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Radionuclide Transfer Factors Of Staple Foods And Its Health Risks In Niger Delta Region Of Nigeria

Avwiri, G.O., Ononugbo C.P. & Olasoji, J.M.

Environmental Physics and Radiation Protection group
Department of Physics, University of Port-Harcourt, Port Harcourt
E-mails: gregory.avwiri@uniport.edu.ng ; onochinyere@yahoo.co.uk

ABSTRACT

Ingestion of food crops grown in a contaminated soil can be a source of human exposure to radioactive elements such as ^{226}Ra, ^{232}Th and ^{40}K which can lead to internal radiation doses. To obtain the TFs of ^{226}Ra, ^{232}Th and ^{40}K from agricultural farm soils to food crops, analysis of the radionuclide levels in both food crops and the associated farm soils were carried out via gamma-ray spectrometry. Yam samples exhibited the highest uptake of ^{226}Ra with an average TF of 6.09 and the lowest TF of 0.65 was measured for coco-yam. However, in the case of ^{232}Th, the highest average TF of 4.75 was observed for potato and the lowest TF of 0.10 was estimated for cassava. Also banana exhibited the highest uptake of ^{40}K with mean TF value of 2.66 and the lowest TF of 0.23 as estimated for beans. It is evident that all the food crops absorbs^{226}Ra and ^{232}Th more than ^{40}K. The estimated effective dose due to ingestion of all the food crops ranges from 26.82 µSvy^{-1}(Rice) to 283.39 µSvy^{-1} (Banana). The radiation doses obtained in banana, yam, cassava and plantain were higher than the reference level of 70 µSvy^{-1} and some literature values. Cancer risks and non-cancer risk components were evaluated from the estimated annual effective doses. The result obtained show that in terms of the lifetime fatality cancer risk to adult, approximately 15 out of 1000,000 may suffer from some form of cancer fatality and for the lifetime hereditary effect, approximately 39 out of 1000,000 may suffer some hereditary effects. From radiation protection point of view, the life-long consumption of these investigated food crops may cause significant radiological health risk.

Keywords: Radionuclide,Transfer factor, annual effective dose, Spectrometry, food crops

1. INTRODUCTION

Food crops from contaminated environment may accumulate radionuclides that could form a direct route of exposure to human population when ingested (Leonid and Najat, 2014). Radionuclides are naturally present in the environment which includes our bodies, food, air and water. We are exposed to radiation from these radionuclides on a daily basis (George and Mark, 2013). The uptake of radionuclides by plant roots constitutes the main pathway for the migration of radionuclides from the soil to humans via food chain. Transfer factor (TF) is an important parameter that encompasses influence of physicochemical properties of soil, environmental conditions, and types of radionuclides (Alsaffar *et al*., 2016).

The knowledge of the contribution of direct contamination of plant fruits and the process of root to fruit transfer can improve the understanding of exposure through ingestion and of the mechanisms determining sorption and translocation (IAEA, 1996). Migration of radionuclides in the soil-plant system is complex and the transfer factor assessment models is commonly utilize to describe the translocation of radionuclides among different environmental matrices, it is defined as the ratio of the concentration of radionuclide in the destination matrix and that in the departure matrix. The transfer factor depends on chemical, physiological and ecological conditions and for this, the large data dispersion present in the literature do not allow a clear interpretation (Whicker *et al*., 1999). The large data dispersion is also due to the fact that some of the ratios between two specific activities are in fact time-dependent, so that the assumption of an equilibrium model is not always valid.

The soil-plant system, usually plant cropped on a contaminated soil, the transfer factor is determined by harvesting the crop/plant at a fixed growth stage and by measuring the specific radionuclide activities. The calculation of the transfer factor based on this methodology is implicitly based on the assumption that the ratio between the specific activities in plant and soil has reached an equilibrium value. However there are indications that uptake of radionuclide by plant is enhanced in the initial growth stage (Whickers *et al*., 1999). The uptake of long-lived radionuclides among different plant species are not the same. Overthe past decades, several investigations on mobilization of natural radionuclides (^{238}U and ^{226}Ra)in different compartments (soil, plant, and water), as well as the transfer between them, have been performed at different mining sites around the world (Krizman *et al*., 1995; Petterson *et al*., 1993 and Fernandes *et al.*, 1996).

