Journal of Scientific Research & Reports

23(5): 1-15, 2019; Article no.JSRR.48782
ISSN: 2320-0227

Uptake and Distribution of Natural Radionuclides in Cassava Crops from Nigerian Government Farms

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Authors' contributions

This work was carried out in collaboration among all authors. Author CPO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors OA and GOA managed the analyses of the study. Author CPO managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2019/v23i530130
Editor(s):
(1) Dr. Rajkumar Venkatesh Raikar, Department of Civil Engineering, KLE Dr. M. S. Sheshgiri College of Engineering and Technology, Karnataka, India.
Reviewers:
(1) Abiola Olawale Ilori, University of KwaZulu-Natal, South Africa.
(2) Nkuba, Leonid Leopold, Tanzania Atomic Energy Commission, United Republic of Tanzania.
Complete Peer review History: http://www.sdiarticle3.com/review-history/48782

Original Research Article

Received 22 February 2019
Accepted 28 April 2019
Published 25 May 2019

ABSTRACT

Radioactivity distribution and transfer factor (TF) in plants are crucial parameters used to assess radioactive contamination in the environment, impact of soil radioactivity on agricultural crops and its risks to humans. The root crop cassava (*Manihot esculenta*) provides about 50 percent of the calories consumed in Nigeria. Gamma - ray spectroscopy was used to measure activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in cassava root and soil. The average activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in cassava was 565.31± 13.17, 21.89±5.94 and 817.28±2.52 Bqkg^{-1} respectively. The mean activity concentration ^{40}K, ^{226}Ra and ^{232}Th in soil range from 92.07±35.08 to 689.28±14.35 Bqkg^{-1}with a mean value of 413.64±21.22 Bqkg^{-1}, 5.37 ± 8.90 to 64.93 ± 7.23 Bqkg^{-1} with a mean value of 54.43 ± 3.22 and BDL to 928.15 ± 2.36 Bqkg^{-1} with a mean value of 561.67 ± 2.21 Bqkg^{-1}. The transfer values for ^{226}Ra, ^{232}Th and ^{40}K were in the range of 0 to 1.81, 0 to 3.41 and 0.68 to 4.5 respectively. The high value of transfer factor for ^{40}k may be due to its importance in plant growth, fertilization and adaptability of plant to environmental pressures. It may have also been enhanced by the application of NPK fertilizers in those farms. Thorium showed the highest mean transfer factor which may be due to its higher accumulation in soil and higher uptake by plants (Figure 3). The average transfer factors of ^{226}Ra (0.99) < ^{40}K (1.55) < ^{232}Th (1.66) show

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that although activity concentration of the natural radioisotopes in the area under study are high, the rate at which they are transferred to cassava are still moderate. The average values of radium equivalent activity (Raeq), absorbed dose rate (D), annual effective dose rate (AEDE), internal hazard index and excess life cancer risk (ELCR) are 1009.27 Bqk^{-1}, 346.50 $nGyh^{-1}$, 1.51 $mSvy^{-1}$, 2.78 and 3.92 x 10^{-3} for respectively. These values were higher than their corresponding permissible values of 370Bqk^{-1}, 55$nGyh^{-1}$, 1.0 $mSvy^{-1}$, 1.0 and 0.29 x 10^{-3} respectively. The mean values of H_{ex} and H_{in} are greater than unity and may, therefore, constitute a significant radiological health risk. The mean annual gonad dose estimated value of 2943.90 $mSvy^{-1}$ was above the world acceptable value of 300 $mSvy^{-1}$ and the annual effective dose in all the samples except in few locations as shown in Figure 2, exceeded the safe value of 1.0 $mSvy^{-1}$. The use of soil from these farms and the crops may constitute a threat to the bone marrow and general health conditions of the inhabitants.

Keywords: Manihot esculenta; transfer factor; spectroscopy; radionuclide; stochastic.

1. INTRODUCTION

Food is one of the most important needs of man and the increasing world population has become a threat to global food security. The need to increase food production therefore arises to ensure food security for the growing world population. Due to this important need of man, Chemical fertilizers are employed in agriculture to reclaim land and enhance crop yield [1]. Chemical fertilizers are chemical compounds that provide necessary elements and nutrients to the plants [2].

Just like the rest of the world, Nigeria's population is increasing and there is also the need to increase availability of food by increasing the rate of food production via application of chemical fertilizers. The major raw materials for the production of chemical fertilizers must therefore supply the essential nutrients necessary for plant growth. The essential nutrients are Nitrogen, phosphorus and potassium. Natural radioactivity of mainly Uranium-238(^{238}U), Thorium-232 (^{232}Th) and Potassium-40 (^{40}K) seen in phosphate fertilizers emanate from the phosphate ore, (due to geological reasons) which is the main raw material used for phosphate fertilizer production. The application of phosphate fertilizer globally for increased crop production and land reclamation has risen to more than 30 million tons annually [3].

The supply of plant nutrient is limited and depleted with every harvest leading to a drastic reduction in quality and yield in crop plant. The normal concentration of uranium in phosphate rocks is between 30 and 260 ppm which by far exceeds its abundance in the earth's crust. The application of chemical fertilizers may increase the phosphate and uranium concentration in the soil thereby increasing the concentration in nutrients. Apparently, the fertilizers applied in the Niger-Delta region may redistribute naturally occurring radionuclides at trace levels throughout the soil and therefore become a source of radioactivity.

