Assessment of Natural Radioactivity and Radiological Hazard indices in Cassava Cultivated in Oil Producing Area, Rivers State, Nigeria

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Abstract: The natural radioactivity and radiological hazard indices associated with the consumption of cassava crops grown in five communities with history of oil spillage, gas flaring, oil bunkering activities and operation of illegal artisanal oil refining in Rivers State was assessed and measured with gamma ray spectroscopy. Five samples of cassava crop and five samples of soil were collected from the five communities. The results obtained were used to evaluate the soil-to-cassava transfer factor (TF) due to ingestion of cassava crops/staple foods by inhabitants in the area. The mean activity of soil samples ranged from 17.77±4.20Bq/kg to 31.84±3.20Bq/kg for ^{238}U, 22.75±3.30Bq/kg to 33.82±4.70Bq/kg for ^{232}Th and 110.44±9.60Bq/kg to 483.15±18.20Bq/kg for ^{40}K, and is within permissible standard, but is higher than the mean activity in the control. The mean activity of cassava samples ranged from 6.50±1.30Bq/kg to 29.70±6.20Bq/kg for ^{238}U, 5.80±2.20Bq/kg to 16.50±6.80Bq/kg for ^{232}Th and 383.20±28.10Bq/kg to 482.30±35.80Bq/kg for ^{40}K and is found higher than those of the control samples, and the international permissible limits. The study revealed that although some of the radiological hazard indices in the cassava samples were below the allowable standards, the estimated committed annual effective dose and excess lifetime cancer risk due to ingestion of cassava crops/staple foods is respectively over 2.9 times and 5.9 times higher than the international permissible limit of 0.29mSv/y. The rate of radionuclides transferred from soil-to-cassava has mean TF of ^{232}Th < ^{238}U < ^{40}K. It is therefore recommended that a community based awareness programme on the issue of environmental contamination from extraneous activities, its health impacts due to consumption of cassava crops/staple foods in the area and possible prevention be organized by the various government agencies involved in environmental protection.

Keywords: Artisanal oil Refining, Committed Annual Effective Dose, Excess Lifetime Cancer Risk, Oil Bunkering, Radionuclides, Transfer Factor

1. Introduction

All living organisms including humans, fauna and flora are continuously exposed to ionizing radiation from natural and anthropogenic sources. The main contributors of natural radiation in the environment are the high energy cosmic radiations that are produced constantly in the atmosphere; and the radionuclides of the uranium and thorium decay series and radioactive potassium in naturally occurring radioactive materials (NORM) existing in the earth crust since the formation of the earth known as primordial radionuclides. Primordial radionuclides of ^{238}U and ^{232}Th decay series are of great importance since they are relatively abundant and some (like ^{228}Ra and ^{226}Ra which are respectively the decay product of ^{238}U and ^{232}Th) are highly toxic in terms of radiation exposure due to their gamma ray emitting potentials (Ocheje and Tyovenda, 2020). Radiation has been implicated in the development of malignant disease and very probably, of other damage to human health (Nwankpa, 2017).

The Niger Delta with the fragile ecosystem is the oil producing area of the country and it is the region of intensive shipping. The oil industry which is the crown jewel of the industrial sector in Nigeria is located in the Niger Delta and it is responsible for over 80% of the external revenue of the country. It is also the largest user of ionizing radiation (Tchokossa et. al., 2013). It has been established that the Niger Delta is the food basket and one of the sanctuaries for one of the world's largest biodiversity, yet wastes containing radionuclides from oil related activities like oil bunkering, illegal artisanal oil refining, pipeline leakages and crude transportation are continuously released into the soil and the intricate creeks and creek lets systems of the Niger Delta which may enhance the concentration level of natural radionuclides in the environment (soil, water and food crops). Again, wastes arising from gas flaring are particulate in nature, and because they are air-borne may be dispersed into the communities surrounding the operatives where they may eventually settle on farmlands, farm crops and in water sources such as hand-dug wells, creeks, rivers and streams. They are inhaled continuously by inhabitants in the area.

Cassava is a perennial woody shrub with an edible fruit. It is widely grown crop in most countries in the tropical region of Africa and ranks as one of the main crops in the tropical countries (Katz and weaver, 2003). In Nigeria, cassava is a major staple food that constitutes a large percentage of the total diet for both low and medium income consumers because it is cheap and affordable. Due to its capacity to yield under marginal soil conditions and its tolerance to drought, it plays a vital role in the food security of the rural economy (Ezedinma et. al., 2006), and as a major source of calories for 40% of Nigerians it has bridge the gap in food security, poverty alleviation and environmental protection (Nweke et. al., 2002; Clair and Etukudo, 2002). Cassava crops and its food constitute a major part of the food consumed daily in the South-south Nigeria. Any contamination of this food crop in the environment by radioactive sources through human activities will affect large portion of the population since it is seen as a potential source of radionuclide pathway to the population living within the area.

The occurrence of oil spillages, gas flaring, illegal artisanal oil refineries as well as oil bunkering activities in communities that host oil wells poses the risk of potential increase in radiation dose burden to the population living within the area due to elevation of natural radionuclides concentration and the uptake of radionuclides by plants via its roots. Ingestion of radionuclides through food intake accounts for a substantial part of average radiation doses to various organs of the body and also represents one of the important pathways for long term health considerations (McDonald et. al., 1999; Fernandez et. al., 2004; Hernandez et. al, 2004).

Radionuclides are mainly responsible for internal exposure through ingestion of food and water and through inhalation of air particulates (Amaral et. al., 2005). Primordial radionuclides enter the soil through weathering of the earth crust (Alharbi and El-Taber, 2013) and when human ingest radium, about 20% is absorbed into the body's circulatory system and the absorbed radium is initially distributed to soft tissues and bone, but its retention is mainly in growing bone (ICRP, 1993). Foods constitute the main source of human daily ingestion of radium (Lima and Penna-Franca, 1988). Tawalbeh et. al (2012) adduced that absorption of radioisotopes from food stuff may damage the kidneys, lungs, liver, skeleton tissues and muscles. 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 (Ononugbo et. al., 2019). Chemical uranium toxicity, for instance, primarily affects the kidney, causing damage to the proximal tubule and it is a potential reproductive toxicant (Linares et. al., 2006). Considerable efforts to investigate the activity of radionuclides in food chain, the radiological health risk and the estimated Soil-to-Plant transfer factor (TF) of radionuclides have been made by many researchers such as Ocheje and Tyovenda (2020), Ononugbo et. al. (2019), Amakom et. al. (2015), Adesiji and Ademola (2019), Al-Absi et. al. (2015), Akpabio and Ituen (2006), Addo et. al. (2013), Jibiri et. al. (2007a, 2007b), Avwiri et. al. (2014), Asaduzzaman et. al. (2014), Shanthi et. al. (2009), Amaral et. al. (2005), Tchokossa et. al. (2013), Nwankpa (2017), Umar et. al. (2012), Jibiri and Abiodun (2012) and Emumejaye (2015).

The TF is essential for estimating and predicting the radionuclide concentration in agricultural crops so as to calculate the radiological dose impact to human beings when the plants are ingested (Chakraborty et. al., 2013; Abiama et. al., 2012). TF is also used to estimate the potential risk of human/population in contracting cancer overtime due to ingestion of crops cultivated in radionuclide laden soil. The accumulation of radionuclides in plants are affected by the concentration of radionuclides in soil, soil pH, climate, speciation of radionuclides in soil solution, organic content of the soil, soil types, e.t.c (Golmakani et. al., 2008). The transfer factor of radionuclide from soil-to-plant is also element specific as a result, root uptake of all the isotopes of a given element is identical (Sheppard and Evenden, 1988; Tome et. al., 2003). The radionuclides in soil are taken up by plants through their root and can be transferred to human when crops harvested from such plants are consumed, leading to internal exposure to ionizing radiations (Adesiji and Ademola, 2019). Children are more vulnerable to radiological health risk due to internal exposure and 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 (Ononugbo et. al., 2019). The fact that children have rapidly developing organ system, 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 (IAEA-TECDOC 1472, 2004). Since it was clearly emphasized by UNDP (2022) that one of its three goals for sustainable food security is to ensure that by 2030 all people have access to sufficient, nutritionally adequate and safe food, this study therefore assessed the concentration level of natural radionuclides in the soil, cassava and evaluates the soil-to-crop transfer factor of the radionuclides in order to ascertain the radiological health risk on the consumers of the cassava crop in the area.

