Ikot Ekwuo Idoro with high values in between as recorded in Mba (119.11± 14.11 Bq/Kg), Uta (105.39 ± 7.56 Bq/Kg), Ayadehe (143.54 ± 7.56 Bq/Kg) and Use Ikot Amama (106. 58 ±8.63 Bq/kg). Low activity concentration of Uranium in the soils were recorded in the studied area with mean values range between 1.65 ± 0.36 Bq/Kg in Mba farm to 24.826 ± 5.425 Bq/Kg in Abak soil. It was also observed that activity concentration of uranium was below detection level in some areas while some swampy areas are richer in uranium with high value of 21.78 ± 2.32 Bq/Kg at Ibeno and 24.86 ± 5.425 Bq/Kg in Abak as observed in similar study elsewhere [19].

3.2 Activity Concentration of Measure Radionuclides in Cassava in Studied Areas

There exist a transfer of radionuclides into plants from the soil due to the uptake of nutrients. Results for activity concentrations of the radionuclides determined in Cassava in the respective farms are presented in Tables 4 and 5.

Table 1. Activity Concentration of measured Radionuclides in Soils in Uta Farm

Sample code	Radionuclides		
	^{40}K (Bq/Kg)	**^{238}U (Bq/Kg)**	**^{232}Th (Bq/Kg)**
W_{11}	44.45 ± 3.19	7.69 ± 1.84	8.82± 0.86
W_{22}	126.42± 9.07	BDL	2.59 ± 0.25
W_{33}	57.33 ± 4.13	1.05 ± 0.24	8.09 ± 0.79
W_{44}	BDL	5.49 ± 1.27	13. 95 ± 1.36
W_{55}	298. 76 ± 21.40	7.95 ± 1.88	12.14 ± 1.18
Min	0.00	0.00	2.59 ± 0.25
Max	298.76 ± 21.40	7.95 ± 1.88	13.95 ± 1.36
Mean	105.39 ± 7.56	4.44 ± 1.05	9.12 ± 0.89

Table 2. Activity Concentration of measured Radionuclides in Soils in Mba Farm

Sample code	Radionuclides		
	^{40}K (Bq/Kg)	**^{238}U (Bq/Kg)**	**^{232}Th (Bq/Kg)**
X_{11}	190.67 ± 13.70	BDL	9.03 ± 0. 88
X_{22}	181. 28 ± 22.46	BDL	5.40 ± 0.53
X_{33}	65.77 ± 4. 73	BDL	16.56 ± 1.61
X_{44}	127.88 ± 9.17	5.25 ± 1.12	10.39 ± 1.01
X_{55}	29. 94 ± 2.15	3.01 ± 0.70	11.79 ± 1.15
Min	29.94 ± 2.15	BDL	5.40 ± 0.53
Max	190.67 ± 13.70	5.25 ± 1.12	16.56 ± 1.61
Mean	119.11 ± 7.12	1.65 ± 0.36	10.63 ± 1.04

Table 3. Activity Concentration of Radionuclides in Soils in different Parts of Akwa Ibom State, Nigeria

Location	Radionuclides			References
	^{40}K	^{238}U	^{232}Th	
Uta. Ini	105.39 ± 7.56	4.44 ± 1.05	9.12 ± 0.89	This study
Mba , Ini	119.11 ± 14.11	1.65 ± 0.36	10.63± 1.04	This study
Ayadehe , Itu	143.54 ± 7.56	2.47 ± 0.26	3.70 ± 0.22	[2]
Oku Iboko, Itu	73.60 ± 3.89	2.04 ± 0.22	2.85 ±0.17	[2]
Odiok Itam, Itu	33.96 ± 1.76	8.84 ± 0.92	3.01 ± 0.18	[2]
Ntak Inyang, Itu	63.77 ± 3.34	7.81 ±0.84	2.30 ± 0.14	[2]
Ikot Ekwuo, Ibiono	238.10 ±22.47	8.26 ± 2.06	9.13 ± 1.03	[15]
Ikot Ekoi, Ibiono	73.84 ±7.35	6.11 ±1.58	8.13 ± 0.91	[15]
Use Ikot Amama, Ibiono	106.58 ± 8.63	3.16 ± 0.80	5.94 ± 0.60	[15]
Uyo, Uyo	67. 37 ± 3.29	12.13 ±1.98	19.09 ± 0.71	[20]
Ibeno	62.34 ± 3.33	21.78 ± 2.32	21.47± 0.76	[20]
Ikot Abasi	76.16 ± 3.24	12.42 ± 1.62	12.76 ± 0.75	[20]
Abak	98.709 ± 7.693	24.826 ±5.425	5.772 ± 0.310	[21]