Uptake of radionuclides by plants occurs both via the root system and from atmospheric deposition through activity trapping onto external plant surfaces [4]. The bioavailability of radionuclides in soils and hence their transfer to plants are rather complex depending on several factors. These factors include the chemistry of the specific radionuclides, soil type and climatic conditions, soil pH, solid/liquid distribution coefficient and organic matter [5, 6, 7]. The uptake of radionuclides by plant roots constitutes the main pathway for the migration of radionuclides from the soil to humans, via food chain.

Cassava, a root crop exhibits greater root absorption of radionuclide than through the trapping onto external plant surfaces though there is some level of atmospheric capture [8]. Cassava (*Manihot esculenta)* represent about 50% of all calories consumed in sub-sahara Africa [9] and is the third most important source of calories in the tropics [10]. The edible root varies significantly in size from 15 to 100 cm as well as in weight from 0.5 to 2.0 kg [11]. In addition to being the most consumed staple crop in the study area and several other communities, cassava is also used as raw material for the production of industrial starch, ethanol and animal feed [12]. Some of the most popular foods prepared from Cassava is garri, fufu (local dish) and tapioca served with nuts and coconut or local dish (African salad). Another Cassava product is the roasted or grilled and boiled Cassava from a special specie (red bark).

The transfer factor (TF) expresses the plant intake of radionuclide from the soil and is commonly used in environmental transfer models to estimate dose impact on humans [5]. Many researches have shown clearly that any dose of radiation increases an individual's risk of developing cancer. However, radiation levels can be concentrated in the food chain and further consumption adds to the cumulative risk of developing cancer and other diseases [13].

The radioactivity level in soil can plausible be used to show the magnitude of contamination in locally grown food crops, but it cannot describe the biological effects of radiation exposure to individuals who consume that food [7]. Therefore the estimation of doses is usually carried out for assessing health safety of an individual undergoing radiation exposure through ingestion of contaminated food. The intake of radionuclide within food is dependent on the concentration of radionuclides in various food crops and on the food consumption rates [7,13]. The risks associated with an intake of radionuclides in the body are proportional to the total dose delivered by radionuclides while staying in various organs. In general, it is assumed that stochastic effects occur linearly with dose and usually the annual effective dose quantities (AEDE) are used to define those risks when prolonged exposure to a single intake of a radionuclide is being considered [9].

Radioactivity can be detected in food and water; the concentrations of these naturally-occurring radionuclides vary depending on factors such as the type of food, local geology, climate and agricultural practices [14]. Scientists have identified that some chemical constituents of food either initially present in the food, formed during preparation (especially cooking), or added for preservation are capable of inducing cancers or tumors in high-dose rodent tests. Children have a higher risk of exposure to carcinogens in food as they consume more foods, drink more liquids, and take in more air than adults do. The fact that children have rapidly developing organ systems, especially the central nervous system and the brain, makes them highly susceptible to chemical interference as they are also less able to metabolize and excrete most toxic substances [15]. Some radionuclides have a tendency to concentrate in certain tissues because of their interaction with normal physiological processes. For example, cesium and strontium isotopes tend to congregate in bones, whereas the thyroid gland selectively concentrates iodine [16,17].

Absorption of radioisotopes from food stuff may damage the kidneys, lungs, liver, skeleton tissues and muscles [18]. The accumulation of enormous levels of radioisotopes in these delicate organs affect the health condition of persons such as weakening the immune system, sterility, cancer, inducing of various shades of diseases and eventually increase mortality rate. There is then obvious need to know the level of radionuclides concentration and ascertain its radiological health risks to the consumers of those products. The aim of this study is to determine the soil to crop (plant) transfer factor (TF) in order to assess the impact of soil radioactivity on agricultural crops and the health implication on man who is the final consumer.

2. MATERIALS AND METHODS

2.1 Study Area

The study area includes the cities of Agbor, Ogwashi-Uku, Ibusa and Igbodo, of Delta state, Nigeria. Agbor lies between Longitudes 6°25’N and Longitude 6°19’E. Ogwashi-Uku lies between Latitude 6 °18’N and Longitude 6°52’E, Ibusa lies within latitude 6°10’N and 6°37’ while Igbodo is between 6°18’N and 6°22’E as shown in Fig. 1. These four cities represent four different districts among the twenty five LGAs in Delta state. Agbor and Igbodo lie between Orogodo and Namomah Rivers and are known as Ika dialect speakers. They belong to Ika south and Ika-North-East LGAs. Ogwashi-Uku and Ibusa are Aniocha South and Oshimili North LGAs respectively. Agbor is bounded on the east by Emuhu, on the West by Alihame, on the north by Ottah in Edo state and on the south by Owanta. Igbodo is bounded on the east by Onitcha-ugbo, west by Akumazi, on the north by Idumuje-Ugboko and south by Obior. Ogwashi-ukwu is located at the west of Asaba, the capital of Delta State. Ibusa (Igbuzo) is bounded on the east by Asaba and Ogwashi-ukwu on the west, Okpanam north-wise and Aballa to the south. Delta State is under the Niger Delta Structural Basin, it has three major sedimentary cycles which have occurred since the early Cretaceous.