2. The Study Area

The study areas are five communities comprising Eleme, Bunu-Tai, Ban-Ogoi, Bodo and Giokoo. Eleme lies within Latitude 04°46’37.6”N and Longitude 007°07’51.0”E, Bunu-Tai lies within Latitude 04°45’41.0”N and Longitude 007°14’29.4”E, Ban-Ogoi lies within Latitude 04°36’43.4”N and Longitude 007°06’41.0”E, Bodo lies within Latitude 04°44’46.2”N and Longitude 007°06’32.1”E while Giokoo lies within Latitude 04°37’41.0”N and Longitude 007°16’21.1”E. The five communities respectively belong to Eleme Local Government Area (LGA), Tai LGA and Gokana LGA of Rivers State, Nigeria (Figure 1). The general topography is relatively flat lying and consists of terrestrial and marine environment. Due to the crude oil spills that polluted the land, the terrestrial environment has patchy regenerating vegetation which consisted mostly of scanty and secondary type residual grasses. Each of the five communities are within 1,000m radius of the spilled sites, gas flaring at flow stations, oil bunkering and illegal artisanal oil refining activities. The soils are dark brown loamy soil to clay loam soil (Avwiri and Agbalagba, 2014).

2.1 Regional Geology

The study area falls within the Niger Delta region which is made up of thick clastic sedimentary sequence with age ranging from Eocene to Recent and it sits astride the Niger flood plains, which overlies the Benin formation that is often called the coastal plain sand (Tattam, 1943). This formation consists predominantly of coarse grained sandy soils with few shale intercalations. The unconsolidated, highly porous sands of the Benin formation is a fresh water bearing sands zone (Amajor, 1991), and all aquifers in this region are located within this lithio-stratigraphic unit. The Benin formation comprises multiple layers of clay, clay conglomerates, peat and/or lignite all of variable thickness and texture and covered by overburden soil (Short and Stauble, 1967).

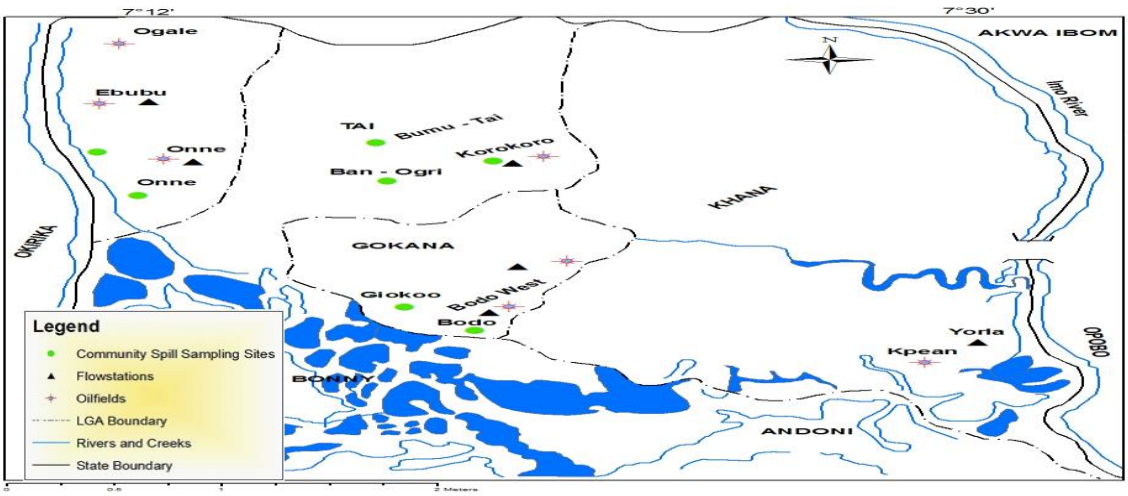


Figure 1: Map of the Study Area

3. Material and Methods

3.1 Sample Collection and Preparation

The sampling strategy adopted was the purposive and stratified sampling methods, and samples were collected according to internationally established experience (ASTM, 1983, 1986; IAEA, 2004). The sites were split into sampling areas and were divided into cells of 50m by 50m grids. The grid blocks were assigned numbers, where a number generator such as N identical cards was used to select the grid points at which samples were collected within defined boundaries of the area concerned. Five cores were drilled in a zigzag pattern (randomly) within each cell and samples were collected from the cores within a 10-foot radius of the centre point for the sample. The samples so collected at different points randomly were mixed together thoroughly to give a composite sample. Each sampling point was selected independent of the location of all other sampling points such that all locations within the area of study had equal chance of being selected.

Five samples of cassava crop and five samples of soil were collected from the five communities. Two samples each of soil and cassava were randomly collected from Eleme, Bunu-Tai Ban-Ogoi, Bodo and Giokoo communities' farm lands across the grids and were thoroughly mixed together to get a composite sample. These farm lands have close proximity with the oil spilled sites, flow stations flaring gases, and areas of oil bunkering and illegal artisanal refining activities. Three samples of cassava and soil were also collected from farmlands soil without history of oil spillage, oil bunkering and artisanal oil refining activities, and gas flaring at flow stations located about 57km away from the sampling communities which serves as control samples. The soil samples were collected from the field by using a steel hand geological coring tool (soil auger). The soil auger was cleaned with acid, detergent and rinsed with tap water before it was used to drill to a depth of 20cm. Avwiri and Agbalagba (2014) recommended that sampling for the average activity concentration in soil be taken in the top 20cm as this is the acceptable international compromise arising from alternate measures that are often based on deposition per unit area assuming atmospheric fallout. Furthermore, because dissemination of radioisotopes is not homogenous in depth in most cases, IUR (1989) recommends a standardized root location in order to deal with the soil depth variability. It recommended soil depth of 10cm for grass and 20cm for all other crops and trees and it is believed that the radioisotope content at this depth is homogenous.

At each sampling site therefore, about 2kg of cassava (fresh weight) were collected, peeled and thoroughly washed with distilled water and the edible portion was chopped into smaller pieces using a stainless steel knife. The chopped cassava pieces were air-dried for about one week. The samples were again freezed using a freeze drier, then grinded into powder with porcelain mortar and pestle. The grinded powders were sieved through a 2mm mesh into a 1-litre Marinelli beaker. The dry weights of the samples were determined. The dried samples were counted for natural radionuclide contents by using the NaI(TI) gamma ray spectrometer detector. For each site, soil samples of about 2kg (wet weight) were collected then air dried for room temperature to constant weight and sun-dry at $25\pm2^{o}C$ to remove the moisture content. The samples were further oven dried at a temperature of $105^{o}C$ for 1-2 hours to remove any remaining moisture content. The removal of the moisture took care of self absorption in each of the sample. The dried samples were pulverized into fine grains so as to increase the total emission area and then were passed through a sieve mesh of 150μm so that clay and mineral particle may homogenize. Thereafter, a sample of $250\pm0.05\%$ was weighed and sealed with adhesive tape in air tight plastic containers of diameter 6.5cm that could seat in the detector head. The sealing with adhesive tape was to prevent the escape of the gaseous radionuclides in the samples. The samples were left for 4 weeks in order to allow for secular equilibrium between the long-lived parent radionuclide and their short-lived daughter radionuclides (^{226}Ra up to ^{210}Pb and ^{228}Th up to ^{208}Pb) in the ^{238}U and ^{232}Th decay series before counting.

