

Original Research Article

UPTAKE AND DISTRIBUTION OF NATURAL RADIONUCLIDES IN CASSAVA CROPS FROM NIGERIAN GOVERNMENT FARMS

Abstract

Radioactivity distribution and transfer factor (TF) in plants are crucial parameters used to assess radioactive contamination in the environment, the 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 , ^{238}U 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 1.98, 0 to 5.80 and 0.68 to 4.5 respectively. 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 3.92×10^{-3} for respectively. These values were higher than their corresponding permissible values of 370Bqk⁻¹, 55nGyh⁻¹, 1.0 mSvy⁻¹, and 0.29×10^{-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

Comment [I1]: Scientific names should always be in italics

Comment [I2]: Gamma-ray is appropriate

Comment [I3]: Why is transfer value as high as this in this locality? Can you kindly include this as part of discussion in the abstract? Has the studied area be reported as a high background area (HBA)?

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40 necessary for plant growth. The essential nutrients are Nitrogen, phosphorus and potassium. Natural
41 radioactivity of mainly Uranium-238(²³⁸U), Thorium-232 (²³²Th) and Potassium-40 (⁴⁰K) seen in
42 phosphate fertilizers emanate from the phosphate ore, (due to geological reasons) which is the main raw
43 material used for phosphate fertilizer production. The application of phosphate fertilizer globally for
44 increased crop production and land reclamation has risen to more than 30 million tons annually [3].

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

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

58 Cassava, a root crop exhibits greater root absorption of radionuclide than through the trapping onto
59 external plant surfaces though there is some level of atmospheric capture [8]. Cassava (*Manihot*
60 *esculenta*) represent about 50% of all calories consumed in sub-sahara Africa [9] and is the third most
61 important source of calories in the tropics [10]. The edible root varies significantly in size from 15 to
62 100 cm as well as in weight from 0.5 to 2.0 kg [11]. In addition to being the most consumed staple crop
63 in the study area and several other communities, cassava is also used as raw material for the production
64 of industrial starch, ethanol and animal feed [12]. Some of the most popular foods prepared from
65 Cassava is garri, fufu (local dish) and tapioca served with nuts and coconut or local dish (African
66 salad). Another Cassava product is the roasted or grilled and boiled Cassava from a special specie (red
67 bark).

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

73 The radioactivity level in soil can plausible be used to show the magnitude of contamination in locally
74 grown food crops, but it cannot describe the biological effects of radiation exposure to individuals who
75 consume that food. Therefore the estimation of doses is usually carried out for assessing health safety
76 of an individual undergoing radiation exposure through ingestion of contaminated food. The intake of
77 radionuclide within food is dependent on the concentration of radionuclides in various food crops and
78 on the food consumption rates. The risks associated with an intake of radionuclides in the body are
79 proportional to the total dose delivered by radionuclides while staying in various organs. In general, it

80 is assumed that stochastic effects occur linearly with dose and usually the annual effective dose
81 quantities (AEDE) are used to define those risks when prolonged exposure to a single intake of a
82 radionuclide is being considered.

83
84 Radioactivity can be detected in food and water; the concentrations of these naturally-occurring
85 radionuclides vary depending on factors such as the type of food, local geology, climate and agricultural
86 practices [14] . Scientists have identified that some chemical constituents of food either initially present
87 in the food, formed during preparation (especially cooking), or added for preservation are capable of
88 inducing cancers or tumors in high-dose rodent tests. Children have a higher risk of exposure to
89 carcinogens in food as they consume more foods, drink more liquids, and take in more air than adults
90 do. The fact that children have rapidly developing organ systems, especially the central nervous system
91 and the brain, makes them highly susceptible to chemical interference as they are also less able to
92 metabolize and excrete most toxic substances [15]. Some radionuclides have a tendency to concentrate
93 in certain tissues because of their interaction with normal physiological processes. For example, cesium
94 and strontium isotopes tend to congregate in bones, whereas the thyroid gland selectively concentrates
95 iodine [16, 17].

96
97 **According to Tawalbeh *et al.*, [18] absorption of radioisotopes from food stuff may damage the**
98 **kidneys, lungs, liver, skeleton tissues and muscles.** The accumulation of enormous levels of
99 radioisotopes in these delicate organs affect the health condition of persons such as weakening the
100 immune system, sterility, cancer, inducing of various shades of diseases and eventually increase
101 mortality rate. There is then obvious need to know the level of radionuclides concentration and
102 ascertain its radiological health risks to the consumers of those products. The aim of this study is to
103 determine the soil to crop (plant) transfer factor (TF) in order to assess the impact of soil radioactivity
104 on agricultural crops and the health implication on man who is the final consumer.