Consuming food containing radionuclides is dangerous. If an individual ingests or inhales a radioactive particles, it continues to irradiate the body as long as it remains radioactive and stays in the body (FAO, 1986). Researches have shown that any dose of radiation increases an individual risk of developing cancer. However, radiation levels can be concentrated in the food chain and continuous consumption of food adds to the cumulative risk of developing cancer and other related diseases (Svetlana *et al*., 2010).In this present work, staple food products and soil samples were randomly collected from nine states in the Niger Delta region of Nigeria and analyzed using spectrometry method in order to determine the radionuclide transfer factors and quantify the ingested dose and their associated health risks to human population.

2. MATERIALS AND METHODS

2.1 Study Area

This work was carried out in nine states of NigerDelta region of Nigeria which are Rivers, Bayelsa, Akwa-Ibom, Cross River, Delta, Edo, Ondo, Abia and Imo States. Niger Delta region extends over about 70,000 km^2 and makes up 7.5% of Nigeria land mass, Niger Delta straddles latitude 5.3223 North and longitude 6.4692 East of equator. Figure 1 shows the map of the Niger Delta States.

Sampling areas within the Niger Delta region as shown in Table 1 are: Emohua, Eket, Obinnze, Odukpani, Ileje, Aba, Adagbabiri, Ughelli and Ologbo. The indigenous occupation of the populace is farming, producing most of the staple foods studied in this work.

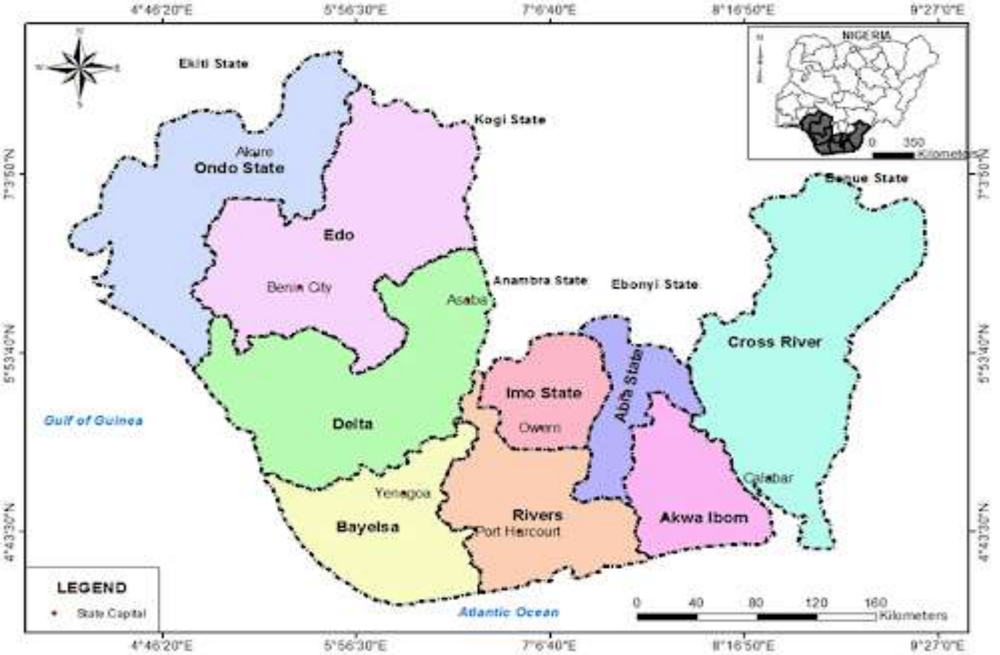

Fig.1: Map of the Study Area

2.2 Samples Collection and Preparation

Food crops and the soil in which they were grown were collected from some selected farmlands in nine states of Niger Delta (Table 1). The food cropscollected were widely grown and consumed by the local communities. These are as white yam (*Discorea rotundata*), maize (*Zeamays*), cassava (*Manihot esculenta*), beans (*Phaseolus vulgaris*), rice (*Rizflorant*), sweet potato (*Ipomea batatas*), groundnut (*Arachis hypogea*), banana (*Musa spientum*), plantain (*musa ssp*) and coco-yam (*xamthosoma ssp*). At each farmland, soil samples and corresponding food crop samples were directly collected to ensure they were site specific samples. The soil samples were collected to a depth of about 20 cm with an average area of 10cm^2 with each spot separated far enough from each other. About 3 kg of soil from each spot was taken from the farmlands and substantial quantity of food samples enough for the analysis was also collected. Rice grains, maize and plantain were harvested and the rice grains stuck together plugged during sample preparation.