3.2 Sample Analysis

The activity of the natural radiouclide of the prepared soil and cassava samples were counted at the Centre for Energy Research and Training, Zaria with gamma ray spectrometer detector for 36,000 seconds to produce strong peaks at gamma emmiting energies at 1,460Kev. The detector is a Thallium activated Canberra 7.6cm x 7.6cm sodium iodide [NaI(TI)] detector (model 803 series) coupled to a Canberra series 10 plus Multichannel-Analyzer through an ORTEC 456 amplifier base. The detector, enclosed in a 10 cm thick lead shielding lined with 1.5mm thick cadmium and 0.8mm thick copper, was connected to a computer program Maestro window that matched gamma energies to a library of possible isotopes. The lead shield was to reduce environmental background radiation. The ^{238}U and ^{232}Th activities were determined indirectly through the activities of their daughter products. The activities of ^{238}U was determined from the average activities of ^{214}Pb at 352kev and ^{214}Bi at 609Kev while that of ^{232}Th was determined from average activities of the decay products of ^{208}Ti at 583kev and ^{228}Ac at 911Kev. The activity of ^{238}U in the samples was calculated after subtracting decay correction. The background spectra measured under the same conditions for both the standard and sample measurements were used to correct the calculated sample activity concentrations. The net area under each photopeak, after background corrections, was used to calculate the activity concentration (Cs) of each radionuclide in the soil and cassava in accordance with Arogunjo et. al. (2005):

$$Cs\ (Bq/kg) = \frac{C_n}{\varepsilon P_\gamma M_s} \quad (1)$$

Where: Cs is the activity concentration of radionuclide in the sample, C_n is the count rate under each photo peak due to each radionuclide, ε is the detector efficiency for the specific γ-ray, P_γ is the absolute transition probability of the specific γ-ray, M_s is the mass of the sample (kg).

3.3 Radiation Hazard Indices

To assess the health status of radiated or irradiated persons due to the ingestion of food in an environment, UNSCEAR (2008) and ICRP (2012) recommended the following hazard indices for radiological risk assessment:

(i) Radium Equivalent Activity (Ra_{eq}): The most hazardous radionuclide that is released during the decay of ^{238}U is radium (^{226}Ra). And because 98.5% of the radiological hazard of uranium series is due to radium and its decay products, ^{238}U is replaced with concentration of ^{226}Ra in hazard assessment. As a result of non-uniform distribution of ^{226}Ra, ^{232}Th and ^{40}K in soil and food crops, uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity (Ra_{eq}) to compare the activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K. Therefore, for the purpose of comparing the radiological effect or activity of materials that contain ^{226}Ra, ^{232}Th and ^{40}K by a single quantity which takes into account the radiation hazards associated with them, a common index termed the radium equivalent activity is used (Baratta, 1990). This index makes possible the use of a single regulatory limit on radionuclide containing building materials rather than having to limit uranium, thorium and potassium separately (Farai and Ademola, 2005). This index also provides a useful guideline in regulating the safety standards on radiation protection for the general public residing in an area. The Ra_{eq} index represents a weighted sum of activities of ^{238}U, ^{232}Th and ^{40}K and it is based on the estimation that 370Bq/kg of ^{238}U, 259Bq/kg of ^{232}Th and 4810Bq/kg of ^{40}K provide the same gamma radiation dose rates.

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

Where A_{Ra}, A_{Th} and A_k are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively measured in Bq/kg or Bq/l. The allowable limit of Ra_{eq} in soil and food is 370 Bq/kg (UNSCEAR, 2000, 2008) therefore the use of a material whose Ra_{eq} concentration exceeds 370Bq/kg is discouraged to avoid radiation hazards (OECD/NEA, 1979; Sam and Abbas, 2010).

(ii) Absorbed Dose Rate (D): It is imperative to calculate the absorbed dose rate based on the fact that radiation exposure pathways involved dermal and ingestion of radioactive pollutants respectively from soil and cassava by the inhabitants in an environment. The absorbed dose rates (D) due to gamma radiation is calculated thus:

$$D= 0.462A_u + 0.604A_{Th} + 0.0417A_K \quad (3)$$

Where: A_u, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg respectively. The unit of D is ηGyh^{-1}.

(iii)The Committed Annual Effective Dose (AEDE): The annual committed effective dose to an individual due to intake of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) from the consumption of cassava in an environment is computed using the expression (Alam and Mohamed, 2011; Khandaker et. al., 2013):

$$AEDE = A_{if}\,[A_{cU}.D_{Cf}U+A_{cTh}.D_{Cf}Th+A_{ck}.D_{Cf}K] \quad (4)$$

Where AEDE is the annual individual effective dose (μSv/y), A_{if} is the annual intake or consumption rate of a particular type of food crop (kg/yr); A_c is the activity concentration of radionuclides in food samples (Bq/kg); A_{cU}, A_{cTh} and A_{cK} are respectively the activity concentration of ^{238}U, ^{232}Th and ^{40}K in the food samples (Bq/kg); D_{Cf} (i.e $D_{Cf}U$, $D_{Cf}Th$ and $D_{Cf}K$) is the ingestion dose conversion factor or coefficient (Sv/Bq) for radionuclides of interest. The values of D_{Cf} for ^{238}U, ^{232}Th and ^{40}K are $4.5x10^{-8}$ Sv/Bq, $2.3x10^{-7}$ Sv/Bq and $6.2x10^{-9}$ Sv/Bq respectively for adult (≥17 years) members of the public.

The mean annual consumption (MAC) rate of cassava staple food in the South-South zone in Nigeria per capita value of 199.62 kg/y (Table 5) was adopted from published literature by Chiaka et. al (2022) to calculate for the annual effective dose due to intake of cassava (that is A_{if} was taken as 199.62 kg/y).

(iv) Excess Lifetime Cancer Risk (ELCR): This deals with the probability of developing cancer over a lifetime at a given exposure level and it is presented as a value representing the number of extra cancers expected in a given number of people on exposure to a carcinogen at a given dose (Ononugbo et. al, 2013). The Excess lifetime cancer risk (ELCR) is given as (Taskin et. al., 2009);

$$ELCR = AEDE \times DL \times RF \quad (5)$$

Where AEDE is the annual committed effective equivalent dose, DL is average duration of life (estimated to be 70 years for Nigeria by Taskin et. al., 2009) and RF is the risk factor (Sv^{-1}) i.e fatal cancer risk per sievert. For stochastic effects, ICRP (2012) uses RF as 0.05 for members of the public.

3.4 Soils-to-Crop Transfer Factor

To obtain the rate at which natural radioisotopes are transferred from soil-to-crops in the environment, the transfer factors (TFs) are calculated from the concentrations of the radioactive or natural isotopes in both crop and soil samples.

The TF is defined and calculated following a simple model (IUR, 1989; Twining et. al., 2003):

$$TF = \frac{\text{The concentration of radionuclides in a crop (Bq/kg dry weight)}}{\text{The concentration of radionuclides in soil (Bq/kg dry weight)}} \quad (6)$$

4. Results and Discussion

The mean activity of soil samples ranged from 17.77±4.20Bq/kg to 31.84±3.20Bq/kg for ^{238}U, 22.75±3.30Bq/kg to 33.82±4.70Bq/kg for ^{232}Th and 110.44±9.60Bq/kg to 483.15±18.20Bq/kg for ^{40}K. These values are higher than the mean activity concentrations of the 3 radionuclides in the control samples (Table 1). However, the mean activity concentration of ^{238}U, ^{232}Th and ^{40}K in the community soil samples are lower than their respective UNSCEAR (2008) permissible standard of 33Bq/kg, 45Bq/kg and 420Bq/kg except for ^{40}K value at Bunu-Tai soil which is higher than the permissible standard by 15%. The high activity value of ^{40}K at Bunu-Tai agrees with the works of Ajayi et. al (2009) who noted that the activity of ^{40}K in sedimentary rocks is due to the presence of feldspar, clay minerals and mica that characterize the formation of the Niger Delta.