The sub-surface stratigraphic units associated with the cycles are, the Benin, the Agbada and the Akata Formations. The surface rock throughout the state consists of the Ogwashi-Ukwu formation. The Benin formation is about

1800m and has free, unconsolidated sands. Agbor and Igbodo lies within this formation, this formation previously known as the coastal Plain sands span over a considerable portion of the coastal region of Nigeria, adjacent to the Deltaic Plain Sediments. The formation generally consists of unconsolidated sandy beds and clay-lenses [19]. The Agbada Formation which consists of sandstone and shales has an abundance of hydrocarbons. It is about 3000m and is underlain by the Akata Formation. The Ogwashi-Asaba Formation that underlies the north-east consists of a transposition of lignite seams and clay. The vegetation of the area is under the savannah vegetation.

2.2 Sample Collection and Sample Preparation

12 samples of cassava crop and 12 samples of soil were collected from three (3) selected Government farms in Niger Delta region of Nigeria. Six (6) samples each of cassava and soil were taken from the Ministry of Agriculture, Agbor, in Ika-South LGA, two (2) samples of cassava and soil each from Agricultural Development Program (ADP), Illoh-Ogwashi-ukwu in Aniocha South LGA, and Ibusa in Oshimili North LGA respectively. All these farms uses fertilizer to improve the crop yield. Two (2) Samples of cassava and soil were taken from an unfertilized farm as control samples.

At each sampling site, about 2 kg cassava (fresh weight) samples were collected using plastic trowel and initially thoroughly washed with tap water and then in distilled water to remove surface sand. From each site soil samples of approximately 1.5 kg (wet weight) were collected into separate plastic containers. The two sets of samples were each placed into separate polyethylene bags. In the laboratory, the cuticles of the cassava were removed with a stainless steel knife and the edible parts were cut into pieces of about 10 mm and put together in polyethylene materials for refrigeration.

The samples were freeze-dried for three days and were pulverized by means of a cleaned industrial blender and kept separately in their respective containers. About half of the samples from one farm were put together and gave exhaustive mixing using a homogenizer and sub-sample of 700 g each were put into fresh cleaned plastic containers and re-labelled.

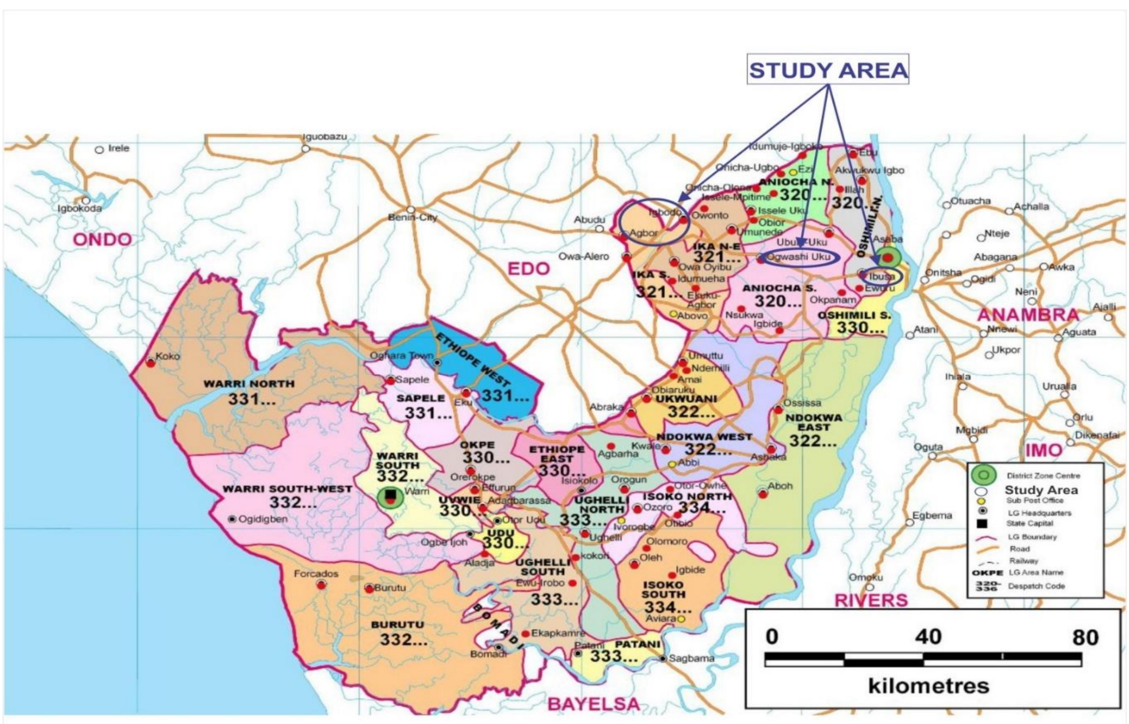

Fig. 1. Map showing the study area
(Source: Delta State Medium Term Development Plan (DSMTDP; 2016-2019)

The soil samples after oven drying at a temperature of 110ºC for 3 days were pulverized in a pulverizer and the sub-samples prepared similarly as the cassava samples [20]. The samples were further sieved in 110 µm mesh sieve to obtain smaller grain sized sand particles before they were subjected to radioactivity measurement. The homogenized samples were weighted and hermetically sealed packed in plastic 500 ml marinelli containers. The containers with the same size and geometry were used for the reference materials for the efficient calibration of the detector system. The samples were filled to an indicated mark on the marinelli container and the mass determined by simple calculation after weighing empty container together with sample and the container alone. The containers were closely tight to limit the escape of radon. Each marinelli container was analyzed after 30 days after ^{226}Ra and ^{232}Th assumed secular equilibrium with their short-lived decay products using sodium iodide detector.