Table 1: Collection plan of soil and Crops from Niger Delta States

S/N	Staple Food Soil Sample	Staple Food Sample	Quantity Soil & food crop	Location/State
1	Soil (Gr)	Groundnut	(3 kg) each	Ilaje (Ondo)
2	Soil (Be)	Beans	(3 kg) each	Ohosu (Edo)
3	Soil (Mz)	Maize	(3 kg) each	Emohua (Rivers)
4	Soil (Rc)	Rice	(3 kg) each	Ughelli (Delta)
5	Soil (Po)	Potato	(3 kg) each	Obio/Akpor (Rivers)
6	Soil (Ba)	Banana	(3 kg) each	Odukpani (Cross Rivers)
7	Soil (Ca)	Cassava*)*	(3 kg) each	Adagbabiri (Bayelsa)
8	Soil (Ym)	Yam	(3 kg) each	Aba (Abia)
9	Soil (Pl)	Plantain	(3 kg) each	Eket (Akwa-Ibom)
10	Soil (Cc)	Cocoyam	(3 kg) each	Obinnze(Imo)

2.3 Sample Preparation

The soil samples and their corresponding food crop samples were transferred into a polythene bag and taken for preparation at the Radiation Physics Laboratory, Federal University of Technology Akure (FUTA), Nigeria. Each soil sample from each spot was mixed thoroughly as a composite sample that is representative of the spot. At the laboratory, extraneous materials like plant materials, roots, pebbles were removed from the soil samples. The samples were then separately dried at 110°C in a temperature controlled oven until there was no detectable change in the mass of the samples. The dried soil samples were thoroughly crushed, grounded and pulverized to powder.

The powder was passed through a 2 mm sieve. Due to the limited space of the detector shield only 200g of the soil samples (dry weight) were used for analysis since, this is the quantity it could conveniently take. After washing and drying, the rice grains were milled to remove the husk. The brown rice obtained from the milling process was then pounded to powdery form and sieved. This was done separately for each sample. The mass of the rice samples used for analysis were dependent on the yield of the rice plant per spot. The mass of rice samples from Delta State was 70g.The samples after weighing were transferred to radon-impermeable cylindrical plastic containers of uniform size (60mm height by 65 mm diameter) and were sealed for a period of about 30 days in order to allow for Radon and its short-lived progenies to reach secular radioactive equilibrium prior to gamma spectroscopy (Ilemona *et al*., 2016).

In the laboratory, the cuticles of the cassava, yam, potatoes, plantain and coco-yam were removed with a stainless steel knife and the edible parts were cut into pieces of about 10 mm^3.All the samples of cassava, yam, maize, beans, potatoes, ground nut, banana, plantain and coco-yam were dried at room temperature until constant weight is achieved, crushed in an industrial blender and then sieved with a 110 µm mesh sieve. Marinelli beakers designed to fit into the sodium iodide gamma spectrometer counting chamber were washed in 0.1Mhydrochloric acid, rinsed in distilled water and dried to avoid contamination. The empty Marinelli beakers were weighed and 200 g of the samples were packed and hermetically sealed. The sealed samples were left for 30 days in order to allow for Radon and its short-lived progenies to reach secular radioactive equilibrium prior to gamma spectroscopy.

2.4 Radioactivity Counting

Radioactivity counting in this work was carried out using a lead-shielded 76 mm × 76 mm NaI(TI) detector crystal (Model No. 802 series, Canberra Inc.) coupled to a Canberra Series 10 plus Multichannel Analyzer (MCA) (Model No. 1104) through a preamplifier. The instrument settings and operational conditions were done in accordance with the manufacturers specification described in the work of Ononugbo *et al.,* (2019).

The activity concentration C and soil-to-food crops transfer factors, TFs were estimated using (Abu-Khadra*et al*., 2008):

$$C\ (\mathrm{Bqkg^{-1}}) \quad = \frac{C_n}{\varepsilon P_\gamma M_S} \qquad (1)$$

Where C (Bqkg^{-1}) is the activity concentration in Bqkg^{-1}, C_n is the net count rate under the corresponding peak which can be written as ($C_n = C_T - C_B$; C_T = gross count rate for the specific γ peak and C_B= count rate for the corresponding γ peak), Pγ is the absolute transition probability of the γ -ray. M is the mass of the sample (kg) and ε is the detector efficiency at the specific γ-ray energy.