Comment [18]: Kindly rephrase as:

Absorption of radioisotopes from food stuff may damage the kidneys, lungs, liver, skeleton tissues and muscles [18].

105 106 **2.0. Materials and Methods**

107 **2.1 Study area**

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109
110
111 The study area includes the cities of Agbor, Ogwashi-Uku, Ibusa and Igbodo of Delta state, Nigeria.
112 Agbor lies between Longitudes 6°25'N and Longitude 6°19'E. Ogwashi-Uku lies between Latitude 6
113 °18'N and Longitude 6°52'E, Ibusa lies within latitude 6°10'N and 6°37' while Igbodo is between
114 6°18'N and 6°22'E as shown in Figure 1. These four cities represent four different districts among the
115 twenty-five LGAs in Delta state. Agbor and Igbodo lie between Orogodo and Namomah Rivers and
116 are known as Ika dialect speakers. They belong to Ika south and Ika-North-East LGAs. Ogwashi-Uku
117 and Ibusa are Aniocha South and Oshimili North LGAs respectively. Agbor is bounded on the east by
118 Emuhu, on the West by Alihame, on the north by Ottah in Edo state and on the south by Owanta.
119 Igbodo is bounded on the east by Oniticha-ugbo, west by Akumazi, on the north by Idumuje-Ugboko
120 and south by Obior. Ogwashi-ukwu is located at the west of Asaba, the capital of Delta State. Ibusa
121 (Igbuzo) is bounded on the east by Asaba and Ogwashi-ukwu on the west, Okpanam north-wise and

144 **2.2 Sample Collection and Sample Preparation**

145
146 12 samples of cassava crop and 12 samples of soil were collected from three (3) selected
147 Government farms in Niger Delta region of Nigeria. Six (6) samples each of cassava and soil were
148 taken from the Ministry of Agriculture, Agbor, in Ika-South LGA, two (2) samples of cassava and
149 soil each from Agricultural Development Program (ADP), Illoh-Ogwashi-ukwu in Aniocha South
150 LGA, and Ibusa in Oshimili North LGA respectively. All these farms uses fertilizer to improve the
151 crop yield. Two (2) Samples of cassava and soil were taken from an unfertilized farm as control
152 samples.

153
154 At each sampling site, about 2 kg cassava (fresh weight) samples were collected using plastic
155 trowel and initially thoroughly washed with tap water and then in distilled water to remove surface
156 sand. From each site soil samples of approximately 1.5 kg (wet weight) were collected into
157 separate plastic containers. The two sets of samples were each placed into separate polyethylene
158 bags. In the laboratory, the cuticles of the cassava were removed with a stainless steel knife and the
159 edible parts were cut into pieces of about 10 mm and put together in polyethylene materials for
160 refrigeration.

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

165
166 The soil samples after oven drying at a temperature of 110 °C for 3 days were pulverized in a
167 pulverizer and the sub-samples prepared similarly as the cassava samples. The samples were
168 further sieved in 110 µm mesh sieve to obtain smaller grain sized sand particles before they were
169 subjected to radioactivity measurement. The homogenized samples were weighted and hermetically
170 sealed packed in plastic 500 ml marinelli containers. The containers with the same size and
171 geometry were used for the reference materials for the efficient calibration of the detector system.
172 The samples were filled to an indicated mark on the marinelli container and the mass determined
173 by simple calculation after weighing empty container together with sample and the container alone.
174 The containers were closely tight to limit the escape of radon. Each marinelli container was
175 analyzed after 30 days after ²²⁶Ra and ²³²Th assumed secular equilibrium with their short-lived
176 decay products using sodium iodide detector.

177
178 **2.3 Determination of Specific Radioactivity in Samples**

179 The measurement of specific activity concentration of radionuclides in the samples under consideration
180 was made with a high resolution gamma-ray spectrometry system. A 2”×2” Sodium iodide [NaI (TI)]
181 detector connected to ORTEC digiBase Multichannel Analyzer (MCA) was used. The digiBase is
182 connected to a computer where data collection and analysis are carried out using ORTEC MAESTRO -
183 32 software. IAEA standard materials were used for calibration [19].