2.3 Determination of Specific Radio-activity in Samples

The measurement of specific activity concentration of radionuclides in the samples under consideration was made with a high resolution gamma-ray spectrometry system. A 2”×2” Sodium iodide [NaI (TI)] detector connected to ORTEC digiBase Multichannel Analyzer (MCA) was used. The digiBase is connected to a computer where data collection and analysis are carried out using ORTEC MAESTRO -32 software. IAEA standard materials were used for calibration [19].

The radioactivity measurement of the samples was made by placing them on the detector inside the lead shielding and spectrum was collected. The same geometry was used to determine peak area of samples and references. Each sample was measured during an accumulation time of 36,000s. The activity concentration was calculated based on the weighted mean value of their respective decay products in equilibrium. The gamma ray lines of 295.2 (18.2), 351(35.1) keV from ^{214}Pb and 609.3 (44.6), 1764.5 (15.1) keV from ^{214}Biwere used to determine the activity concentration of ^{226}Ra. The gamma lines of 338.4, the 911.2 (26.6) keV from ^{228}Ac , the 727.3 keV from ^{212}Bi and 583.2 (30.6) keV from 208 Ti were used to determine the activity concentration of ^{232}Th.

The activity concentration of ^{40}K was measured directly by its own gamma ray at 1460.8 (10.7) keV. The values inside the bracket indicate the absolute emission probability of the gamma decay. The gamma-ray background around the detector inside the shielding was determined using an empty container under identical measurement conditions. The background counts were determined by counting an empty container of the same dimension as those containing the samples and subtracting from the gross count. The activity content of the samples was evaluated by the net area under the photo peaks using:

$$A_c = \frac{C_n}{P\gamma\ M\ \varepsilon} \tag{1}$$

Where, A_c is the activity concentration in Bqkg^{-1}, C_n is the net count rate under the corresponding peak; Pγ is the absolute transition probability of the γ -ray. M is the mass of the sample (kg) and e is the detector efficiency at the specific γ-ray energy.

2.4 Radionuclide Uptake and Transfer Factor

Natural radionuclides are in different concentrations in soil. Human activities like routine and accidental discharge of nuclear waste, production of energy, use of fertilizers and mining have altered their natural concentration in the environment. The earth contains varied degrees of radioactivity due to radioactive decay of ^{238}U and ^{232}Th series [21].

Generally plants take in radionuclides via foliar absorption and root uptake from the soil. The expected content of radioisotopes is described by the transfer factor parameter. It describes the radionuclides expected in plants sequel to their concentration in the soil. Absorption of radioisotopes is enhanced at the initial plant growth stage meaning that absorption varies with plant growth. The transfer factor depends also on the mass of plant. Equation 1 below expresses the dependence of transfer factor on mass [22].

$$TF(m) = TF(0)(\frac{m}{m_0})^{\alpha-1} \tag{2}$$

Where m_0 is the initial plant mass, TF (0) is the initial value of the transfer factor at t = 0, m = m_0, α is a function that determines the rate of decrease of transfer factor with increasing plant mass. Transfer factors can also be defined based on dry weight, as ratio of activity content

(Bqkg^{-1}) in plant to activity content (Bq·kg^{-1}) of soil or can be based on surface area of soil and expressed as Bq·kg^{-1} dry weight of plant to Bq·m^{-1} in soil [21].

In most cases, the dissemination of radioisotopes is not homogeneous in depth. The International Union of Radioecology (IUR) recommends a standardized root location in order to deal with this soil depth variability. The recommended soil depth is 10 cm for grass and 20 cm for all other crops and trees. The radioisotope content at this depth is homogeneous.

This transfer factor is then expressed as [22]:

$$TF = \frac{A_p Bq\ kg^{-1}}{A_S Bqkg^{-1}} \quad (3)$$

Where A_P = Activity concentration in the plant (Bqkg^{-1} dry weight) and A_S = Activity concentration in soil (Bqkg^{-1} dry weight).

3. RESULTS AND DISCUSSION

3.1 Radioactivity Concentration in Cultivated Fertilized Soil and Cassava Food Crop

The radioactivity concentration of radionuclides in the fertilized soil and cassava crop samples are presented in Tables 1 and 2 respectively. With the exception of one sampling site (S-Illoh 1), the activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in the soil samples are quite higher than those of the reference soil samples. The lower concentration at point (S-Illoh 1) could be attributed to sloping nature of the point which resulted in poor crop yield due to nutrient depletion. The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in soil were comparatively higher than the global average values of 400, 30 and 35 Bqkg^{-1} respectively [23].