$$\mathrm{TF} = \frac{Activity\ of\ Radionuclide\ in\ dry\ weight\ of\ food\ crop\ (Bqkg-1)}{Activity\ of\ Radionuclide\ in\ dry\ weight\ of\ soil\ (Bqkg-1)} \qquad (2)$$

2.5: Estimation of Radiological Health Risk Parameters

2.5.1Estimation of Absorbed Dose Rates and Annual Effective Dose in Soil Samples

From the guidelines provided by UNSCEAR (2000), the absorbed gamma dose rate (nGy h^{-1}) in air was determined at 1m above the ground surface to ensure uniform distribution of radionuclides. This parameter can be used to assess any radiological hazard and radiation exposure from radionuclides in the soil. The absorbed dose rate was calculated using the formula (Veiga *et al.*, 2006):

$$DR(\mathrm{nG\ h^{-1}}) = 0.427C_{\mathrm{Ra}} + 0.623C_{\mathrm{Th}} + 0.043\ C_{\mathrm{K}}, \qquad (3)$$

Where DR is the dose rate in nGy h^{-1}and C_{Ra}, C_{Th}, and C_{K} are the activity concentrations (Bq kg^{-1}) of radium (^{226}Ra),thorium (^{232}Th), and potassium (^{40}K), respectively. The absorbed dose rate indicates the received dose outdoors from radiation emitted by radionuclides in environmental materials.

Annual effective dose was calculated to assess the health effects of the absorbed dose by using a conversion coefficient (0.7 SvGy^{-1}) to transform absorbed dose in air to the effective dose received by humans, with an outdoor occupancy factor (0.2), which is equivalent to an outdoor occupancy of 20%and 80% for the indoors (Ghazwa *et al.,* 2016).This factor is suitable for determining the pattern of life in the studied area. Annual effective dose rate (AEDR, in mSv y^{-1}) received by the population can be calculated using (Cervik *et al.,* 2008).

$$\mathrm{AEDR\ (mSv\ y^{-1})} = \mathrm{D\ (nGy\ h^{-1})} \times 8760\ \mathrm{h} \cdot \mathrm{yr{-}1} \times 0.7 \times (10^{3}\mathrm{mSv}/10^{-9}) \times 0.2\ (\mathrm{nGy^{-1}})$$
$$= D \times 1.2264 \times 10^{-6}\ (\mathrm{mSv\ y^{-1}})\ , \qquad (4)$$

where$D$ (nG/h) is the total air absorbed dose rate in the outdoors; 8760 h is the number of hours in one year; 0.2 is the outdoor occupancy factor; 0.7 SvGy^{-1} is the conversion coefficient from absorbed dose in air to effective dose received by adults; 10^{-6} is the conversion factor between nano- and milli measurements.

2.5.2 Evaluation of annual ingestion Effective dose from food crops

Radiation doses obtained due to the intake of food crops is calculated from the amount of radionuclide deposited on foodstuff, the activity concentration of particular radionuclide in food per unit deposition, the consumption rate of the food products and the dose per unit activity ingested. The effective dose E (Svy^{-1}) due to intake of a radionuclide with the ingested material is calculated using the following expression (Addo *et al.,* 2013; Hamideen and Sharaf , 2012):

$$E\ (Svy^{-1}) = C \sum A_i \times DCF_i \qquad (5)$$

Where C (kgy^{-1}) = mean annual consumption of food stuff, Ai ($Bqkg^{-1}$) = activity concentration of radionuclide i in the ingested food and DCFi ($SvBq^{-1}$) = dose coefficients for radionuclide i.

Ideally the summation over i should include all the radionuclides present in the ingested material, so the three most important radionuclide which were identified in the samples are considered in the calculation. The ICRP (2012) values of ingestion coefficient for ^{226}Ra, ^{232}Th and ^{40}K radionuclides for age groups above 17 years are 2.8 E-07, 6.2E-07 and 6.2 E-09 $SvBq^{-1}$ respectively. Presently, no site specific consumption data exist in the study area and as such we have adopted the Nigerian mean annual consumption rate per capita values (Table 2) to enable us calculate the effective dose due intake of the food stuffs using Equation (5).