The mean activity of cassava samples cultivated from the community farmland ranged from 6.50±1.30Bq/kg to 29.70±6.20Bq/kg for ^{238}U, 5.80±2.20Bq/kg to 16.50±6.80Bq/kg for ^{232}Th and 383.20±28.10Bq/kg to 482.30±35.80Bq/kg for ^{40}K. While that of the control samples ranged from 1.30±0.40Bq/kg to 1.60±0.20Bq/kg for ^{238}U, 1.03±2.10Bq/kg to 1.42±1.10Bq/kg for ^{232}Th and 121.30±13.10Bq/kg to 255.30±21.3Bq/kg for ^{40}K (Table 2). The mean activity values of ^{238}U, ^{232}Th and ^{40}K in the community crops are found higher than those of the control and they are also higher than the international permissible standard of 8(1-9)Bq/kg for ^{238}U, 3(2-10)Bq/kg for ^{232}Th and 50(25-75)Bq/kg for ^{40}K by UNSCEAR (2000) for food crops. The radium equivalent activity (Ra_{eq}) and the absorbed dose rates due to the presence of ^{238}U, ^{232}Th and ^{40}K in the cassava samples ranged from 47.2Bq/kg to 84.8Bq/kg and from 24.0ηGy/h to 40.8ηGy/h which is respectively lower than the permissible limit of 370Bq/kg and 59ηGy/h (Table 3). ^{238}U, ^{232}Th and ^{40}K constitutes 22%, 20% and 58% respectively of the absorbed dose rate of the cassava samples (Figure 2).

Table 1: Mean Activity of Radionuclides in the community's Soil Samples with Control

S/No	Sample Name	Specific Activity ($Bqkg^{-1}$)		
		^{238}U	^{232}Th	^{40}K
1	SS_{Eleme}	17.77±4.2	27.37±5.4	208.20±10.6
2	$SS_{Bunu\text{-}Tai}$	21.24±2.2	33.82±4.7	483.15±18.2
3	$SS_{Ban\text{-}Ogoi}$	31.84±3.2	22.75±3.3	110.44±9.6

4	SS_{Bodo}	30.29±3.7	24.25±2.4	248.90±15.4
5	SS_{Giokoo}	29.51±3.3	27.42±2.1	210.20±10.5
CONTROL SOIL SAMPLES				
1	S_{CS1}	2.91±0.5	4.58±1.2	35.20±5.3
2	S_{CS2}	3.85±1.3	7.02±1.4	118.42±11.4
3	S_{CS3}	3.12±2.2	6.48±3.1	120.04±8.5
UNSCEAR (2008) Standard		**33**	**45**	**420**

Table 2: Mean Activity of Radionuclides in the community's Cassava Samples with Control

S/No	Sample Name	Specific Activity ($Bqkg^{-1}$)		
		^{238}U	^{232}Th	^{40}K
1	CS_{Eleme}	14.30±2.50	13.00±3.30	428.20±43.50
2	$CS_{Bunu\text{-}Tai}$	18.70±5.20	11.80±4.00	482.30±35.80
3	$CS_{Ban\text{-}Ogoi}$	6.50±1.30	5.80±2.20	420.40±35.60
4	CS_{Bodo}	29.70±6.20	16.50±6.80	409.70±29.60
5	CS_{Giokoo}	12.30±3.10	8.50±1.80	383.20±28.10
CONTROL CASSAVA SAMPLES				
1	C_{CS1}	1.60±0.20	1.03±2.10	121.30±13.10
2	C_{CS2}	1.40±0.10	1.08±1.20	255.30±21.30
3	C_{CS3}	1.30±0.40	1.42±1.10	142.10±19.20
UNSCEAR (2000)		**8(1-9)**	**3(2-10)**	**50(25-75)**

The mean annual committed effective dose due to ingestion of cassava crop varied from 0.84mSv/y to 1.53mSv/y. These mean values of committed annual effective dose due to ingestion of cassava crops cultivated in the farmlands at Eleme, Bunu-Tai, Ban-Ogoi, Bodo and Giokoo communities are respectively 4.3 times, 4.5 times, 2.9 times, 5.3 times and 3.3 times higher than the international permissible limit of 0.29mSv/y (Figure 3). This implies that the inhabitants of the area are very susceptible to high dose related disease through the ingestion of cassava staple foods or products made from cassava. Furthermore, the five communities recorded high mean values of excess lifetime cancer risks (ELCR) above the recommended standard of 0.29mSv/y (Figure 4) implying that the chances of having cancer overtime due to ingestion of cassava grown in these communities are very high to cause death. Results showed that ^{238}U, ^{232}Th and ^{40}K constitutes 25%, 24% and 50% respectively of the gross activity of the cassava samples (Figure 5). This was calculated from the assumption that 370Bq/kg of ^{238}U, 259Bq/kg of ^{232}Th and 4810Bq/kg of ^{40}K produce equal gamma dose.

The soil-to-cassava transfer factor (TF) ranged from 0.20 to 1.56 for ^{238}U, 0.25 to 0.68 for ^{232}Th and 0.99 to 3.81 for ^{40}K. The TF values of the arithmetic mean for ^{238}U and ^{232}Th in the 5 communities was higher than the IAEA-TECDOC-1616 AM (2009) permissible standards. The TF values for ^{40}K at Eleme, Bunu-Tai, Bodo and Giokoo communities were lower than the IAEA-TECDOC-1616 AM (2009) permissible standard but was observed higher than the standard in Ban-Ogoi community (Figure 6). The TF value of the cassava samples for this study are found to be lower than the 1.03 and 0.71 obtained for ^{238}U and ^{232}Th, but higher than the 1.16 value obtained for ^{40}K in the works of Avwiri and Agbalagba (2014) in the assessment of natural radioactivity, associated radiological health hazards indices and soil-to-crop transfer factors in cultivated area around a fertilizer factory in Onne, PortHarcourt. The radionuclide that was mostly transferred from the soil to the cassava is ^{40}K and the trend of transfer of radionuclides due to their mean values is ^{232}Th (0.41) < ^{238}U (0.66) < ^{40}K (2.07). This implies that eating of cassava products in the study area by the inhabitants or members of the public may not cause immediate health hazard, but long time accumulative effect from the present dose intake may cause future side effects. The high TFs of ^{40}K were due to the fact that potassium is important in fertilizing the crop and also plays a vital role in the ability of the plant adapting to environmental pressures. Therefore potassium remains in homeostatic equilibrium in the plant and is readily adapted by the cassava tubers (Jibiril et. al., 2007; Avwiri and Ononugbo, 2012). According to Prajapati and Modi (2012), potassium activates the enzymes that maintain the turgidity of the cells which could be the reason for the highest values of ^{40}K observed in the cassava samples. Sheppard and Evenden (1988) defined plant accumulation strategy as a condition where the TF of radionuclides decreased as the concentration of the radionuclides in the soil increased, thus it can be deduced that ^{40}K maintained the plant accumulation strategy in all the cassava samples across the soil in the farmland.

