https://dx.doi.org/10.4314/WOJAST.v15i1.85

ISSN: 2141 – 3290
www.wojast.com

ESTIMATION OF TRANSFER FACTOR FROM SOIL TO CASSAVA IN ETHIOPE EAST, DELTA STATE, NIGERIA

[1]EJOH, E. F.; [1]ESSIETT, A. A.; [1]ESSIEN, I. E.;
[2]BEDE, M. C.; [1]BENJAMIN, E. U.; [*1]ATAT, J. G.
[1]Physics Department, University of Uyo, Akwa-Ibom State, Nigeria.
[2]Physics Department, Federal University of Technology, Ikot Abasi, Nigeria.
josephatat@uniuyo.edu.ng

ABSTRACT

Cassava is a very important staple food crop in Delta state. The aim of this research is to assess the activity concentration level and determine the transfer factor of radionuclide from soil to cassava in Ethiope Local Government Area of Delta state, Nigeria. The activity concentration of ^{40}K, ^{238}U and ^{232}Th in soil and cassava samples collected from the study area were analysed using gamma spectrometry. A lead-shielded 3 x 3 inch coaxial type Sodium Iodide Thallium [NaI(TI)] doped detector crystal (Model No. 802 series, Canberra Inc.) coupled to a Canberra series multichannel Analyzer (MCA) (Model N0.1104) through a preamplifier was used. The results of the activity concentration in soil samples indicate that, ^{40}K has the highest mean activity concentration ((38.66 ± 3.69) BqKg^{-1}) with the highest value ((62.47 ± 5.67) BqKg^{-1}) recorded at E2. The mean activity concentrations of ^{238}U and ^{232}Th are 3.65 ± 0.90 BqKg^{-1} and 0.46 ± 0.05 BqKg^{-1} respectively. The peak values of ^{238}U and ^{232}Th are 5.07 ± 1.17 BqKg^{-1} and 0.98 ± 0.11 BqKg^{-1}. From cassava, ^{40}K varies from 75.06 to 200.08 BqKg^{-1} with the highest mean activity concentration of 99.62 ± 8.32 BqKg^{-1} and 200.08 ± 14.90 BqKg^{-1} as the highest value noted at C5. The mean activity concentrations of ^{238}U and ^{232}Th are 3.89 ± 0.93 BqKg^{-1} and 0.81 ± 0.09 BqKg^{-1} respectively. The maximum values of ^{238}U and ^{232}Th determined from the computation from cassava samples are 11.10 ± 2.48 BqKg^{-1} and 1.70 ± 0.18 BqKg^{-1}. The results of this study show that the activity concentration of ^{40}K, ^{238}U and ^{232}Th in the study area are lower than world average values of 420, 30 and 35 BqKg^{-1} in soil and cassava respectively, and it is therefore not harmful if consumed. The mean transfer factor of ^{40}K, ^{238}U and ^{232}Th from soil to cassava are 3.12 ± 0.44, 0.95 ± 0.31 and 2.96 ± 0.91 respectively. The range of values of ^{40}K, ^{238}U and ^{232}Th varied as 1.41 to 5.82, BDL to 2.98 and 0.21 to 9.35 correspondingly. Peak values of the TF were noted as 5.82 for ^{40}K at E8, C8, 2.98 for ^{238}U at at E9, C9 and 9.35 for ^{232}Th at E9, C9. The high value of TR is accredited to the richness of the organic matter in the soil. The quick recycling of natural radionuclides through the soil-cassava suggests the presence of an internal cycling that help the build-up of the natural radionuclides

Keywords: Transfer factor, cassava, excess lifetime cancer, radionuclides, food crop, gamma spectrometry.

INTRODUCTION

Radionuclides found in our surroundings are unstable form of nuclides (Ekpo *et al.*, 2020) that disintegrate spontaneously into different daughter nuclides in order to achieve stable nuclide. The radionuclides present in the environment are normally in very low activity concentrations. The sources of these radionuclides are natural as well as man-made. Natural radionuclides are present in every human environment and Human health status is a function of his environment (Essien *et al*., 2016); earth material, water, air, foods and even our own body contain naturally occurring radioactive materials (NORM). The assessments of natural environments are of high importance because every living organism is exposed to ionizing radiation (Ademola, 2019). When radionuclides that occur naturally in ores, soils, water, or other natural materials are concentrated or exposed to the environment by industrial activities, technologically enhanced naturally occurring radioactive materials (TENORM) are produced (Iwetan *et al*., 2015). Sowole and Egunjobi (2019) stated that the artificial sources of radionuclides are largely due to medical and industrial activities. In the coastal regions of Nigeria, away from medical exposure, the petroleum industry is the biggest importer and consumer of radioactive substances and Delta State is a major contributor to the oil sector in Nigeria. The uses of radioactive materials in the industry stretches across various operations which include pipeline leakages, drilling operations, well-logging, automated ionizing radiation gauge, radiography and application of radiotracers in oil well management (Davies *et al*., 2019). However, activities associated with utilizing geological resources that influences the concentration of natural radionuclides can also be seen in cases of minerals, oil and gas explorations, and the production of phosphate fertilizer. Due to these processes, the concentrations of naturally occurring radioactive isotopes in the environment have increased to a large extent. Also, the redistribution of radioactive isotopes in the environment by both physical and biogeochemical processes has been enhanced (Davies *et al*., 2019). Radionuclides are introduced in the soil (which is significant in the yield of our planet ecosystems (Atat *et al.*, 2017)).