4. DISCUSSION

4.1 Activity Concentration of ^{40}K, ^{226}Ra and ^{232}Th in Soil and Cassava Crops

The average activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in soil from cultivated government farms were higher than the world average of 400, 35 and 30 Bqkg^{-1} respectively. ADP Illoh had the highest ^{40}K concentration which may be due to enhanced use of NPK fertilizers compared to other locations with lower values, while ADP Igbodo had the highest average value for ^{232}Th which may be due to higher clay content compared to other locations with lower values. The average activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in cassava crop were found to be much greater than the world value of 50(25-75), 8(1-9) and 3(2-10) Bqkg^{-1} [24]. By comparing Tables 1 and 2, it is obvious that the mean concentration of ^{40}K and ^{232}Th in the sample crops are repeatedly higher than their corresponding mean activity composition in soil. The content of radioisotopes in the soil should be greater when related to the corresponding food crop owing to radioisotope solubility. The opposite has been observed in this work and may be due to difference in soil properties of the study area considered by Ole, relative to radionuclide retention under different weather conditions. High values of ^{232}Th and ^{40}K were observed in all samples. This may be due to high clay content of the soil (for ^{232}Th) [22,25] and the use of fertilizers (for ^{40}K). ^{40}K is also known as a very important nutrient for fertilization hence the high uptake by plants. Also, the high values of thorium observed in the crops may have been acquired during the process of sun drying in the open air during which natural radioactive particles in air could settle on them [26]. The result of this work is generally higher than the results obtained in available literatures [27,28, 29,30,31]. These values suggest that the consumption of the cassava crop in this area might pose a high potential health hazard to consumers.

The mean activity concentrations ^{40}K and ^{232}Th in soil samples were higher than the world average value of 400 Bqk^{-1} and 30 Bqk^{-1} [32]. It is pertinent to note that different soil properties and weather conditions affect the accumulation of radioisotopes. The accumulation of ^{40}K may be affected by several determinants such as cation exchange capacity (CEC), type and pH of the soil [7,33]. The soil type fall under the clay mineral property which usually bear a negative charge. According to Wild, [34], the negative charge on the clay is balanced by that on the cations through the CEC process. Potassium is one of the basic cations and so the ability of the soil to hold cations increases its presence. The high values of thorium obtained may be due to the occurrence of thorium erosion process during which it is adsorbed in the soil immediately [34]. It may also have been due to the application of fertilizers to the soil and high clay content [18]. It is important to note that the activity composition

Table 1. Specific activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in soil samples from agricultural farms

S/N	Sample location	Sample code	GPS Position	^{40}K Bqkg^{-1}	^{226}Ra Bqkg^{-1}	^{232}Th Bqkg^{-1}	Raeq Bqkg^{-1}
1	Ministry of Agriculture, Agbor	SMOA1	N: 6°15'37'.0075 E:6°11'16'.29683	92.07 ± 35.08	33.23 ± 4.46	229.96 ± 4.15	369.16
2	Ministry of Agriculture, Agbor	SMOA2	N:6°15'34.48112 E:6°11'16'.57248	556.21 ± 13.25	35.15 ± 8.15	734.10 ± 2.75	1127.74
3	Ministry of Agriculture, Agbor	SMOA3	N:6°15'29.38142 E: 6°11'15.45835	425.67 ± 13.79	45.72 ± 8.59	880.37±2.36	1337.43
4	Ministry of Agriculture, Agbor	SMOA4	N: 6°15' 40.235 E:6°11'16'.39362	278.21 ± 23.62	64.93 ± 7.23	725.33 ± 2.76	1123.57
5	Ministry of Agriculture, Agbor	SMOA5	N:6°15' 29.334 E:6°11'16'.46425	347.10 ± 16.67	28.91 ± 7.43	880.37±2.36	1314.57
6	Ministry of Agriculture, Agbor	SMOA6	N: 6°15' 35.434 E:6°11'16'.54682	119.87 ± 53.69	33.23 ± 7.66	ND	42.46
7	ADP Illoh	S-Illoh 1	N: 6°6' 4.90612 E: 6°31'56.33285	315.68 ± 25.50	5.37 ± 8.90	146.10 ± 4.95	238.60
8	ADP Illoh	S-1lloh 2	N: 6°6' 5.07892 E: 6°31'56.46072	487.31 ± 14.01	51.48 ± 3.68	928.15 ± 2.36	1416.26
9	ADP Ibusa	S-Ibusa1	N: 6°11' 1.58359 E: 6°39' 7'.85948	448.63 ± 19.30	46.20 ± 6.13	826.74 ± 2.48	1262.98
10	ADP Ibusa	S-Ibusa 2	N: 6°11' 1'.59473 E:6°39' 7'.73865	505.44 ± 12.90	25.55 ± 4.90	824.79 ± 2.46	1243.92
11	ADP Igbodo	S Idumu 1	N: 6°18'4.99745 E: 6°23'5.24733	689.16 ± 12.53	27.47 ± 5.18	864.77 ± 2.45	1317.16
12	ADP Igbodo	S Idumu 2	N:6°18'0'.94656 E: 6°23'0'.43534	689.28 ± 14.35	35.40 ± 6.47	718.69 ± 2.88	1317.44
Average				**413.64±21.22**	**54.43 ±3.22**	**561.67±2.21**	**1009.27**

Table 2. Specific activity concentration of ^{40}K, ^{238}U and ^{232}Th in cassava crop samples from agricultural farms