5. Conclusion

The activity concentration of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) in the soil and cassava samples in an environment with history of oil spillage, illegal artisanal oil refining, oil bunkering activities and gas flaring have been measured by gamma ray spectroscopy. The result showed that the activity concentrations of the three radionuclides in soil are within the permissible limits whereas the cassava samples recorded higher activity concentrations above the recommended permissible standards and the control. The study also revealed that although some of the radiological hazard indices in the cassava samples were below the allowable standards, the estimated committed annual effective dose and excess lifetime cancer risk due to ingestion of cassava crops/staple foods by the inhabitants in the area is respectively over 2.9 times and 5.9 times higher than the international permissible standard of 0.29mSv/y. This implies that the inhabitants of the area are very susceptible to high dose related disease through the ingestion of cassava crops/staple foods or other products made from cassava. It also implies that the chances of having cancer overtime due to ingestion of cassava grown in these communities are very high to cause death. The percentage radionuclide contribution to the gross activity in the cassava samples is $^{40}K > ^{238}U > ^{232}Th$ while the rate of radionuclides transferred from soil-to-cassava has mean TF of $^{232}Th < ^{238}U < ^{40}K$. Thus, the cassava crop accumulation strategy was observed only for ^{40}K since it had the highest TF when compared with the TF of ^{238}U and ^{232}Th although the arithmetic mean values for ^{238}U and ^{232}Th in the five communities farmlands was higher than the IAEA-TECDOC-1616 (2009) AM permissible standards. It is therefore recommended that a community based awareness programme on the issue of environmental contamination from extraneous activities, its health impacts due to consumption of cassava crops/staple foods in the area and possible prevention be organized by the various government agencies involved in environmental protection.

Table 3: Mean Activity Concentrations of Natural Radionuclides in the Cassava samples and the Associated Radiation Hazard Indices

Sample ID	Specific Activity ($Bqkg^{-1}$)			MAC (kg/y)	Ra_{eq} (Bq/kg)	D (ηGy/h)	Committed Annual Effective Dose (mSv/y)	ELCR (mSv/y)
	^{238}U	^{232}Th	^{40}K					
CS_{Eleme}	14.30 ±2.50	13.00±3.30	428.20±43.50	199.62	65.9	32.3	1.25	2.56
$CS_{Bunu-Tai}$	18.70 ±5.20	11.80±4.00	482.30±35.80	199.62	72.7	35.8	1.31	2.66
$CS_{Ban-Ogoi}$	6.50± 1.30	5.80±2.20	420.40±35.60	199.62	47.2	24.0	0.84	1.72
CS_{Bodo}	29.70 ±6.20	16.50±6.80	409.70±29.60	199.62	84.8	40.8	1.53	3.12
CS_{Giokoo}	12.30 ±3.10	8.50±1.80	383.20±28.10	199.62	53.9	26.8	0.97	1.96
UNSCEAR (2008), IAEA (2007), OECD (1979); ICRP (2012), Taskin et. al., (2009) Standard					**≤ 370**	**59**	**0.29**	**0.29**

Table 4: Soil-to-Cassava Transfer Factor of Radionuclide in the Community Farmland

S/No	Host Community	Soil-to-cassava Transfer Factor of Radionuclide			LGA
		^{238}U	^{232}Th	^{40}K	
1	Eleme	0.80	0.47	2.06	ELEME
2	Bunu-Tai	0.88	0.35	0.99	TAI
3	Ban-Ogoi	0.20	0.25	3.81	
4	Bodo	0.98	0.68	1.65	GOKANA

5	Giokoo	0.42	0.31	1.82	
Mean		**0.66**	**0.41**	**2.07**	
IAEA-TECDOC-1616 (2009) AM Standard		**0.025**	**1.3×10^{-5}**	**2.7**	

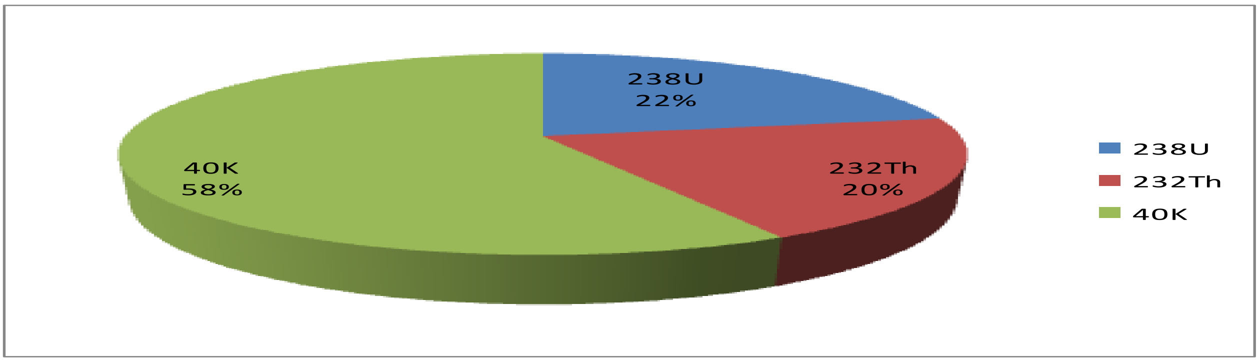


Figure 2: Percentage Contribution of the three radionuclides in the cassava samples to the absorbed dose rates