Natural radionuclides found in terrestrial and aquatic food chains can be transferred to humans through ingestion of food. For this reason, international efforts were brought together collectively to apply adequate procedures in investigating radionuclides in food (Inuyomi *et al*., 2019), and to set crucial guidelines to protect against high levels of internal exposure that may be caused by food consumption. Radionuclides are introduced in the soil (which is significant in the yield of our planet ecosystems through application of inorganic fertilizers, chemical sprays, pesticides and erosion of NORM emit radiations that pose

. https://dx.doi.org/10.4314/WOJAST.v15i1.85

danger to human beings. The transportation of radionuclides from soil to plants is possible through root uptake and deposition of dust on plant leaves and to humans through inhalation, breathing, and ingestion. Soil–plant–human route is a major pathway for the transfer of radionuclides to human beings. The uptake of radionuclides from soil to plant is characterized by a Transfer Factor (TF) which is defined as the ratio of radionuclide concentration in plant to soil per unit mass. This parameter is essential for environmental transfer models, which are advantageous in the prediction of radionuclide concentration in agricultural crops for the estimation of dose impact to human beings (Ademola, 2019). Many factors, both natural and physicochemical, affect the build-up of radionuclides in plant and they are identified to include: concentration of radionuclides in the soil, soil pH, climate, speciation of radionuclide in soil solution, organic content of the soil, soil type and time (Essien *et al.*, 2017). The presence of radioactivity in the edible parts of crops causes human internal exposure to ^{226}Ra and ^{232}Th which are radiotoxic elements, whereas ^{40}K is both radiotoxic and nutritionally important (Rilwan *et al.*, 2022). It is therefore necessary to determine and estimate the concentration of primordial radionuclides and their TF to plant, in order to assess the radiation doses to man and animal, and for economic sustainable development

MATERIALS AND METHOD

Study Area

Delta state is an agricultural and oil producing state in the South-South geopolitical zone of Nigeria, consisting of twenty-five LGAs and lying about latitude 5.7040˚N and longitude 5.9339˚E. Ethiope East is one of the local Government Areas in Delta State whose headquarter is at Isiokolo (Ekpo, *et al.*, 2021); it is also about latitude 5.642^{0}N and longitude 6,069^{0}E. The people in the area are predominantly farmers. The study area lies within the Niger Delta sedimentary basin which is characterized by both marine and mixed continental quaternary sediments that are composed of abandoned beach ridges and mangrove swamps. The area experience wet and dry season which are typical seasons in Nigeria (Emumejaye, 2015). The samples were collected during the rainy season from four farmlands in Ethiope East LGA of Delta state. The study locations are shown in Figure 1 with GPS information.

Sample Collection and Preparation

Twenty samples of soil and twenty samples of cassava were collected from cultivated farmlands in Ethiope East. Only farms where cassava was cultivated were used for the study. Soil samples of about 2.0 kg (wet weight) was collected around the root area of the cassava plants from each position, and corresponding edible part of cassava tuber samples was also collected. At each sampling site, the soil samples were cleared of surface vegetation and debris. The soil samples were sun dried in a dust-free environment in order to remove moisture. Each dried soil sample was ground using a mortar and pestle and sieved using a 2mm mesh sieve to obtain homogenized sample, and thereafter weighed. The weight of each soil sample was about 500g to 700g. The large particles were disposed of and the meshed soil samples were stored in a black polythene bag for four weeks to allow time for secular equilibrium (Al-Alawy *et al.*, 2020).