184
185 The radioactivity measurement of the samples was made by placing them on the detector inside the
186 lead shielding and spectrum was collected. The same geometry was used to determine peak area of

187 samples and references. Each sample was measured during an accumulation time of 36,000s. The
188 activity concentration was calculated based on the weighted mean value of their respective decay
189 products in equilibrium. The gamma ray lines of 295.2 (18.2), 351(35.1) keV from ^{214}Pb and 609.3
190 (44.6), 1764.5 (15.1) keV from ^{214}Bi were used to determine the activity concentration of ^{226}Ra . The
191 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
192 from ^{208}Tl were used to determine the activity concentration of ^{232}Th .

Comment [I10]: Change units to KeV

193
194 The activity concentration of ^{40}K was measured directly by its own gamma ray at 1460.8 (10.7) keV.
195 The values inside the bracket indicate the absolute emission probability of the gamma decay. The
196 gamma-ray background around the detector inside the shielding was determined using an empty
197 container under identical measurement conditions. The background counts were determined by
198 counting an empty container of the same dimension as those containing the samples and subtracting
199 from the gross count. The activity content of the samples was evaluated by the net area under the photo
200 peaks using:

$$A_c = \frac{C_n}{P_\gamma M \epsilon} \quad 1$$

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

2.4 Radionuclide Uptake and Transfer factor

208 Natural radionuclides are in different concentrations in soil. Human activities like routine and
209 accidental discharge of nuclear waste, production of energy, use of fertilizers and mining have altered
210 their natural concentration in the environment. The earth contains varied degrees of radioactivity due
211 to radioactive decay of ^{238}U and ^{232}Th series [20].

212 Generally plants take in radionuclides via foliar absorption and root uptake from the soil. The expected
213 content of radioisotopes is described by the transfer factor parameter. It describes the radionuclides
214 expected in plants sequel to their concentration in the soil. According to Whicker *et al.*, [21],
215 absorption of radioisotopes is enhanced at the initial plant growth stage meaning that absorption varies
216 with plant growth. According to Sabbarese *et al.*, [22], the transfer factor depends also on the mass of
217 plant. Equation 1 below expresses the dependence of transfer factor on mass.

Comment [I11]: Rephrase as:

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

The transfer factor depends also on the mass of plant. Equation 1 below expresses the dependence of transfer factor on mass [22].

219 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
220 a function that determines the rate of decrease of transfer factor with increasing plant mass. Transfer
221 factors can also be defined based on dry weight, as ratio of activity content (Bqkg^{-1}) in plant to activity
222 content ($\text{Bq}\cdot\text{kg}^{-1}$) of soil or can be based on surface area of soil and expressed as $\text{Bq}\cdot\text{kg}^{-1}$ dry weight of
223 plant to $\text{Bq}\cdot\text{m}^{-1}$ in soil [20].

224 In most cases, the dissemination of radioisotopes is not homogeneous in depth. The International
225 Union of Radioecology (IUR) recommends a standardized root location in order to deal with this soil

226 depth variability. The recommended soil depth is 10 cm for grass and 20 cm for all other crops and
 227 trees (IUR 1999). The radioisotope content at this depth is homogeneous

228 This transfer factor is then expressed as:

229
$$TF = \frac{A_p \left(\frac{Bq}{kg} \right) \text{ dry weight}}{A_s \left(\frac{Bq}{kg} \right) \text{ dry weight}}$$

3

Comment [112]: $TF = \frac{A_p(Bq.kg^{-1})}{A_s(Bq.kg^{-1})}$

230 Where A_p = Activity concentration in the plant ($Bqkg^{-1}$ dry weight) and A_s = Activity concentration
 231 in soil ($Bqkg^{-1}$ dry weight).