Table 2: Consumption rate for different food crops (Source: FAO ,2002, 2009, 2011, 2012)

S/N	Food Stuffs	Consumption rate (kgy^{-1})
1	Cassava	102.0
2	Yam	76.0
3	Maize	151
4	Plantain	20.7
5	Groundnut	73.5
6	Rice	24.8
7	Potato	22.3
8	Banana	190.0
9	Beans	11.9
10	Coco-yam	57.1

2.5.3 Cancer Risk and Hereditary Effects Due to ingestion of food crops

The cancer risk and hereditary effect due to low dose without any threshold doses known as stochastic effect were estimated using ICRP, (2012) cancer risk assessment method:

Cancer Risk = Total Annual Effective Dose (Sv) X Cancer Risk Factor ($0.05Sv^{-1}$) (6)

Hereditary Effect = Total Annual Effective Dose (Sv) X Hereditary Effect Factor (7)

Severe hereditary effect in adult per year = Total effective dose X $0.2 \times 10^{-2} sv^{-1}$

Estimated lifetime hereditary effect in adult is = Total effective dose x 70 x 0.002

2.7 Radium Equivalent Dose (Raeq)

The radium equivalent (Ra_{eq}) activity represents a weighted sum of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in sediment samples which allows comparison with their individual ^{226}Ra, ^{232}Th and ^{40}K activity concentration(Suregandhi *et al.,* 2014) . It is based on the estimation that 1 Bq kg^{-1} of ^{226}Ra, 0.7 Bq kg^{-1}

of ^{232}Th and 13 Bq kg^{-1} of ^{40}K produce the same radiation dose rates. The radium equivalent activity index was estimated using the relation (Avwiri and Agbalagba, 2013).

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (8)$$

Where C_u, C_{Th} and C_K are the activity concentration in Bqkg^{-1} or Bql^{-1} of ^{226}Ra, ^{232}Th and ^{40}K.

3: RESULTS

The mean specific activity concentration of ^{40}K, ^{226}Ra and ^{232}Th measured in soil samples and their corresponding staple food crops samples are presented in Tables 3and 4 respectively. The Transfer factors of ^{226}Ra, ^{232}Th and ^{40}K for all the samples and the calculated radiological hazard indices are presented in Tables 5 and 6 respectively.

Table 3: Mean Specific Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Soil samples and Radium equivalent

S/N	Soil Sample	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	Raeq (Bqkg^{-1})	D (nGyh^{-1})	AEDR mSvy^{-1}
1	Soil (Gr)	15.25±2.48	26.88±2.48	222.01±3.66	70.74	32.89	0.040
2	Soil (Be)	19.11±3.70	57.26±2.42	206.54±4.01	230.02	52.71	0.065
3	Soil (Mz)	13.39±1.89	24.08±3.13	170.75±3.52	60.91	28.06	0.034
4	Soil (Rc)	15.21±2.16	21.68±2.49	188.16±3.70	57.91	28.09	0.034
5	Soil (Po)	7.49 ± 2.32	4.89 ± 4.12	153.34±3.89	27.40	12.84	0.016
6	Soil (Ba)	11.39±3.25	9.29 ± 2.83	80.79 ± 3.89	87.77	14.13	0.017
7	Soil (Ca)	19.88±3.24	289 ± 4.48	175 ± 4.87	44.82	196.06	0.240
8	Soil (Ym)	13.63±2.83	16.88±3.39	138 ± 4.35	47.06	22.27	0.027
9	Soil (Pl)	15.25±3.75	14.09±3.08	143.66±2.40	46.95	21.47	0.026
10	Soil (Cc)	19.11±3.49	21.28±3.16	165.91±4.02	7.42	28.55	0.035

Table 4: Mean Specific Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in Staple food sample and Radium equivalent

S/N	Food sample	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	Ra_{eq} (Bqkg^{-1})
1	Groundnut	22.73±5.20	20.18±5.46	84.73±7.10	59.20
2	Beans	24.15±2.55	24.45±5.87	57.57±7.31	63.41
3	Maize	12.39±4.98	24.45±4.65	80.85±4.21	48.40
4	Rice	19.46±5.20	20.18±5.28	57.57±4.56	52.52
5	Potato	38.58±4.23	23.23±5.23	146.80±2.45	90.23
6	Banana	55.65±4.15	24.04±7.11	214.69±4.36	120.14
7	Cassava	77.51±4.99	28.86±5.79	67.27 ± 4.55	144.59
8	Yam	82.96±4.03	17.53±5.17	133.22±4.67	146.41
9	Plantain	38.58±4.36	23.0 ± 5.16	53.69 ± 5.37	82.33
10	Cocoyam	12.39±5.55	22.62±6.14	65.33 ± 5.79	2.02

Table 5: Mean Transfer factor of ^{226}Ra, ^{232}Th and ^{40}K for all the samples