In Uta farm the AC in cassava (Table 3) was determined and ^{40}K was ranged between 289.03 ± 20.77 - 520.67 ± 37.56 (440.58 ± 24.09) Bq/Kg (DW), the deposited ^{238}U ranged between BDL -7.77 ± 1.81 (4.14 ± 0.96) Bq/Kg (DW) while the AC of ^{232}Th ranged between BDL – 16.34 ± 1.59 (9.24 ± 0.90) Bq/Kg (DW). Measurements of AC in cassava in Mba farm recorded an activity concentration of ^{40}K value ranging between 213. 96 ±15.38 – 476.37 ± 34.21 (138.81 ± 27.29) Bq/Kq (DW), ^{238}U recorded an AC range of 10.68 ± 2.48 – 33.02 ± 8.91(20.86 ± 5.26) Bq/Kq (DW) while activity concentration of ^{232}Th values recorded ranged from 4.71± 0.46 – 12. 15 ±1.18 with a mean of 7.94 ± 0.78 Bq/Kq (DW). Results presented show a high deposition of potassium in the cassava tubers while absorption of other radionuclides is low. Comparison of the activity concentration in cassava in this study with previous study in the Akwa Ibom State is impossible because literature searches reveal no report in the study area. Therefore we compare with study elsewhere in Nigeria. The mean value of the AC of potassium obtained for this study is higher than that obtained in Oyo state, Nigeria [20], Delta State, Nigeria [21,22,23]. However, the mean value in Uta farm is higher than world mean of 400 Bq/Kg for ^{40}K. This high value of potassium could be as a result of the fact that potassium is an essential element required for proper plant growth [24,25]. Furthermore, it was reported that the presence of potassium and calcium in the soil affect the transfer of other radionuclides into the plants which could also be responsible for the lower value of activity concentration of uranium and thorium presented [26]. It is also observed that the mean AC values obtained for ^{238}U and ^{232}Th are lower than the world mean of 35 Bq/Kg and 30 Bq/Kg respectively.

Table 4. Activity concentration of measured radionuclides in Cassava in Uta farm

Sample code	Radionuclides		
	^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)
W_1	520.67 ± 37.25	4.22 ± 0.98	15.47 ±1.51
W_2	289.03 ± 20.77	7.77 ± 1.81	BDL
W_3	520.67 ± 37. 25	3.51 ± 0.82	12.89 ± 1.26
W_4	350.96 ± 25.17	6.15 ± 1.40	7.58 ± 0.77
W_5	418. 02 ± 29.93	BDL	16.34 ± 1.59
Min	289.03 ± 20.77	5.18 ± 1.21	1.49 ± 0.15
Max	520.67 ± 37.25	7.77 ± 1.81	16.34 ± 1.59
Mean	440.58 ± 24.09	4.14 ± 0.96	9.24 ± 0.90