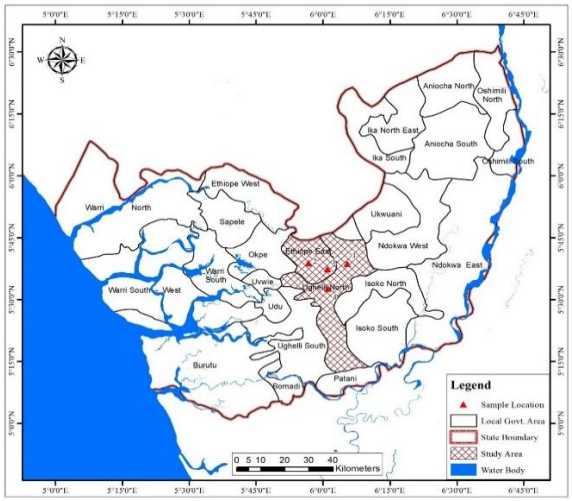

Figure 1. Map showing the study area

The cassava samples collected were thoroughly washed with tap water and then in distilled water to remove surface sand and they were placed into separate polyethylene bags and labelled. The samples were grated into small pieces using a grater, sun dried to a constant weight, ground to powdery form, and sieved to attain homogeneity. The weight of the plant samples varied between 600g and 900g. Thereafter, the samples were taken to the National Institute of Radiation Protection and Research, University of Ibadan, Oyo State, Nigeria, for analysis.

Sample Analysis

Gamma ray spectroscopy was employed for the measurement of the activity concentration in the samples. A lead-shielded 3 x 3 inch coaxial type Sodium Iodide Thallium [NaI(TI)] doped detector crystal (Model No. 802 series, Canberra Inc.) coupled to a Canberra series multichannel Analyzer (MCA) (Model N0.1104) through a preamplifier was used. It has a resolution full width at half maximum (FWHM) of about 8% at energy of 0.662 Mev. The choice of radionuclides to be detected was predicted based on the fact that the NaI (TI) detector has a modest resolution.

Transfer factor

To facilitate the comparison process and the differences that occur due to the different environmental conditions, plant contamination is calculated on the basis of dry weight (Al-Alawy *et al.*, 2020). Soil to plant transfer is influenced by several factors: the physicochemical characteristics of the radionuclides, the form of the fallout or the waste, the time after fallout, soil properties, the type of crop, and the soil management practices (IAEA, 2010). The TF in the samples was calculated using Equation 2 (Alausa, 2020).

$$TF = \frac{Activity\ concentration\ of\ radionuclide\ in\ plant\ (BqKg^{-1})}{Activity\ concentration\ in\ soil(BqKg^{-1})} \quad (2)$$

. https://dx.doi.org/10.4314/WOJAST.v15i1.85

Radium Equivalent Concentration (Raeq)
The radium equivalent is an index used to describe the gamma output from different mixtures of Uranium (that is, ^{226}Ra), ^{232}Th, and ^{40}K in a material. This factor is used in comparing the radionuclides present in any material and this was adopted in this study for the purpose of comparing the measured radioactive concentration in the samples used. From the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K, the radium equivalent was calculated using Equation 3.

$$Ra_{eq} = C_U + 1.43C_{Th} + 0.077C_K \quad (3)$$

Where C_U, C_{Th} and C_K are the radioactivity concentrations in Bqkg^{-1} of ^{238}U, ^{232}Th and ^{40}K respectively. ^{238}U will be used in place of ^{226}Ra in the calculations, although there may be disequilibrium between these radionuclides. This disequilibrium is given as 1.03 by UNSCEAR (2000). Equation 3 is based on the assumption that 370 Bqkg^{-1} of ^{238}U, 259 Bqkg^{-1} of ^{238}Th and 4810 Bqkg^{-1} of ^{40}K produce the same gamma radiation dose rate. To minimize radiation hazards, samples whose Ra_{eq} are greater than 370 Bqkg^{-1} should not be ingested into the body Essiett *et al.*, 2019).

Annual Effective Dose due to Ingestion of Food Crops
The effective dose (AEDE) due to ingestion of food crops is a useful concept in the radioactivity measurement that enables the summation of all radiations absorbed by different organs. It can be evaluated from the amount of radionuclide deposited in foodstuff, the activity concentration of a particular radionuclide in food per unit deposition, the consumption rate of the food products and the dose per unit activity ingested. The model of radiation effective dose delivered due to the ingestion of food contaminated with radionuclides were obtained from Equation 4 (Avwiri *et al*., 2021).

$$E(Svyr^{-1}) = C\sum A_i DCF_i \quad (4)$$

Where, $E(Svyr^{-1})$ is the annual effective dose, C (Kgyr^{-1}) is the mean annual consumption of food stuff, A_i (BqKg^{-1}) is the activity concentration of radionuclide i, in the ingested food and DCF_i (SvBq^{-1}) is the dose coefficient for radionuclide i. The summation is for all the radionuclides considered in the sample material under study.