		Transfer Factor		
S/N	**Staple Food Crops**	**^{226}Ra**	**^{232}Th**	**^{40}K**
1	Groundnut	1.49	0.75	0.38
2	Beans	1.26	0.43	0.28
3	Maize	0.93	1.02	0.47
4	Rice	1.28	0.93	0.31
5	Potato	5.16	4.75	0.96
6	Banana	4.89	2.59	2.06
7	Cassava	3.90	0.10	0.38
8	Yam	6.09	1.04	0.97
9	Plantain	2.53	1.63	0.37
10	Coco-yam	0.65	1.06	0.39

Table 6: Annual Effective doses and Estimated Cancer risks and Hereditary Effects on Adult member of the Public

S/N	Food sample	E (μSvy^{-1})	FCR (x10^{-6})	LFCR (x 10^{-4})	SHE (x 10^{-7})	ELHE (x10^{-6})
1	Groundnut	57.45	3.16	2.21	1.149	8.05
2	Beans	28.01	1.54	1.08	0.559	3.92
3	Maize	26.90	1.48	1.04	0.538	3.77
4	Rice	26.82	1.47	1.03	0.536	3.75
5	Potato	45.54	2.50	1.75	0.910	6.37
6	Banana	283.39	15.58	10.91	5.667	39.67
7	Cassava	88.22	4.85	3.40	1.764	12.35
8	Yam	96.87	5.33	3.73	1.937	13.56
9	Plantain	88.31	4.86	3.40	1.766	12.36
10	Cocoyam	40.62	2.23	1.56	0.812	5.68

E = annual effective dose equivalent, FCR = Fatal Cancer Risk, LFCR = lifetime fatality cancer risk, SHE = Severe Hereditary Effect, ELHE = Estimated lifetime Hereditary Effect.

4: DISCUSSIONS

4.1: Activity Concentration of^{226}Ra, ^{232}Th and ^{40}K in soil and Food Crops

From Table3, the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from the nine state range from are 7.49 ± 2.32 to 19.88±3.24, 4.88±4.12 to 289±4.48 and 80.79 ± 3.89 to 222.01 ±3.66 Bqkg^{-1}respectively. The lowest activity concentration of ^{226}Ra and ^{232}Th in all the soil samples was found in Rivers State which could be due to non- existence of anthropogenic activities in the area where the samples were collected. The samples were collected at Emohua and Obio-Akpor community settlement area, so the activities of radionuclides in the soil are mainly from natural sources. The highest activity concentration of ^{226}Ra and ^{232}Th value was obtained in Bayelsa state. This could be due to high clay deposit in Bayelsa state and oil exploration activities going on in Adagbabiri, Bayelsa State where the samples were taken. The highest activity concentration of ^{40}K was found in soil samples from Ondo state. This primarily could be due to fertilizer application and geological constituent of the area because of the massive application of non-organic fertilizer in farms in these areas. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in agricultural farm soils in the present study are lower than those reported by Ghazwa *et al*., (2016); Ahmad *et al*., (2015); Ilemona *et al*., 2016;Alaamer, 2008; Saleh *et al*.,(2013) which was carried out by the first researcher to assess the concentration of radionuclides in agricultural areas and virgin farms of North Malaysia. Variations in the radionuclide levels in agricultural farm soils obtained in this work and others works obtained in other countries depends on the geographical and geological conditions of the zones and the extent of fertilizer utilization in farmlands (Jibiri and Abiodun, 2012). The mean activity concentration obtained in this work is lower than the stipulated safe values of 35.0, 30.0 and 400 Bqkg^{-1}(UNSCEAR, 2000).

From Table 4, the activity concentration of ^{226}Ra in food crops varies between 12.39±4.98 Bqkg^{-1} (maize and coco-yam) and 82.96±4.03 Bqkg^{-1} (yam). The activity concentration of ^{232}Th varies between 17.53±5.17 Bqkg^{-1} (yam) and 28.86±5.79 Bqkg^{-1} (cassava). The activity concentration of ^{40}K varies between 53.69 ±5.37 Bqkg^{-1} (plantain) and 214.69 ±4.36 Bqkg^{-1} (banana). The activity concentration of ^{226}Ra was more in root vegetables when compared to grains and foliage. This could be due to the fact that root vegetables absorbs a great amount of nutrient including radionuclides and also radionuclides absorbed by the root are distributed to other parts of the plant differently depending on the type of radionuclide and other environmental factors (Wang *et al.*, 1993). The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K obtained in rice samples are higher than the values of 10.36 ± 1.72, 12.73 ± 3.77 and 41.15 ± 5.41Bqkg^{-1} obtained by Ilemona *et al*., (2016) for Lokoja rice samples. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K obtained in cassava, yam, plantain and maize are higher than the values obtained by Jibiri and Abiodun (2012) in the western part of Nigeria. Also activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in groundnut measured in this work is higher than the result obtained in Indian groundnut by Nabiha *et al*., (2019). This could be due to difference in geological constituent of the areas and differences in farming system.