Table 5. Activity concentration of measured radionuclides in cassava in Mba farm

Sample code	Radionuclides		
	^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)
X_1	476.37 ± 34.21	33.02 ± 8.91	7.98 ± 0.79
X_2	381. 68 ± 27.34	28.32 ± 7.16	5.05 ± 0.49
X_3	378. 35 ± 28. 69	10. 68 ± 2.48	12.15 ± 1.18
X_4	453.68 ± 32.50	11.72 ± 2.74	9.83 ± 0.96
X_5	213.96 ± 15.38	20.55 ± 4.99	4.71 ± 0.46
Min	213.96 ± 15.38	10.68± 2.48	4.71 ±0.46
Max	476.37 ± 34.21	33.02 ± 8.91	12.15 ± 1.18
Mean	138. 81 ± 27.29	20.86 ± 5.26	7.94 ± 0. 78

3.3 Transfer Factors of Radionuclides from Soil to Cassava Tubers

Transfer factor of radionuclides in plant measures the contamination level of the plant by the radionuclide. It is useful in evaluating radiological risk to humans and animals when the plant is consumed. Using equation 2, the soil – to – cassava transfer factor of ^{40}K, ^{238}U and ^{232}Th were determined and presented in Table 6. Transfer factors obtained ranged between 3.21 to 4.18 for ^{40}K; 0.93 to 12. 64 for ^{238}U and 0.75 to 1.01 for ^{232}Th. The TF value for potassium obtained for this work is higher while TF for Thorium is lower than those obtained elsewhere [12, 18]. It is also observed that in one of the farms the TF of ^{238}U is higher while its activity concentration in the soil is low which agrees with findings obtained in other works showing that TF are not linearly related to radionuclide activity concentration [18,16]. However, the radiological health effect of the contaminated food could be reduced by cooking the food stuff before consumption since radionuclide content in food crops are reduced when cooked [27]. There are evidences of non-linearity in the transfer of elements, both stable and radioactive, from soil to plants [28,29]. Regression analyses performed did not show a linear relationship between the transfer factor and activity concentration in soil for the primordial radionuclides. There were cases where activity concentrations in plants were relatively constant or with narrower variation range at widely varying soil concentrations. This resulted in a large random variation between the two parameters [28]. Reports from other studies have also shown that the transfer factor for various natural radionuclides were not constant over a wide range of soil concentrations [30,31,32,33,34]. There is a non-linear relationship between the activity concentrations of radionuclides in the soil and plant.

3.4 Effective Dose Due to Consumption of Radionuclide in Food Stuff

Effective dose E (mSv/yr) due to the consumption of the cassava tubers from the studied area by children and adults are calculated and presented in Table 7. In the calculation of the dose, it is assumed that the mean annual consumption of cassava in Akwa Ibom State, Nigeria is 127.20 Kg/yr and 343.10 Kg/yr for children and adult respectively [35]. Effective ingestion dose ranges from 1.31 mSv/yr to 1.74 mSv/yr for children while the ingestion dose for adult range from 3.52 mSv/yr to 4.69 mSv/yr for adult. These values are higher than 1 mSv/yr which is the annual dose limit recommended for safety of the general public. This could pose a serious radiological health hazard to the consumer [17].

Table 6. Transfer factors from soil to cassava in the studied areas

Farm	Radionuclides		
	^{40}K	^{238}U	^{232}Th
Uta	4.18	0.93	1.01
Mba	3.21	12.64	0.75

Table 7. Ingestion dose for children and adult due to consumption of cassava from study areas

Farm	Effective dose for children and adult	
	Children (mSv/yr)	Adult (mSv/yr)
Uta	1.31	3.52
Mba	1.74	4.69

4. CONCLUSION

This study was conducted to provide baseline data for transfer factors of radionuclides from soil to cassava for Ini Local Government Area, Akwa Ibom State. The TF and effective ingestion dose results for this study were above the recommended value of unity which suggests that consumption of cassava from the studied area may pose radiological health risk, hence to minimize these effect it is recommended that the food stuff be cooked even though it is reported that there is no low dose of radiation exposure that does not have radiological effect on human.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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