S/N	Sample crop location	Sample code	GPS Position	Activity concentrations (Bqkg^{-1})			Raeq Bqkg^{-1}
				^{40}K	^{238}U	^{232}Th	
1	Ministry of Agriculture, Agbor	CMOA 1	N: 6°15'37'.0075 E:6°11'16'.29683	455.89 ± 14.72	60.13± 6.83	792.61 ± 2.53	1228.67
2	Ministry of Agriculture, Agbor	CMOA 2	N:6°15'34.48112 E: 6°11'16'.57248	654.11 ± 11.07	6.33±2.99	819.91 ± 2.60	1229.17
3	Ministry of Agriculture, Agbor	CMOA-3	N:6°15'29.38142 E: 6°11'15.45835	443.80 ± 12.32	12.10 ± 8.67	776.03 ± 2.53	1156.00
4	Ministry of Agriculture, Agbor	CMOA 4	N: 6°15' 40.235 E: 6°11'16'.39362	534.45 ± 13.19	33.71± 6.66	833.56 ± 2.63	1266.85
5	Ministry of Agriculture, Agbor	CMOA-5	N:6°15' 29.334 E:6°11'16'.46425	544.11± 11.79	26.99 ± 6.72	930.10 ± 2.40	1398.93
6	Ministry of Agriculture, Agbor	CMOA 6	N: 6°15' 35.434 E:6°11'16'.54682	753.22 ± 10.12	BDL	576.13 ± 2.85	887.05
7	ADP Illoh	C- Illoh 1	N: 6°6' 4.90612 E: 6°31'56.33285	505.44± 15.59	10.66± 7.62	848.19±2.47	238.60
8	ADP Illoh	C-Illoh 2	N: 6°6' 5.07892 E: 6°31'56.46072	795.53± 9.96	13.54± 6.23	826.74±2.39	1262.49
9	ADP Ibusa	C-Ibusa 1	N: 6°11' 1.58359 E: 6°39' 7'.85948	403.91 ± 18.00	26.99 ± 7.46	814.06 ± 2.48	1257.03
10	ADP Ibusa	C-Ibusa 2	N: 6°11' 1'.59473 E:6°39' 7'.73865	564.67 ± 14.93	28.43 ± 6.23	955.46 ±2.33	1222.20
11	ADP Igbodo	M-Idumu1	N: 6°18'4'.99745 E: 6°23'5'.24733	472.81± 10.26	24.59 ±10.87	918.40 ± 2.46	1438.22
12	ADP Igbodo	M-Idumu 2	N:6°18'0'.94656 E: 6°23'0'.43534	546.54 ± 10.77	25.07 ± 10.87	800.41 ± 2.47	1211.74
Average				**746.08 ± 0.48**	**24.83 ± 10.87**	**859.41 ± 2.47**	**1324.98**

Table 3. Transfer factors of ^{40}K, ^{226}Ra and ^{232}Th for cassava crop

S/N	Sample location	Sample	^{40}K	^{226}Ra	^{232}Th
1	Ministry of Agriculture, Agbor	MOA 1	4.50	1.81	3.41
2	Ministry of Agriculture, Agbor	MOA 2	1.18	1.81	1.11
3	Ministry of Agriculture, Agbor	MOA 3	1.04	0.26	0.88
4	Ministry of Agriculture, Agbor	MOA 4	1.92	0.51	1.17
5	Ministry of Agriculture, Agbor	MOA 5	1.28	0	0
6	Ministry of Agriculture, Agbor	MOA 6	1.56	0.93	0.61
7	ADP Illoh	ADP Illoh 1	1.60	1.98	5.80
8	ADP Illoh	ADP Illoh 2	1.63	0.26	0.89
9	ADP Ibusa	ADP Ibusa 1	0.90	0.58	0.98
10	ADP Ibusa	ADP Ibusa 2	1.12	1.11	1.10
11	ADP Igbodo	Idumu 1	0.68	0.89	1.06
12	ADP Igbodo	Idumu 2	0.71	0.76	1.28
Average			**1.55**	**0.99**	**1.66**

Table 4. Radiological risk parameters for soil

S/N	Soil sample location	Soil sample	D ($nGyh^{-1}$)	Indoor AED ($mSvy^{-1}$)	Outdoor AEDE ($mSvy^{-1}$)	AGDE $Bqkg^{-1}$	ELCR	H_{ex}	H_{in}	Iγr	AUI
1	Ministry of Agriculture, Agbor	SMOA1	162.40	0.42	0.58	1092.82	1.46	1.00	1.09	2.58	3.25
2	Ministry of Agriculture, Agbor	SMOA2	496.58	1.28	1.77	3351.80	4.48	3.04	3.14	7.95	9.93
3	Ministry of Agriculture, Agbor	SMOA3	587.17	1.51	2.09	3954.88	5.29	3.61	3.73	9.39	11.74
4	Ministry of Agriculture, Agbor	SMOA4	493.33	1.27	1.75	3319.87	4.45	3.03	3.21	7.87	9.87
5	Ministry of Agriculture, Agbor	SMOA5	576.17	1.48	2.05	3878.27	5.19	3.55	3.63	9.23	11.52
6	Ministry of Agriculture, Agbor	SMAO6	20.28	0.05	0.07	140.32	0.18	0.11	0.20	0.30	0.41
7	ADP Illoh	S-Illoh 1	106.57	0.27	0.38	726.41	0.96	0.64	0.66	1.71	2.13
8	ADP Illoh	S-Illoh 2	622.14	1.60	2.21	4191.76	5.61	3.82	3.96	9.95	12.44
9	ADP Ibusa	S-Ibusa 1	554.93	1.43	1.97	3739.40	5.00	3.41	3.54	8.87	11.10
10	ADP Ibusa	S-Ibusa 2	546.551	1.41	1.94	3685.28	4.93	3.36	3.43	8.76	10.93
11	ADP Igbodo	S-Idumu 1	579.95	1.49	2.06	3916.02	5.23	3.56	3.63	9.29	11.60
12	ADP Igbodo	S-Idumu 2	492.43	1.81	1.21	3329.94	4.24	3.01	3.11	6.77	9.86
Average			**346.50**	**1.17**	**1.51**	**2943.90**	**3.92**	**2.68**	**2.78**	**6.89**	**8.73**