232

233 3.0 Results and Discussion

234 3.1 Radioactivity Concentration in Cultivated Fertilized Soil and Cassava food crop

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

242

243 **Table 1: Specific Activity Concentration of ^{40}K , ^{226}Ra and ^{232}Th in Soil Samples from**
 244 **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-Illloh 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-Illloh 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

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Table 2 : Specific Activity Concentration of ⁴⁰K, ²³⁸U and ²³²Th 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

249	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
250	Table 3; 8; 9; 10; 11; 12; Average	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
251		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
252		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
253		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
254		11	ADP Igbodo	M-Idumu 1	N: 6°18'4.99745 E: 6°23'5.24733	472.81± 10.26	24.59 ±10.87	918.40 ± 2.46
255		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
256		Average				746.08 ± 0.48	24.83 ± 10.87	859.41 ± 2.47
257								1324.98
258								
259								

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

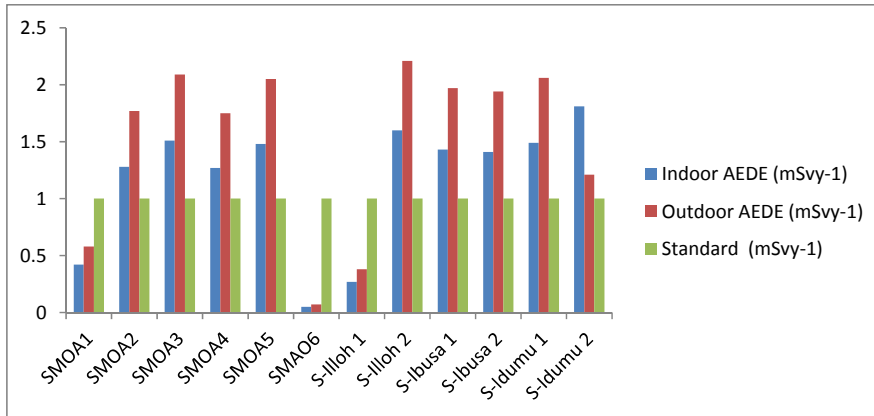
11	ADP Igbodo	Idumu 1	0.68	0.89	1.06
12	ADP Igbodo	Idumu 2 Average	0.71 1.55	0.76 0.99	1.28 1.66

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Table 4: Radiological Risk Parameters for Soil

S/ N	Soil Sample location	Soil Sample	D (nGyh ⁻¹)	Indoor AEDE (mSvy ⁻¹)	Outdoor AEDE (mSvy ⁻¹)	AGDE Bqkg ⁻¹	ELCR	H _{ex}	H _{in}	I _{yr}	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

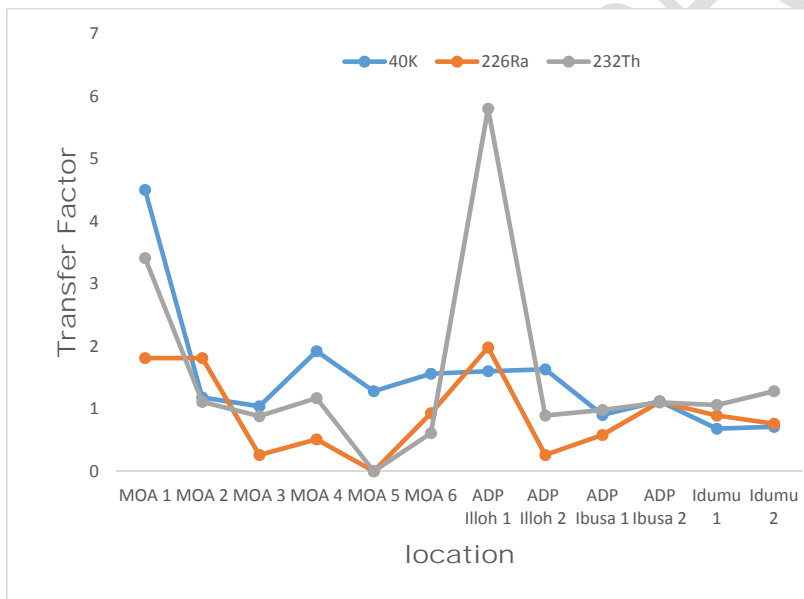
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278 **Fig.2: Annual Effective Dose (AED) against Standard for Soil**

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281 **Fig.3: Variation of Transfer Factor according to sample location**

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283 **4. Discussion**

284 **4.1 Activity concentration of ⁴⁰K, ²²⁶Ra and ²³²Th in soil and cassava crops**

285 The average activity concentration of ⁴⁰K, ²²⁶Ra and ²³²Th in soil from cultivated government farms
 286 were higher than the world average of 400, 35 and 30 Bqkg⁻¹ respectively. ADP Illloh had the highest