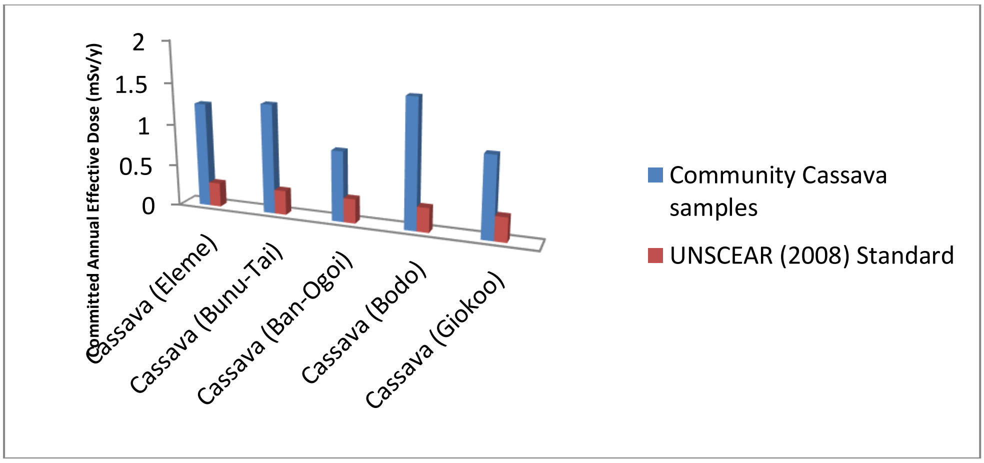


Figure 3: Annual Committed Effective Dose due to Consumption of Cassava

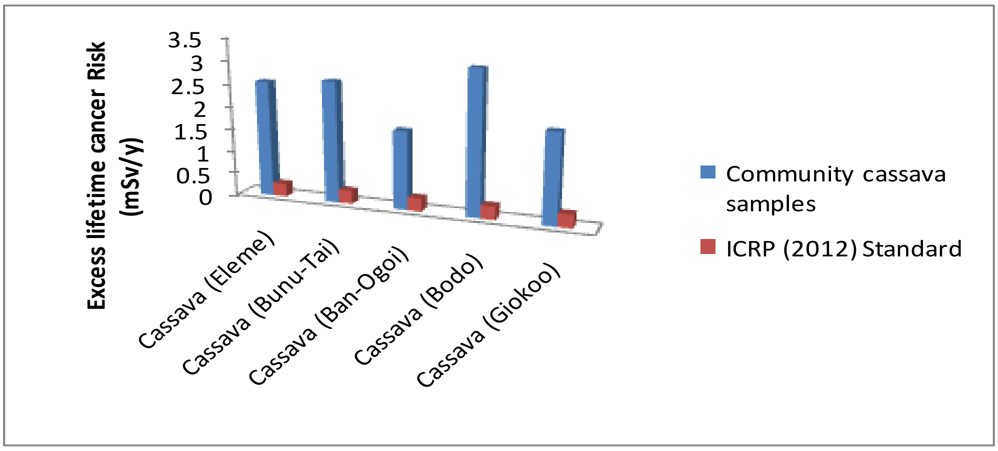


Figure 4: Excess Lifetime Cancer Risk due to ingestion of Cassava

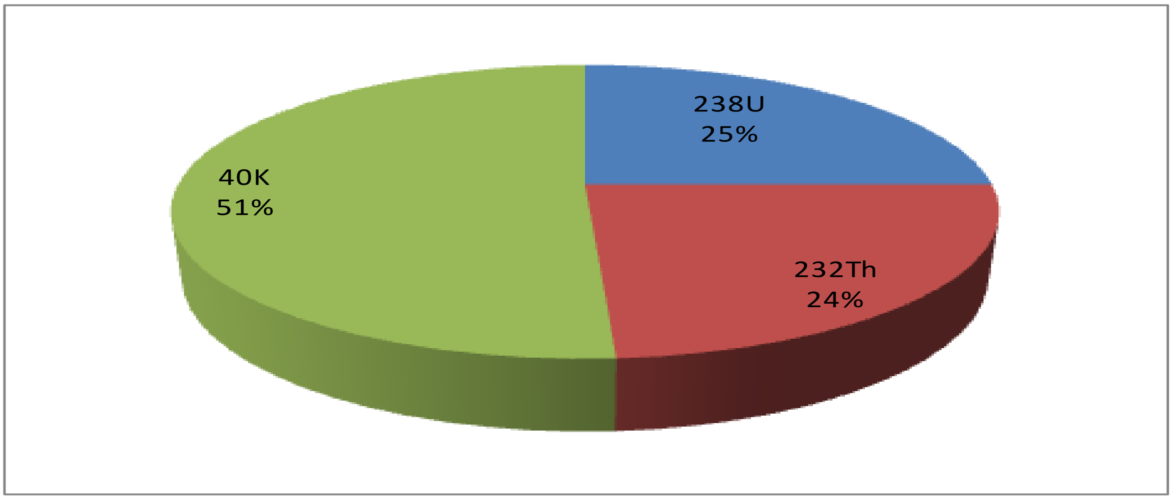
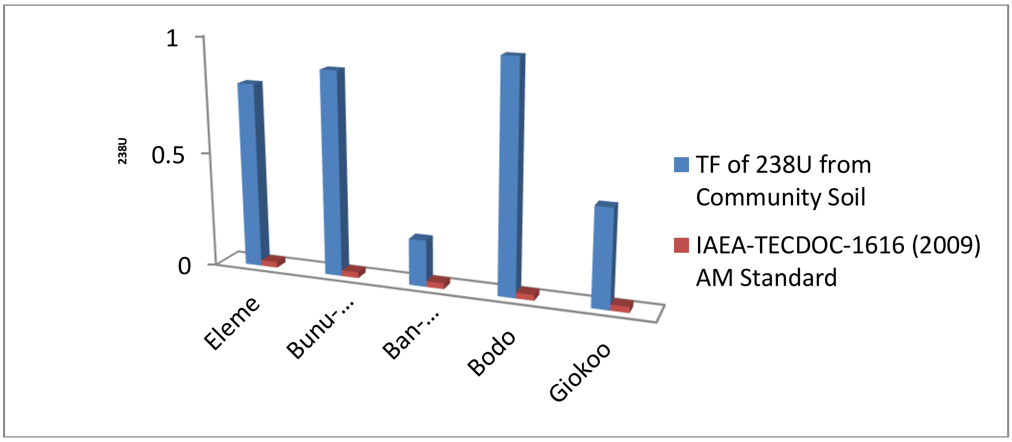
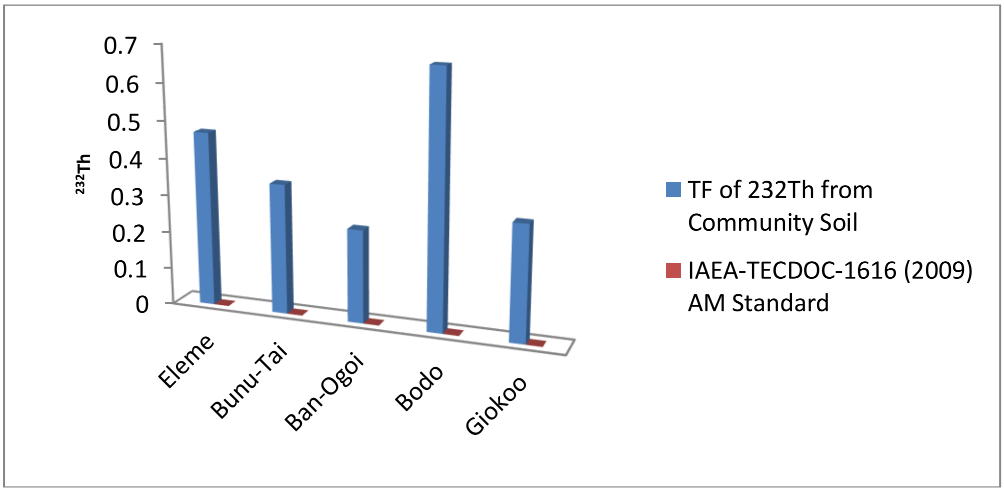


Figure 5: Percentage Contribution of the three radionuclides in the cassava samples to the Gross activity of the cassava Sample in the Area





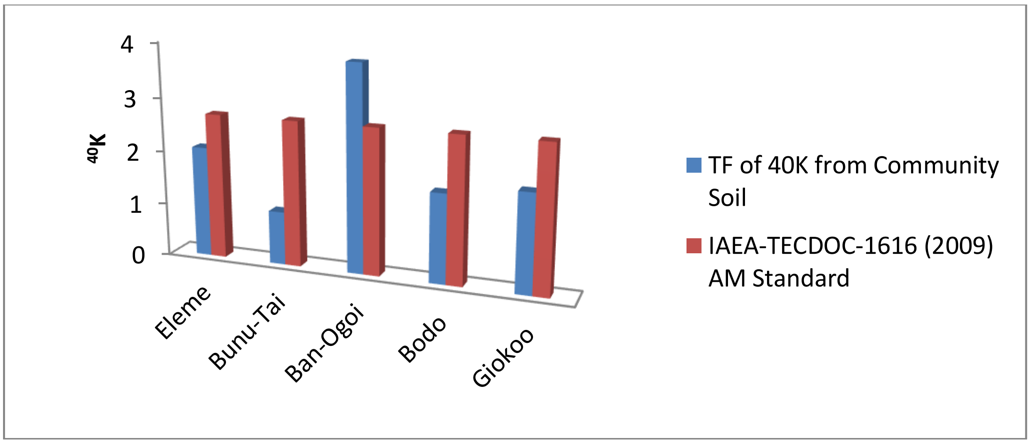


Figure 6: Soil-to-Cassava TF with Radionuclides (^{238}U, ^{232}Th and ^{40}K)

Table 5: Mean Annual Consumption Rate of Cassava per capital in the Six Geopolitical zones in Nigeria (Chiaka et. al., 2022)

Zones	Food Type	Food Consumption (kg/Capita/Year)	Total Household Food Consumption (kg year^{-1})
North Central	Rice	90.05	513.30
	Maize	59.54	339.37
	Cassava	88.96	507.10
	Yam	68.23	388.93
	Cowpea	15.02	85.59
	Onion	28.19	160.66
	Tomato	25.75	146.79
North East	Rice	112.10	885.59
	Maize	186.04	1469.69
	Cassava	17.88	141.22
	Yam	22.74	179.66
	Cowpea	18.36	145.06
	Onion	28.58	225.81
	Tomato	23.62	186.61
North West	Rice	137.81	1019.82
	Maize	139.49	1032.20
	Cassava	13.99	103.52
	Yam	12.55	92.86
	Cowpea	11.36	84.04
	Onion	28.38	210.00
	Tomato	22.76	168.43
South East	Rice	40.84	175.61
	Maize	8.48	36.48
	Cassava	159.66	686.55
	Yam	158.99	683.66
	Cowpea	13.09	56.28
	Onion	51.69	222.25
	Tomato	43.39	186.56
South South	Rice	31.25	153.12
	Maize	4.43	21.71
	Cassava	199.62	978.13
	Yam	132.04	647.00
	Cowpea	16.13	79.03
	Onion	27.28	133.68