Evaluation of the ingested dose estimates the radiation induced deleterious health effects associated with consumption of radionuclides. This is because the ingested dose in the body is proportional to the total dose delivered by the radionuclides into the body. The effective radiation doses from the consumption of contaminated food are obtained by measuring the activity concentration of radionuclide in the food and multiplying the activities by dose conversion factors and the mean annual consumption of food stuffs. The ICRP 2012 values of ingestion coefficient for ^{226}Ra, ^{232}Th and ^{40}K radionuclides for age groups above 17 years are 2.8×10^{-7}, 6.2×10^{-7} and 6.2×10^{-9} SvBq^{-1} respectively. The mean annual consumption rate of cassava staple food in Nigerian per capita value of 102.0 kgyr^{-1} was used for calculating the effective dose due to ingestion of food stuff (Avwiri *et al*., 2021).

Excess Lifetime Cancer Risk due to Ingestion of Food Crops
Excess lifetime cancer risk due to ingestion (ELCR) is defined in this study as an estimation of the risk to a member of a population dying from cancer as a result of the intake of a radionuclide in food from the study area. The ELCR associated with the intake of food crops will be evaluated using Equation 5 (Alausa, 2020).

$$ELCR = \sum r_i I_i \quad (5)$$

Where $ELCR$ is the lifetime cancer risk due to ingestion of food crop, r_i denotes the cancer risk coefficient for ith radionuclide, and I_i is ACT, signifies the per capital activity intake of the radionuclide. A is the activity concentration of the ith radionuclide, C is food consumption rate, and T is the average life expectancy. The risk coefficients, r for ^{226}Ra, ^{232}Th, and ^{40}K used in the study are 9.56×10^{-9} Bq^{-1}, 2.45×10^{-9} Bq^{-1}, and 5.89×10^{-10} Bq^{-1} respectively. The mean life expectancy at birth is 45.5 years in Nigeria in addition (Alausa, 2020). The food consumption statistics used in this study is the mean annual consumption rate of cassava in Nigerian per capita value of 102.0 kgyr^{-1} (Avwiri *et al.*, 2021).

RESULTS
Table 1 presents the information concerning the sample codes with their corresponding locations of selected farm lands. The results of the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in soil samples are seen in Table 2. Table 3 has the results of the activity concentrations of ^{40}K, ^{238}U and ^{232}Th, AEDE and ELCR in cassava samples. Figures 1 and 2 represent the variation of Activity concentrations with corresponding location. There exists a transfer of radionuclides from soil to plant due to the uptake of nutrients; Figure 3 is adequate for the variation of Transfer Factor results from soil to cassava. Each result in the table is expressed with the statistical error from the detector used, and the mean values are expressed with the calculated standard deviation.
The 20 locations are listed with codes as E1, E2, E3, ……, E20 (where soil samples were taken); also, as C1, C2, C3, ……, C20 (where cassava samples were obtained).

The transfer factor from soil to cassava in this study was calculated using Equation 2.
Table 1: Sample Codes with corresponding Location

LGA	Sample Codes	Latitude (N)	Longitude (E)
Ethiope East	E1, C1 – E5, C5	05˚37.349’	006˚01.038’
Ethiope East	E6, C6 – E10, C10	05˚38.845’	005˚56.761’

https://dx.doi.org/10.4314/WOJAST.v15i1.85

Table 2: Radionuclide Activity Concentration in soil samples

Sample Code	Surface Dose Rate ($mR.hr^{-1}$)	$^{40}K(BqKg^{-1})$	$^{238}U(BqKg^{-1})$	$^{232}Th(BqKg^{-1})$	Ra_{eq} $(BqKg^{-1})$
E1	0.006	29.45 ± 3.02	3.98 ± 0.99	0.98 ± 0.11	7.65
E2	0.004	62.47 ± 5.67	2.24 ± 0.56	0.34 ± 0.04	7.54
E3	0.004	59.30 ± 5.43	3.11 ± 0.79	0.17 ± 0.02	7.92
E4	0.006	36.03 ± 3.51	4.17 ± 0.96	0.56 ± 0.06	7.75
E5	0.005	47.74 ± 4.51	3.24 ± 0.82	0.17 ± 0.02	7.16
E6	0.014	51.23 ± 4.78	4.32 ± 1.15	0.95 ± 0.11	9.62
E7	0.002	27.47 ± 2.77	5.07 ± 1.17	0.79 ± 0.09	8.31
E8	0.005	13.78 ± 1.46	BDL	0.28 ± 0.03	1.46
E9	0.009	15.04 ± 1.55	3.72 ± 0.92	0.17 ± 0.02	5.12
E10	0.009	44.10 ± 4.20	3.07 ± 0.76	0.19 ± 0.02	6.74
Range		**13.78 – 62.47**	**BDL – 5.07**	**0.17 – 0.98**	**1.46 – 9.62**
Mean		**38.66 ± 3.69**	**3.65 ± 0.90**	**0.46 ± 0.05**	**6.93 ± 0.82**