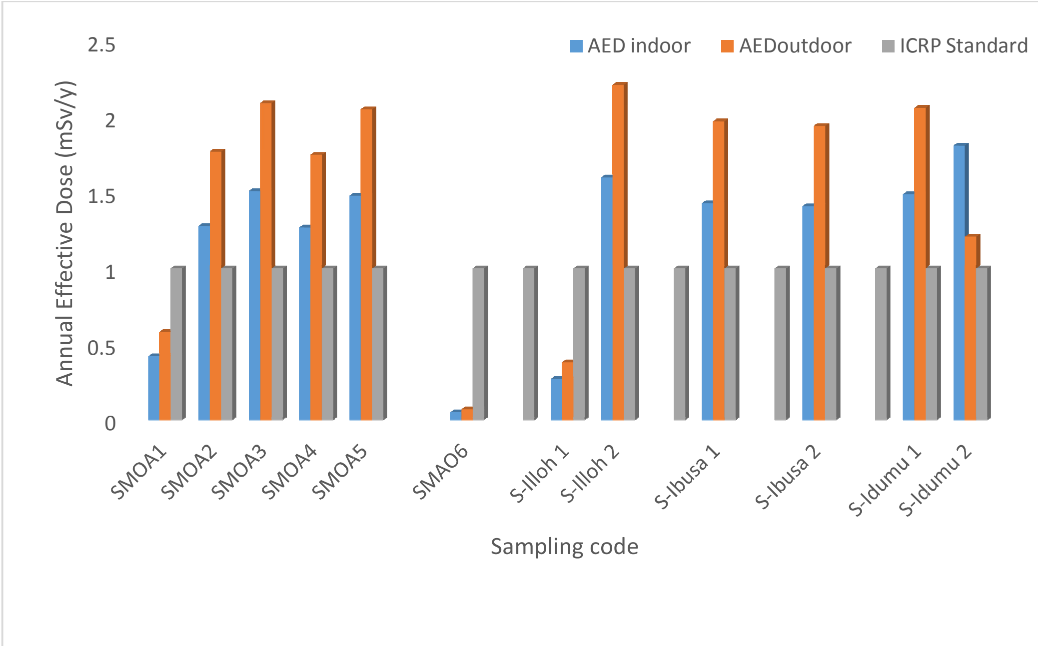

Fig. 2. Annual Effective Dose (AED) against standard for soil

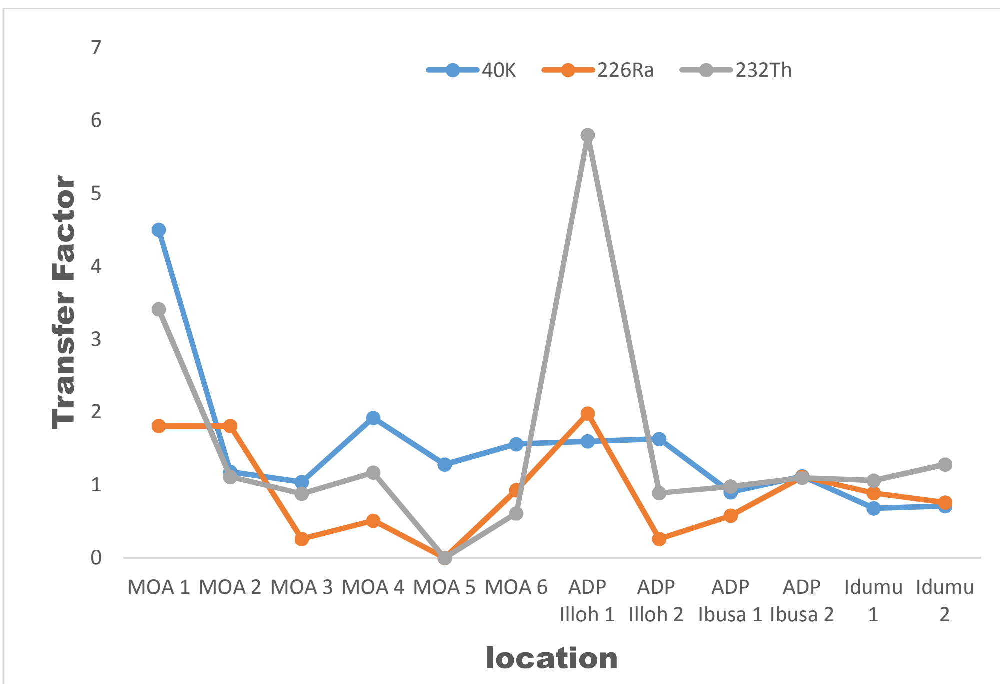

Fig. 3. Variation of transfer factor according to sample location

of all radioisotopes in the control sample are less than the mean values measured in the experimental samples. The average activity concentration of ^{226}Ra shows a slight increase in concentration higher than the world average of 35 $Bqkg^{-1}$ [32] which may be due to the application of fertilizers to recover soils of depleted nutrients due to farming and erosion

[35]. The variation in activity concentration of ^{40}K, ^{232}Th and ^{226}Ra in the three farms studied may be due to differences in fertilizer application and system of farming. The result of activity concentration of ^{40}K, ^{232}Th and ^{226}Ra obtained in this study were higher than those obtained in similar work done by other researchers except for potassium – 40 [2,8,18]. This may be due to differences in soil physio-chemical properties of the study areas and different fertilizers application.