287 ⁴⁰K concentration which may be due to enhanced use of NPK fertilizers compared to other locations
288 with lower values, while ADP Igbodo had the highest average value for ²³²Th which may be due to
289 higher clay content compared to other locations with lower values. The average activity concentration
290 of ⁴⁰K, ²²⁶Ra and ²³²Th in cassava crop were found to be much greater than the world value of 50(25-
291 75), 8(1-9) and 3(2-10) Bqkg⁻¹ [24]. By comparing Tables 1 and 2, it is obvious that the mean
292 concentration of ⁴⁰K and ²³²Th in the sample crops are repeatedly higher than their corresponding mean
293 activity composition in soil. The content of radioisotopes in the soil should be greater when related to
294 the corresponding food crop owing to radioisotope solubility. The opposite has been observed in this
295 work and may be due to difference in soil properties of the study area considered by Ole, relative to
296 radionuclide retention under different weather conditions. High values of ²³²Th and ⁴⁰K were observed
297 in all samples. This may be due to high clay content of the soil (for ²³²Th)[22] and the use of fertilizers
298 (for ⁴⁰K). ⁴⁰K is also known as a very important nutrient for fertilization hence the high uptake by
299 plants. Also, the high values of thorium observed in the crops may have been acquired during the
300 process of sun drying in the open air during which natural radioactive particles in air could settle on
301 them [26]. The result of this work is generally higher than the results obtained in available literatures
302 [27, 28, 29, 30, 31]. These values suggest that the consumption of the cassava crop in this area might
303 pose a high potential health hazard to consumers.
304

305 The mean activity concentrations ⁴⁰K and ²³²Th in soil samples were higher than the world average
306 value of 400 Bqk⁻¹ and 30 Bqk⁻¹ [32]. It is pertinent to note that different soil properties and weather
307 conditions affect the accumulation of radioisotopes. The accumulation of ⁴⁰K may be affected by
308 several determinants such as cation exchange capacity (CEC), type and pH of the soil [7]. The soil type
309 fall under the clay mineral property which usually bear a negative charge. According to Wild, [34], the
310 negative charge on the clay is balanced by that on the cations through the CEC process. Potassium is
311 one of the basic cations and so the ability of the soil to hold cations increases its presence. The high
312 values of thorium obtained may be due to the occurrence of thorium erosion process during which it is
313 adsorbed in the soil immediately [34]. It may also have been due to the application of fertilizers to the
314 soil and high clay content [18]. It is important to note that the activity composition of all radioisotopes
315 in the control sample are less than the mean values measured in the experimental samples. The average
316 activity concentration of ²²⁶Ra shows a slight increase in concentration higher than the world average
317 of 35 Bqkg⁻¹ [32] which may be due to the application of fertilizers to recover soils of depleted
318 nutrients due to farming and erosion. The variation in activity concentration of ⁴⁰K, ²³²Th and ²²⁶Ra in
319 the three farms studied may be due to differences in fertilizer application and system of farming. The
320 result of activity concentration of ⁴⁰K, ²³²Th and ²²⁶Ra obtained in this study were higher than those
321 obtained in similar work done by other researchers except for potassium – 40 [2,8,18]. This may be
322 due to differences in soil physio-chemical properties of the study areas and different fertilizers
323 application.
324

325 The radiological health risk parameters calculated from activity concentration of radionuclides in the
326 soil are presented in Table 4. The average values of radium equivalent activity (Raeq), absorbed dose
327 rate (D), annual effective dose rate (AEDE), internal hazard index and excess life cancer risk (ELCR)
328 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

329 were higher than their corresponding permissible values of 370Bqk^{-1} , 55nGyh^{-1} , 1.0mSvy^{-1} , and $0.29 \times$
330 10^{-3} respectively. The mean values of H_{ex} and H_{in} are greater than unity and may therefore constitute a
331 significant radiological health risk. The mean annual gonad dose estimated value of 2943.90mSvy^{-1}
332 was above the world acceptable value of 300mSvy^{-1} and the annual effective dose in all the samples
333 except in few locations as shown in Figure 2, exceeded the safe value of 1.0mSvy^{-1} . The use of soil
334 from these farms and the crops may constitute a threat to the bone marrow and general health
335 conditions of the inhabitants [30].