	Tomato	19.00	93.10
South West	Rice	56.71	181.49
	Maize	31.27	100.07
	Cassava	65.45	209.44
	Yam	49.85	159.52
	Cowpea	12.21	39.07
	Onion	35.46	113.48
	Tomato	31.13	99.62

REFERENCES

1. Abiama, P. E., Ben-Bolie, G. H., Amechmachi, N., Najid, F., Khoukhi, T. E. and Ateba, P. O. (2012). Annual intake of 226Ra, 228Ra and 40K in staple foodstuffs from a high background radiation area in the southwest region of Cameroon. Journal of Environmental Radioactivity, 110: 59-62.
2. Addo, M. A., Darko, E. O., Gordon, C. and Nyarko, B. J. B. (2013). A preliminary study of natural radioactivity ingestion from cassava grown and consumed by inhabitants around a cement production facility in the Volta region, Ghana. International Journal of Environmental Sciences, 3(6): 2312-2323.
3. Adesiji, N. E. and Ademola, J. A. (2019). Soil-to-Maize Transfer Factor of Natural Radionuclides in a Tropical Ecosystem of Nigeria. Nigeria Journal of Pure and Applied Physics, 9(1): 6-10.
4. Ajayi, O. S. and Adesida, G. (2009). Radioactivity in some Sachet drinking water samples produced in Nigeria. Iran Journal of Radiation Research, 7(3): 151-158.
5. Akpabio, G. T. and Ituen, E. E. (2006). Comparative effect of radioactive radiation on roots in coastal and hinterland locations in Akwa Ibom State, Nigeria. Nigerian Journal of Physics, 8(1): 52-65.
6. Al-Absi, E., Al-Abdullah, T., Shehadeh, H. and Al-Jundi, J. (2015). ^{226}Ra, ^{228}Ra, and ^{40}K activity concentration in some vegetables consumed in Jordan, and resultant annual ingestion effective dose. Radiation Protection and Environment, 38: 29-34.
7. Alam, L. and Mohamed, C. A. R. (2011). Natural Radionuclide of Po-210 in the edible sea food affected by coal-fired power plant industry in Kapar coastal area of Malaysia. Environmental Health, 10: 43-52
8. Alharbi, W. R. and El-Tahar, A. (2013). Natural radioactivity and dose assessment for brands of chemical and organic fertilizers used in Saudi-Arabia. Journal of Modern Physics, 4: 344-348
9. Amajor, L. C. (1991). Aquifers in Benin Formation (Miocene-Recent), Eastern Niger Delta: Lithostratigraphy, Hydraulics and Water Quality. Environmental Geology and Water Science, (17)2: 85-101.
10. Amakom, C. M., Jibiril, N. N. and Orji, C. E. (2015). Gross alpha and beta activity concentrations in cassava tubers (manihot esculenta) from old coal mining area in Enugu, South Eastern Nigeria. British Journal of Applied Sciences and Technology, 9(2): 200-205.
11. Amaral, R. D. S., Wagner, E. D. V., Edvane, B., Sueldo, V. S. and Barbara, P. M. (2005). Intake of Uranium and radium-226 due to food crops consumption in the phosphate region of Pernambuco-Brazil. Journal of Environmental Radioactivity, 82(2005): 383-393.
12. American Society for Testing Materials. (1983). Standard Method for sampling surface soils for radionuclides. American Society for Testing Materials, Report No. C (PA: ASTM)
13. American Society for Testing Materials. (1986). Recommended Practice for investigation and sampling soil and rock for engineering purposes. In: Annal Book of ASTM Standards; (04/08), American Society for Testing Materials, Report No. D, 420 (PA: ASTM).
14. Aregunjo, A. M., Farai, I. P. and Fuwape, I. A. (2005). Impact of oil and gas industry to the natural radioactivity distribution in the delta region of Nigeria. Nigeria Journal of Physics, 16: 131-136.
15. Asaduzzaman, K. H., Khandaker, M. U., Amin, Y. M., Bradley, D. A., Mahat, R. H. and Nor, R.M.(2014). Soil-to-root vegetable transfer factors for ^{226}Ra, ^{232}Th, ^{40}K, and ^{88}Y in Malaysia. Journal of Environmental Radioactivity, 135: 120-127.
16. Avwiri, G. O. and Ononugbo, C. P. (2012). Natural Radioactivity levels in surface soil of Ogba/Egbema/Ndoni Oil and Gas Fields. Energy Science and Technology, 4(2): 92-101.
17. Avwiri, G. O. and Agbalagba, E. O. (2014). Assessment of natural radioactivity, associated radiological health hazards indices and Soil-to-Crop transfer factors in cultivated area around a fertilizer factory in Onne, Nigeria. Journal of Environmental Earth Science, 71: 1541-1549.
18. Avwiri, G. O., Ononugbo, C. P. and Nwokeoji, I. E. (2014). Radiation Hazard indices and Excess Lifetime Cancer Risk in Soil, Sediment and water around Mini-Okoro/Oginigba Creek, Port-Harcourt, Rivers State, Nigeria. Comprehensive Journal of Environment and Earth Sciences, 3(1): 38-50.