BDL: Below Detection Limit

Table 3: Radionuclide Activity Concentration in cassava samples

Sample Code	$^{40}K(BqKg^{-1})$	$^{238}U(BqKg^{-1})$	$^{232}Th(BqKg^{-1})$	Raeq $(BqKg^{-1})$	AEDE $(mSvBq^{-1})$	ELCR $(\times10^{-3})$ $(Bqkg^{-1})$
C1	117.41 ± 8.76	0.79 ± 0.18	0.80 ± 0.08	10.97	0.15	0.32
C2	88.05 ± 6.66	0.72 ± 0.16	0.29 ± 0.03	7.91	0.09	0.24
C3	96.88 ± 9.45	5.07 ± 1.26	1.02 ± 0.12	13.99	0.27	0.26
C4	76.33 ± 7.30	3.21 ± 0.82	0.44 ± 0.05	9.72	0.17	0.21
C5	200.08 ± 14.90	2.90 ± 0.61	0.62 ± 0.06	19.19	0.25	0.55
C6	98.07 ± 7.44	1.82 ± 0.41	0.20 ± 0.02	9.66	0.13	0.27
C7	83.99 ± 8.31	5.50 ± 1.48	1.70 ± 0.18	14.4	0.32	0.23
C8	80.20 ± 7.44	7.07 ± 1.73	0.98 ± 0.11	14.65	0.31	0.22
C9	80.13 ± 7.24	11.10 ± 2.48	1.59 ± 0.17	19.54	0.47	0.22
C10	75.06 ± 5.71	0.69 ± 0.16	0.44 ± 0.04	7.10	0.09	0.21
Range	**75.06 – 200.08**	**0.69 – 11.10**	**0.20 – 1.70**	**7.10–19.54**	**0.09–0.47**	**0.21–0.55**
Mean	**99.62 ± 8.32**	**3.89 ± 0.93**	**0.81 ± 0.09**	**12.71 ± 1.24**	**0.23**	**0.27**

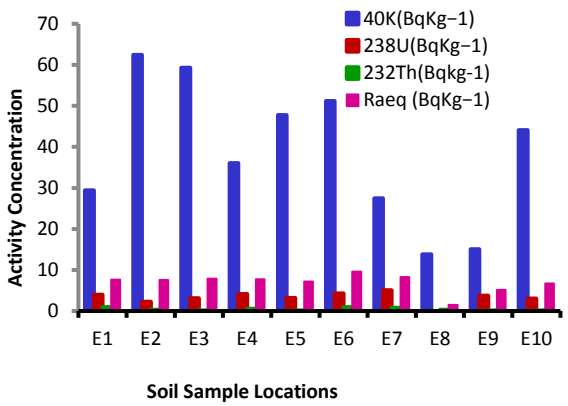

Figure 1: Activity Concentration in Soil Samples

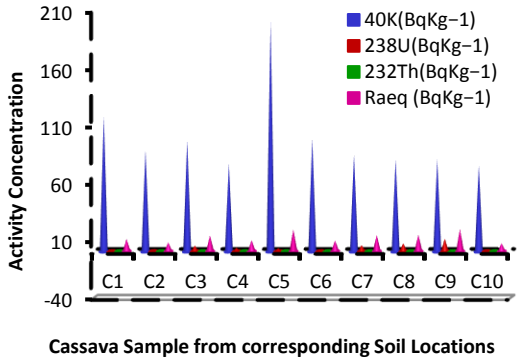

Figure 2: Activity Concentration in Cassava Samples

. https://dx.doi.org/10.4314/WOJAST.v15i1.85

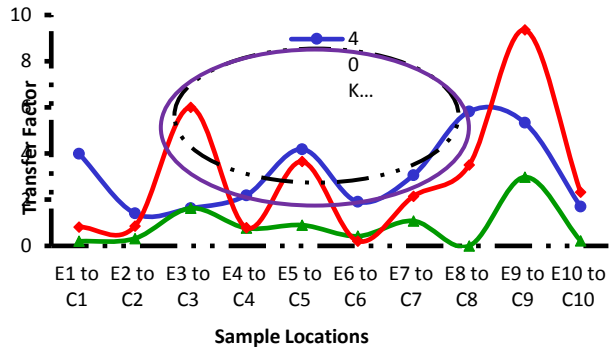

Figure 3: Variation of Transfer Factor of Radionuclides from Soil to Cassava

DISCUSSION

Activity Concentration in Soil

The activity concentration was determined using Equation 6 (Beretka and Mathew, 1985).