336

337 4.2 Transfer Factor

338 The transfer factor (TF) is the ratio that depicts the quantity of radionuclide expected to enter the crop
339 from soil (Rodriguez *et al.*, 2002). TF for all radioisotopes were calculated using equation 2 and are
340 recorded in Table 3. For ^{40}K , the transfer factor ranges from 0.68(Idumu_1) to 4.50 (MOA) with an
341 average value of 1.55. ^{226}Ra was from 0.00 (MOA₅) to 1.81(MOA) with an average value of 0.99 while
342 TF for ^{232}Th ranges from 0.00 (MOA₅) to 3.41 (MOA₁) with an average of 1.66. These values imply a
343 moderate rate of radioisotope absorption by cassava. These values were above the recommended IAEA
344 values for Thorium (8.2×10^{-3}) and Uranium (^{226}Ra) (8.9×10^{-2}) for cassava for tropical environments.
345 The high value of transfer factor for ^{40}K may be due to its importance in plant growth, fertilization and
346 adaptability of plant to environmental pressures [36]. It may have also been enhanced by the
347 application of NPK fertilizers. Thorium showed the highest mean transfer factor which may be due to
348 its higher accumulation in soil and higher uptake by plants (Figure 3). The average transfer factors of
349 ^{226}Ra (0.99) < ^{40}K (1.55) < ^{232}Th (1.66) show that although activity concentration of the natural
350 radioisotopes in the area under study are high, the rate at which they are transferred to cassava are still
351 moderate. According to Tchokossa *et al.*, [28] a lot of care must be taken in the use of transfer factor to
352 determine food safety for consumption. The mean transfer factor for ^{40}K , ^{226}Ra and ^{232}Th cassava crop
353 samples obtained in this work are higher than the values of 0.18, 0.29 and 0.25 obtained by Ibitola *et*
354 *al.* [37]. This could be due to differences in soil type, pH, organic matter and other related factors.

355

356 Transfer factor varies with location and plant type (figure 3). From the definition of transfer factor, it is
357 assumed that the plant concentration increases with increased soil concentration. The result of this
358 work shows the opposite of this assumption. For example, the activity concentration of ^{40}K in soil
359 sample SMOA1 is $92.07 \pm 35.08\text{Bqkg}^{-1}$ with a transfer factor of 4.50 while SMOA2 is 556.21 ± 13.25
360 Bqkg^{-1} with a transfer factor of 1.18. Figure 3 show the variation of TF according to the sample
361 location. It is very obvious that ^{232}Th recorded TF value of 5.80 at ADP-Illloh 1. ADP farm uses
362 phosphate fertilizer to improve soil fertility and such enhanced the concentration of thorium in that
363 soil. The TF result of this work buttresses the fact that TFs are not linearly related to soil concentration
364 [38]. Many factors affect the transfer factor such as physiochemical characteristics of radioisotopes and
365 soil, plant species, soil pH and fertility, plant type, organic matter content and soil management
366 practices. Comparing the result with available literatures, the transfer factor in this work is higher than
367 the values obtained by Tchokossa *et al.*, [28] (2013) except for potassium. It is also higher for all
368 radionuclides when compared with results obtained by other researchers [30, 39, 40 and 41]. This may
369 be due to difference in soil properties and climatic conditions of the areas [19].

370

Comment [I13]: A lot of care must be taken in the use of transfer factor to determine food safety for consumption [28].

371 **5. Conclusion**

372 The uptake and distribution of natural radionuclide in cassava crops from Nigerian government farms
373 was determined using gamma spectroscopy and radiation models. The activity concentration of ^{40}K ,
374 ^{232}Th and ^{226}Ra in soil and cassava crop samples were higher than the world average recommended by
375 UNSCEAR and IAEA respectively. The mean values of the transfer factor for ^{226}Ra , ^{232}Th and ^{40}K are
376 0.99, 1.66 and 1.55 respectively. These transfer factors for the radioisotope estimated show they are
377 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
378 concentration of radioisotopes in the food stuffs may not cause immediate health hazard to the public
379 but there may be a long term accumulative effect following the dose intake from the consumption of
380 the crops. The radiological parameters estimated from the activity concentration of radionuclide in soil
381 exceeded their respective permissible limits. This implies that the use of fertilizer in agricultural farms
382 enhances the concentration of nuclides in the soil thereby aiding the radiological contamination of
383 agricultural products. Consumption of such products like the cassava in this study could be detrimental
384 to human health.

385

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UNDER PEER REVIEW