19. Baratta, E. J. (1990). Radon, radium and Uranium in Drinking Water. Lewis Publisher, Washington DC. Pp. 203-212.
20. Chakraborty, S. R., Azim, R., Rahman, A. K. M. R. and Sarker, R. (2013). Radioactivity concentrations in soil and transfer factors of radionuclides from soil to grass and plants in the Cittagong city of Bangladesh. Journal of Physical Science, 21(1): 95-113.
21. Chiaka, J. C., Zhen, L. and Xiao, Y. (2022). Changing Food Consumption Patterns and Land Requirements for Food in the Six Geopolitical Zones in Nigeria. Foods, Retrieved online from https://doi.org/10.3390/foods11020150. (Accessed: 5th May, 2022).
22. Clair, A. W. and Etukudo, O. J. (2002). Food Security and Nigeria Agriculture. A Paper presented in food security conference in Lokoja, Nigeria.
23. Emumejaye, E. (2015). Activity Concentration of Cassava Tubers Grown in Ebedei Community, an oil Producing Area of Delta State, Nigeria. International Journal of Sciences and Research, 6(14): 2457-2460.
24. Ezedinma, C. I., Okafor, C., Asumugha, G. N. and Nweke, F. I. (2006). Trends in farm labour productivity and implications for cassava industralization in Nigeria. Proceedings of the 40th Annual Conference of the ASN held at NRCRI Umuahia, Abia State, October 16th-20th, 2006: 109-115.
25. Farai, I. P. and Ademola, J. A. (2005). Radium Equivalent Activity Concentration in concrete Building blocks in eight cities in South Western Nigeria. Journal of Environmental Radioactivity, 79: 119-125
26. Fernandez, G., Rodriquez, I. M., Castro, G. V., Carrazana, G. and Martizez, R. N. (2004). Radiological Surveillance of foods and drinking water in the Cuban Republic. Proceedings of the 11th Conference of the International Radiation Protection Association (IRPA), Madrid, Spain, May 23-28.
27. Golmakani, S., Moghaddam, M. V. and Hosseini, T. (2008). Factors affecting the transfer of radionuclides from the environment to plants. Radiation Protection Dosimetry, DOI: 10.1093/rpd/ncn063
28. Hernandez, F., Hernandez-Armas, J., Catalan, A., Fernandez-Aldecoa, J. C. and Landeras, M. I. (2004). Activity concentrations and mean effective dose of foodstuffs on the Island of Tenerife, Spain. Radiation Protection Dosimetry, 111: 205-210.
29. International Atomic Energy Agency-Technical Documentation (IAEA-TECDOC 1472). (2004). Proceedings of an international conference on naturally occurring radioactive materials (NORM IV). Szczyrk, Poland.
30. International Atomic Energy Agency-Technical Documentation (IAEA-TECDOC-1616). (2009). Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments. IAEA, Vienna, Australia, Pp. 213-220.
31. International Commission on Radiological Protection (ICRP). (1993). Radon-222 at home and at work. Publication 65. Annals of ICRP, 23(2): 1-45.
32. International Commission on Radiological Protection (ICRP). (2012). Compendium of dose coefficients based on ICRP Publication 60. ICRP Publication 119. Annals of ICRP 41 (Supplementary).
33. International Union of Radioecoloists (IUR) (1989). 6th Report of the working group Soil plant transfer factors (Report of the working group meeting in Guttannen), Grimselpass.
34. Jibiril, N. N., Farai, I. P., and Alausa, S. K. (2007a). Activity concentrations of ^{226}Ra, ^{228}Th, and ^{40}K in different food crops from a high background radiation area in Bitsichi, Jos Plateau, Nigeria. Radiation and Environmental Biophysics, 46: 53-59.
35. Jibiril, N. N., Farai, I. P., and Alausa, S. K. (2007b). Estimation of annual effective dose due to natural radioactive elements in ingestions of foodstuffs in tin mining area of Jos Plateau, Nigeria. Journal of Environmental Radioactivity, 94: 31-40.
36. Jibiril, N. N. and Abiodun, T. H. (2012). Effects of food preparation techniques on radionuclide intake and its implications for individual ingestion effective dose in Abeokuta, Southwestern Nigeria. World Journal of Nuclear Science and Technology, 2: 106-113
37. Katz, S. H. and Weaver, W. W. (2003). Encyclopedia of Food and Culture. Schribner: NY,USA.
Khandaker, M. U., Norfadira, B. W., Amin, Y. M. and Bradley, D. A. (2013). Committed Effective dose from naturally occurring radionuclides in shellfish. Radiation Physics and Chemistry, 88: 1-6
38. Lima, V. T. and Penna-Franca, F. (1988). Uptake of endogenous and exogenous ^{226}Ra by vegetables from soils of a high radioactive region. Radiation Protection Dosimetry, 24(1/4): 123-126
39. Linares, V., Belles, M., Albina, M. I., Sirvent, J. J., Sanchez, D. J. and Domingo, J. I. (2006). Assessment of the pro-oxidant activity of uranium in kidney and testis of rats. Toxicology Letters, 167: 152-161.
40. McDonald, P., Jackson, D., Leonard, D. R. P. and McKay, K. (1999). An assessment of ^{210}Pb and ^{210}Po terrestrial foodstuffs from regions of potential technological enhancement in England and Wales. Journal of Environmental Radioactivity, 43: 15-29.

41. Nwankpa, A. C. (2017). Determination of food crops contamination in Osun State, Nigeria Due to Radium-226, Thorium-232 and Potassium-40 Concentrations in the Environment. European Journal of Sustainable Development, 6(4): 169-174.
42. Nweke, F. I., Spencer, D. S. C. and Lynam, J. K. (2002). The cassava transformation: Africa's Best-kept Secret. East Lansing, USA: Michigan State University Press.
43. Ocheje, J. A. and Tyovenda, A. A. (2020). Determination of the Transfer Factor and Dose Rate of Radionuclides in some selected Crops in Kogi State, Nigeria. IOSR Journal of Applied Physics, 12(3): 7-12.
44. Ononugbo, P. C., Avwiri, G. O. and Egieya, J. M. (2013). Evaluation of natural radionuclide content in surface and groundwater and excess lifetime cancer risk due to gamma radioactivity. Academic Research International, 4(6): 636-647.
45. Ononugbo, C. P., Azikiwe, O. and Avwiri, G. O. (2019). Uptake and Distribution of Natural Radionuclides in Cassava Crops from Nigerian Government Farms. Journal of Scientific Research and Reports, 23(5): 1-15.
46. Organization for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA). (1979). Exposure to radiation from natural radioactivity in building Materials. Report by NEA Group of Experts, Nuclear Energy Agency (Paris: OECD).
47. Prajapati, K. and Modi, H. A. (2012). The importance of potassium in plant growth-A Review. Indian Journal of Plant Science, 1: 177-186.
48. Sam, A. K. and Abbas, N. (2010). Assessment of radioactivity and associated hazards in local and imported cement types used in Sudan. Radiation Protection Dosimetry, 88: 225-260
49. Shanthi, G., Maniyan, C. G., Allan, G. R. G. and Kumaran, J. T. T. (2009). Radioactivity in food crops from high-background radiation area in Southwest India. Current Science, 97: 9-10
50. Sheppard, S. C. and Evenden, W. G. (1988). Critical compilation and review of plant/soil concentration ratios for uranium, thorium and lead. Journal of Environmental Radioactivity, 8: 255-285.
51. Short, K. C. and Stauble, A. J. (1967). Outline of the Geology of the Niger Delta. American Association of Petroleum Geologists Bulletin, 51: 761 -779.
52. Tattam, C. M. (1943). A Review of Nigerian Stratigraphy. Geological Survey of Nigeria Report, Lagos Pp. 27-46.
53. Tawalbeh, A. A., Samat, S. B., Yasir, M. S. and Omar, M. (2012). Radiological Impact of drinks intake of naturally occurring radionuclides on adults of central zone of Malaysia. Malaysian Journal of Analytical Sciences, 16(2): 187-193.
54. Taskin, H. M., Karavus, P., Ay, A., Touzogh, S., Hindiroglu and Karaham, G. (2009). Radionuclide Concentration in Soil and lifetime cancer risk due to the gamma radioactivity in Kirklareli. Turkey. Journal of environmental radioactivity, 100: 49-53.
55. Tchokossa, P., Olomo, J. B., Balogun, F. A. and Adesanmi, C. A. (2013). Assessment of radioactivity contents of food in the oil and gas producing areas in Delta State, Nigeria. International Journal of Science and Technology, 3(4): 245-250.
56. Tome, F. V., Rodriguez, M. P. B. and Lozano, J. C. (2003). Soil-to-plant transfer factors for natural radionuclides and stable elements in a Mediterranean area. Journal of Environmental Radioactivity, 65: 161-175
57. Twining, J., Shotton, P., Tagami, K., Payne, T., Itakura, T., Russell, R., Wilde, K., McOrist, G. and Wong, H. (2003). Transfer of radioactivity Caesium, Strontium and Zinc from Soil to Sorghum and Mung beans under field conditions in tropical northern Australia. In: Proceedings of joint FAO/IAEA programme of nuclear techniques in food and agriculture, held in China. IAEA-TECDOC-1497, Pp. 21-34.
58. Umar, A. M., Onimisi, M. Y. and Jonah, S. A. (2012). Baseline measurement of natural radioactivity in soil, vegetation and water in the industrial district of the Federal Capital Territory (FCT) Abuja, Nigeria. British Journal of Applied Science & Technology, 2(3): 266-274
59. United Nations Environment Programme (UNEP) (2022). Sustainable Development Goals integration. Retrieved online from https://undp.org/sustainabledevelopmentgoalsintegration. (Accessed: 26th May, 2022).
60. United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) (2000). Exposures from Natural Sources, 2000 report to General Assembly, Annex B, New York.
61. United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) (2008). Sources and Effects of Ionizing Radiation, UNSCEAR 2008 Report to the General Assembly with Scientific Annexes Vol. I, United Nations, New York, 2010