The activity concentration of ^{40}K is higher than ^{226}Ra and ^{232}Th in all the food crop samples. ^{40}K is usually of limited interest because as an essential element, it is homeostatically controlled in the human cells. As a result, the body content of ^{40}K is determined largely by the physiological characteristics rather than by its intake (Jibiril and Abiodun, 2012). Researches have shown that mean annual effective dose due to natural sources can be attributed to food intake. The radionuclide in the naturally occurring ^{238}U and ^{232}Th series contribute about 30 to 60% of the internal radiation dose (UNSCEAR, 2000). From Table 4, it is clearly evident that there is radionuclide addition of ^{226}Ra and ^{232}Th in all the food crops. ^{232}Th because of its low solubility does not biomagnify in terrestrial or aquatic food chains which accounts for its lower concentration in all the food crops while ^{226}Ra, solubility may account for its higher concentration in the food crops sampled (Nabiha *et al.,*, 2019). The activity concentration of ^{226}Ra in potato, cassava, yam and banana are higher than world safe values of 35 Bqkg^{-1}.

4.2: Transfer Factors of ^{226}Ra, ^{232}Th and ^{40}K in Food Crops

Table 5 showed the radionuclide Transfer Factors (TF) from soil to food crops collected from different states of Niger Delta region. The transfer factor estimated in groundnut are 1.49, 0.75 and 0.38 for ^{226}Ra, ^{232}Th and ^{40}Krespectively with the implication that groundnut plants take up radium and Thorium more easily than it does for Potassium. For potatoes samples, TF are 5.15, 4.75 and 0.96 for ^{226}Ra, ^{232}Th and ^{40}K respectively and banana samples recorded 4.89, 2.59 and 2.66 for ^{226}Ra, ^{232}Th and ^{40}Krespectively. In beans, maize and rice, TF for ^{226}Ra, ^{232}Th and ^{40}K varies from 0.93 (maize) to 1.28 (Rice), 0.43 (beans) to 1.02 (maize) and 0.28 (beans) to 0.47(maize) respectively. For cassava, yam, plantain and coco-yam, the TF for ^{226}Ra, ^{232}Th and ^{40}K varies from 0.65 (coco-yam) to 6.09 (yam), 0.10 (cassava) to 1.63 (plantain) and 0.37(plantain) to 0.97 (yam) respectively. TF of ^{226}Ra is higher than ^{232}Th and ^{40}K in all the food crops due to its solubility nature in terrestrial and aquatic environment. The transfer factors (TF) were higher than literature values, primary reason being differences in geology of the areas (Ilemona *et al*., 2016; Shyamal *et al*., 2013, Ononugbo *et al*., 2019). It was observed that ^{40}K was the least radionuclide taken up by all the food crops in all the states as against some literature results. This is attributable to the geology of the area and solubility/form of the radionuclide in the particular soil.

According to International Atomic Energy Agency (IAEA, 1993), root vegetables, fruits and grains for human consumption have normal transfer factor of 4.9 x 10^{-3} and 2.1 x 10^{-4} for ^{226}Ra and ^{232}Th respectively while ^{40}K is 3.0 x 10^{-1} (NCRP, 1991). From the results obtained, the TF estimated in both root vegetables and grains exceeded the recommended values as stated earlier. This could be attributed to differences in geology of the area and the agricultural practices employed in these areas.

4.3 Radiological Health Risk Parameters from soil and Food crop samples

The result of the gamma absorbed dose rates and their corresponding annual effective doses due to farm soils are also presented in Table 3. The value of the absorbed doses varies from 12.84 (Rivers State) to 196.06 $nGyh^{-1}$ (Cross River State). The corresponding annual effective dose varies from 0.016 $mSvy^{-1}$ (Rivers State) to 0.240 $mSvy^{-1}$ (Cross River). The values obtained were within their normal world averages (UNSCEAR, 2000). These values deviated a little from the anticipated high levels in the soil indicated in previous studies (Ononugbo *et al*., 2016). This may be attributed to the fact that the villages and farmlands considered in the study are located away from the industrialized cities of the Niger Delta. This reflected on the concentration of radionuclides in the food crops and soil. The radium equivalent estimated from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil ranges from 27.40 to 230.02 $Bqkg^{-1}$ which is lower than the recommended value of 370 $Bqkg^{-1}$ (UNSCEAR, 2000).