$$A_r\left(\frac{Bq}{kg}\right) = \frac{N-N_0}{I\gamma\,\xi mt} \qquad (6)$$

Where A_r is the activity concentration of the radionuclide in the sample, N is the net counts of a given peak for a sample, N_0 is the background of the given peak, $I\gamma$ is the number of gamma photons per disintegration, ξ is the detector efficiency at the specific gamma- ray energy, m is the mass of the measured sample (fresh weight in kg); and t is the measuring time for the sample.

From Table 2, ^{40}K has the highest mean activity concentration ((38.66 ± 3.69) BqKg^{-1}) with the highest value ((62.47 ± 5.67) BqKg^{-1}) recorded at E2. The mean activity concentrations of ^{238}U and ^{232}Th are 3.65 ± 0.90 BqKg^{-1} and 0.46 ± 0.05 BqKg^{-1} respectively. The peak values of ^{238}U and ^{232}Th are 5.07 ± 1.17 BqKg^{-1} and 0.98 ± 0.11 BqKg^{-1}. This is from the soil samples.

The mean activity concentrations of ^{40}K, ^{238}U and ^{232}Th in soil from cultivated farmlands in the study area are below the world average of 420, 33 and 45 BqKg^{-1} respectively (Eke *et al*., 2022). The activity concentrations of ^{40}K are lower in soil samples than in cassava samples, while in ^{238}U and ^{232}Th, the difference in activity concentration is relatively small. This is not in line with the conclusion from a study conducted by Alausa (2020) on the assessment of farm soils and food crops in Kuru-Jos where the radionuclides in soil were higher than those of food crops. The low activity concentration of radionuclides may be due to the non use of fertilizers on the farmlands. It is of relevance to note that the accumulation of radioisotopes can be affected by difference in properties of soil and weather conditions. The accumulation of ^{40}K may be affected by several determinants such as cation exchange capacity (CEC), type and pH of the soil. Potassium is one of the basic cations and so the ability of the soil to hold cations increases its presence (Ononugbo *et al*., 2019).

The mean concentrations of ^{40}K, ^{238}U and ^{232}Th in soil was found to be lower than those reported by Ademola (2019), Alausa (2020), Emumejaye and Sawere (2018), Ononugbo, *et al*. (2019), Alausa and Omotosho, 2017, Avwiri and Agbalagba, 2013. The results were also compared with those reported in studies conducted in other countries. The mean concentrations were lower than those obtained in Saudi Arabia (Al-Ghamdi, 2019), North of Malaysia (Alzubaidi *et al*., 2016), Iraq (Al-Way *et al*., 2020) and South Africa (Ilori and Chetty, 2020).

Radium equivalent was determined using Equation 3 (Tables 2 and 3). To minimize radiation hazards, samples whose Ra_{eq} are greater than 370 Bqkg^{-1} should not be ingested into the body (Emumejaye and Sawere, 2018; Essiett *et al*., 2019). The result is below this standard. The radium equivalent in soil ranged from 1.46 BqKg^{-1} to 9.62 BqKg^{-1} with an average of 6.93 ± 0.82 BqKg^{-1} which is over 98% less than the world average of 370 BqKg^{-1} (UNSCEAR, 2000). This means that the soil from the study area will pose no health risk to inhabitants if used as components of building materials.

The latitude and longitude of each sample point was recorded using a GPS. The coordinates obtained were converted to degrees using Microsoft excel. The world Geodetic system of 1984 was used for definition of the coordinate system and it was used to generate the contour lines. The contour maps for the activity concentrations of ^{40}K, ^{238}U and ^{232}Th for soil samples from the study areas are shown in Figures 4, 5 and 6. The numbers on the contour lines represent the activity concentrations of the radionuclides involved and the intervening spaces are marked with colours to further highlight the concentrations of these radionuclides. The higher the number on the contour line, the higher the concentration of the radionuclides involved.