The radiological health risk parameters calculated from activity concentration of radionuclides in the soil are presented in Table 4. The average values of radium equivalent activity (Raeq), absorbed dose rate (D), annual effective dose rate (AEDE), internal hazard index and excess life cancer risk (ELCR) are 1009.27 Bqk^{-1}, 346.50 $nGyh^{-1}$, 1.51 $mSvy^{-1}$, 2.78 and 3.92 x 10^{-3} for respectively. These values were higher than their corresponding permissible values of 370Bqk^{-1}, 55$nGyh^{-1}$, 1.0 $mSvy^{-1}$, and 0.29 x 10^{-3} respectively. The mean values of H_{ex} and H_{in} are greater than unity and may therefore constitute a significant radiological health risk. The mean annual gonad dose estimated value of 2943.90 $mSvy^{-1}$ was above the world acceptable value of 300 $mSvy^{-1}$ and the annual effective dose in all the samples except in few locations as shown in Fig. 2, exceeded the safe value of 1.0 $mSvy^{-1}$. The use of soil from these farms and the crops may constitute a threat to the bone marrow and general health conditions of the inhabitants [30].

4.2 Transfer Factor

The transfer factor (TF) is the ratio that depicts the quantity of radionuclide expected to enter the crop from soil [33]. TF for all radioisotopes were calculated using equation 3 and are recorded in Table 3. For ^{40}K, the transfer factor range from 0.68(Idumu$_1$) to 4.50 (MOA) with an average value of 1.55. ^{226}Ra was from 0.00 (MOA$_5$) to 1.81(MOA) with an average value of 0.99 while TF for ^{232}Th ranges from 0.00 (MOA$_5$) to 3.41 (MOA$_1$) with an average of 1.66. These values imply a moderate rate of radioisotope absorption by cassava. These values were above the recommended IAEA values for Thorium (8.2× 10^{-3}) and Uranium (^{226}Ra) (8.9 ×10^{-2}) for cassava for tropical environments. The high value of transfer factor for ^{40}k may be due to its importance in plant growth, fertilization and adaptability of plant to environmental pressures [36]. It may have also been enhanced by the application of NPK fertilizers. Thorium showed the highest mean transfer factor which may be due to its higher accumulation in soil and higher uptake by plants (Fig. 3). The average transfer factors of ^{226}Ra (0.99) < ^{40}K (1.55) < ^{232}Th (1.66) show that although activity concentration of the natural radioisotopes in the area under study are high, the rate at which they are transferred to cassava are still moderate. A lot of care must be taken in the use of transfer factor to determine food safety for consumption [28]. The mean transfer factor for ^{40}K, ^{226}Ra and ^{232}Th cassava crop samples obtained in this work are higher than the values of 0.18, 0.29 and 0.25 obtained by Ibitola et al. [37]. This could be due to differences in soil type, pH, organic matter and other related factors.

Transfer factor varies with location and plant type (Fig. 3). From the definition of transfer factor, it is assumed that the plant concentration increases with increased soil concentration. The result of this work shows the opposite of this assumption. For example, the activity concentration of ^{40}K in soil sample SMOA1 is 92.07 ± 35.08 $Bqkg^{-1}$ with a transfer factor of 4.50 while SMOA2 is 556.21 ± 13.25 $Bqkg^{-1}$ with a transfer factor of 1.18. Fig. 3 show the variation of TF according to the sample location. It is very obvious that ^{232}Th recorded TF value of 5.80 at ADP-Illoh 1. ADP farm uses phosphate fertilizer to improve soil fertility and such enhanced the concentration of thorium in that soil. The TF result of this work buttresses the fact that TFs are not linearly related to soil concentration [38]. Many factors affect the transfer factor such as physiochemical characteristics of radioisotopes and soil, plant species, soil pH and fertility, plant type, organic matter content and soil management practices. Comparing the result with available literatures, the transfer factor in this work is higher than the values obtained by Tchokossa et al. [28] except for potassium. It is also higher for all radionuclides when compared with results obtained by other researchers [30, 39,40,41]. This may be due to difference in soil properties and climatic conditions of the areas [19].

5. CONCLUSION

The uptake and distribution of natural radionuclide in cassava crops from Nigerian government farms was determined using gamma spectroscopy and radiation models. The activity concentration of ^{40}K, ^{232}Th and ^{226}Ra in soil and cassava crop samples were higher than the world average recommended by UNSCEAR and

IAEA respectively. The mean values of the transfer factor for ^{226}Ra, ^{232}Th and ^{40}K are 0.99, 1.66 and 1.55 respectively. These transfer factors for the radioisotope estimated show they are higher than the safe limit of 8.9×10^{-2} for ^{226}Ra, 8.2×10^{-6} to 3.9×10^{-5} for ^{232}Th in cassava crop. The concentration of radioisotopes in the food stuffs may not cause immediate health hazard to the public but there may be a long term accumulative effect following the dose intake from the consumption of the crops. The radiological parameters estimated from the activity concentration of radionuclide in soil exceeded their respective permissible limits. This implies that the use of fertilizer in agricultural farms enhances the concentration of nuclides in the soil thereby aiding the radiological contamination of agricultural products. Consumption of such products like the cassava in this study could be detrimental to human health.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle3.com/review-history/48782