The annual effective dose due to ingestion of all the food crops was estimated for adults considering only the ingestion of ^{226}Ra and ^{232}Th presented in Table 6. Potassium (^{40}K) values were not considered during the calculation of the radiation dose because the absorption of the essential potassium element is under homeostatic control and takes place mainly from ingested food. Thus, the potassium contribution to the dose from ingestion in food crops, with its relatively low dose conversion factor will be much less than that of many other radionuclides (Jibiri and Abiodun, 2012). The estimated effective dose ranges from 26.82 μSvy^{-1} (Rice) to 283.39 μSvy^{-1} (Banana). It is evident that banana contributed the highest doses of radiation to adult population of Cross Rivers state where the samples were taken. The doses from tubers were higher than that of the grains. This could be attributed to the differences in radionuclide transfer factors. The doses obtained in banana, yam, cassava and plantain are higher than the recommended reference level of 70 μSvy^{-1} (Ilemona *et al.*, 2016) and from radiation protection point of view, life-long consumption of these investigated food crops may cause significant radiological health risk.

In order to evaluate the radiation risk due to ingestion of the selected radionuclides, the ICRP methodology was adopted in this study and the results shown in Table 6. The results of the cancer and non-cancer risk components were evaluated from the estimated annual effective doses of the sampled food crops. The result of the evaluated fatal cancer risk to adult per year in each sample ranged from 1.47×10^{-6} (Rice) to 15.58×10^{-6} (Banana) with an associated lifetime fatality cancer risk of 1.03×10^{-4} (Rice) to 10.91×10^{-4} (Banana). The evaluated lifetime severe hereditary effect to adult per year varied from 0.536×10^{-7} (Rice) to 5.67×10^{-7} (Banana) with an associated lifetime hereditary effect in adult of 3.75×10^{-6}(Rice) to 39.67×10^{-6} (Banana).

The findings mean that in terms of the lifetime fatality cancer risk to adult, approximately 15 out of 1000,000 may suffer from some form of cancer fatality and for the lifetime hereditary effect, approximately 39 out of 1000,000 may suffer some hereditary effects. The negligible cancer fatality risk value recommended by USEPA is in the range of 1.0×10^{-6} to 1.0×10^{-4} (ie 1 person out of 1 million or 10,000 suffering from some form of cancer fatality is considered trivial). Comparing the estimated results of the lifetime fatality cancer risk in this study with the acceptable risk factor, it can be inferred that all the estimated results of the lifetime fatality risk in adult citizen of selected states of Niger Delta population due to ingestion of radionuclide in food crops are within the range of acceptable risk values recommended by USEPA (2008).

5: CONCLUSION

Radionuclide transfer factor in staple food crops and its health risks in Niger Delta have been determined. The activity concentrations in farm soils and major food crops of dietary importance to the population were measured via gamma spectrometry and the transfer factors estimated. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples were lower than their recommended values except ^{232}Th in farm soil from Bayelsa state. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in staple food crops (groundnut, beans, maize, rice, potato, banana, cassava, yam, plantain and coco-yam) were lower than their recommended values except ^{226}Ra in yam crop from Abia state.

The transfer factor of ^{226}Ra, ^{232}Th and ^{40}K in all the samples of food crops were higher than their recommended values. The absorbed dose of radiation and annual effective dose estimated in farmland soil ranged from 12.84 nGyh^{-1} to 196.06 nGyh^{-1} and 0.016 to 0.240 mSvy^{-1}. The annual effective dose due to ingestion of all the food crops was estimated for adults' ranges from 26.82 µSvy^{-1} (Rice) to 283.39 µSvy^{-1} (Banana). The doses obtained in banana, yam, cassava and plantain are higher than the recommended reference level of 70 µSvy$^{-1.}$ The lifetime cancer risk and hereditary risk assessment show that 15 out of 1,000,000 population may suffer from some form of cancer fatality and approximately 39 out of 1,000,000 may suffer some hereditary effects. The result of this work show that long term consumption of the food crops especially banana may be detrimental to human health,

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