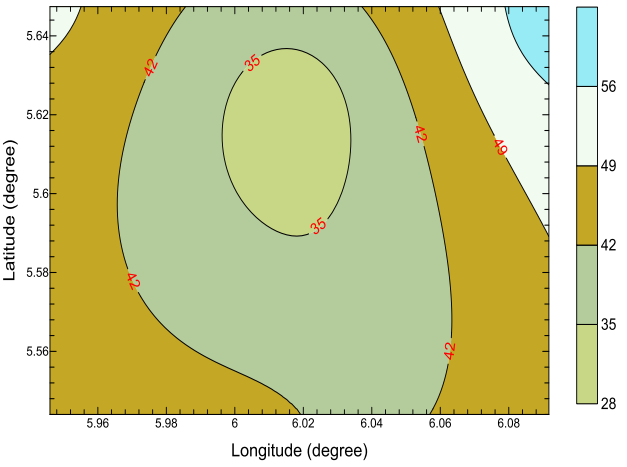

Figure 4: Contour diagram for the activity concentration of ^{40}K (Bqkg^{-1}) for soil samples

. https://dx.doi.org/10.4314/WOJAST.v15i1.85

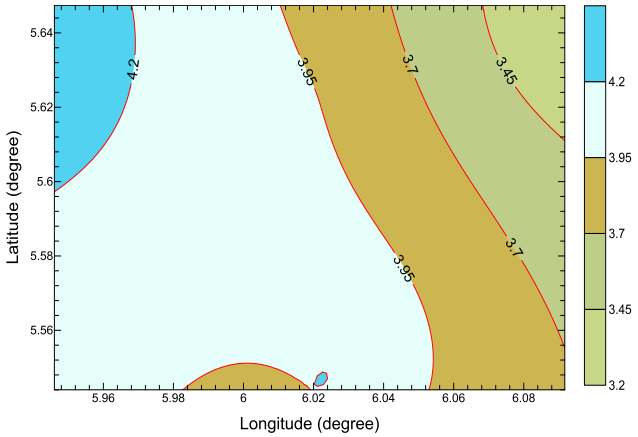

Figure 5: Contour diagram for the activity concentration of ^{238}U (Bqkg^{-1}) for the soil samples

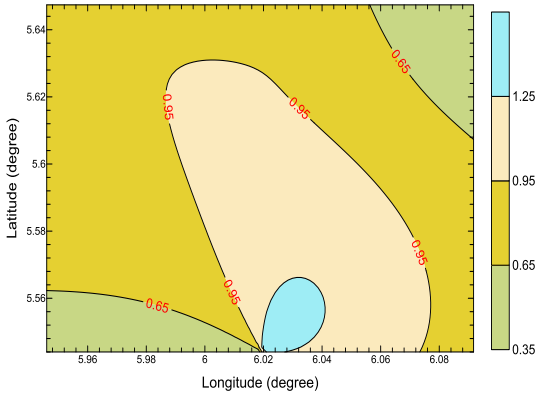

Figure 6: Contour diagram for the activity concentration of ^{232}Th (Bqkg^{-1}) for soil samples

Activity concentration in cassava

Cassava tubers are usually big and long penetrating into the soil with increased ability to absorb more radionuclides. This may be the reason for the high concentration of radionuclides in cassava samples as compared to those of soil (Emumejaye, 2015). Tables 3 shows the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in cassava samples from the study area. Considering Equation 6, the result of activity concentration was achieved in Table 3 from cassava samples. ^{40}K varies from 75.06 to 200.08 BqKg^{-1} with the highest mean activity concentration of 99.62 ± 8.32 BqKg^{-1} and 200.08 ± 14.90 BqKg^{-1} as the highest value noted at C5. The mean activity concentrations of ^{238}U and ^{232}Th are 3.89 ± 0.93 BqKg^{-1} and 0.81 ± 0.09 BqKg^{-1} respectively. The maximum values of ^{238}U and ^{232}Th determined from the computation from cassava samples are 11.10 ± 2.48 BqKg^{-1} and 1.70 ± 0.18 BqKg^{-1}.

The mean activity concentrations of ^{40}K, ^{238}U and ^{232}Th in cassava samples was found to be less than those reported by Ononugbo *et al*. (2019), Alausa (2020), Alausa and Omotosho (2017), Avwiri, and Agbalagba (2013). The radium equivalent obtained from cassava samples ranged from 7.10 BqKg^{-1} to 22.51 BqKg^{-1} with an average of 12.71 ± 1.24 BqKg^{-1} which is over 95% less than the world average of 370 BqKg^{-1} (UNSCEAR, 2000). This means that the cassava from the study area will pose no health risk at all to inhabitants if ingested.

Equation 4 was adequate for the determination of the annual effective dose due to ingestion of cassava grown in the sample area ranged from 0.09 mSvBq^{-1} to 0.47 mSvBq^{-1} (Table 3) with an average of 0.23 ± 0.04 mSvBq^{-1}. The values obtained are less than the world average of unity and lower than 0.45 and 0.31 mSvBq^{-1} reported in other areas of Delta State by Emumejaye (2015).

Equation 5 satisfies the result of excess lifetime cancer risk due to ingestion calculated (Table 3) ranged from 0.21×10^{-3} BqKg^{-1} to 0.55×10^{-3} BqKg^{-1} with an average of (0.27 ± 0.03) ×10^{-3} BqKg^{-1}. This value is lower than the recommended world average of 1.0x10^{-3} BqKg^{-1}.

The contour maps for the activity concentrations of ^{40}K, ^{238}U and ^{232}Th for cassava samples from the study areas are shown in Figures 7, 8, and 9. The numbers on the contour lines represent the activity concentrations of the radionuclides involved and the intervening spaces are marked with colours to further highlight the concentrations of these radionuclides. The higher the number on the contour line, the higher the concentration of the radionuclides involved.

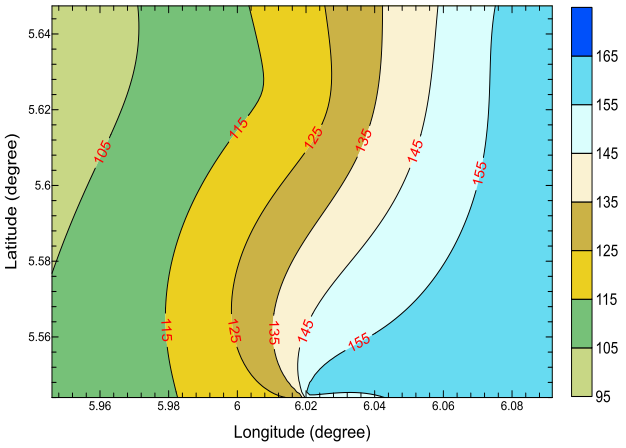

Figure 7: Contour diagram for the activity concentration of ^{40}K (Bqkg^{-1}) for cassava samples

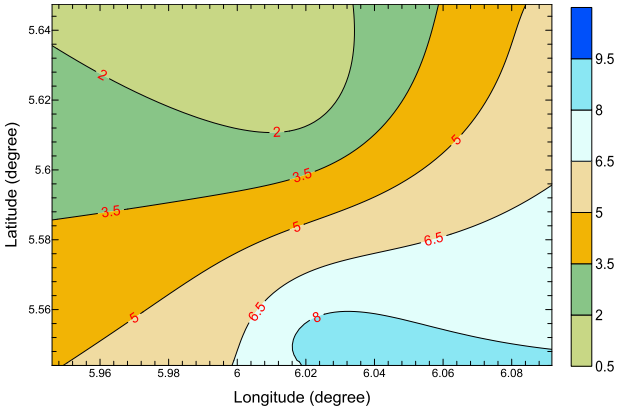

Figure 8: Contour diagram for the activity concentration of ^{238}U (Bqkg^{-1}) for cassava samples

. https://dx.doi.org/10.4314/WOJAST.v15i1.85

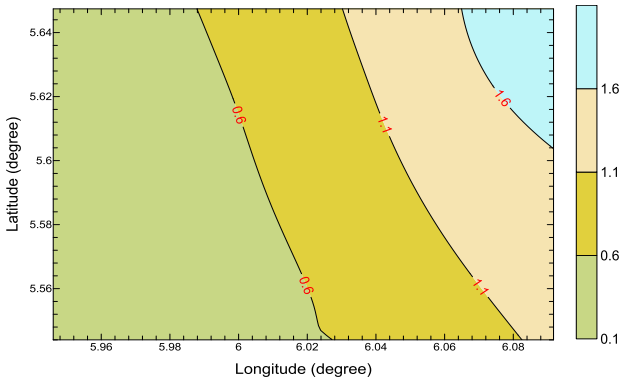

Figure 9: Contour diagram for the activity concentration of ^{232}Th (Bqkg^{-1}) for cassava samples

Transfer Factor (TF)

Equation 2 was employed to determine the transfer factor; Figure 3 shows the graphical representation of these results. The mean transfer factor of ^{40}K, ^{238}U and ^{232}Th from soil to cassava are 3.12 ± 0.44, 0.95 ± 0.31 and 2.96 ± 0.91 respectively. The range of values of ^{40}K, ^{238}U and ^{232}Th varied as 1.41 to 5.82, BDL to 2.98 and 0.21 to 9.35 correspondingly. Peak values of the TF were noted as 5.82 for ^{40}K at E8, C8, 2.98 for ^{238}U at E9, C9 and 9.35 for ^{232}Th at E9, C9. The high value of TR is accredited to the richness of the organic matter in the soil. The quick recycling of natural radionuclides through the soil-cassava suggests the presence of an internal cycling that help the build-up of the natural radionuclides (Harb *et al*., 2014). The mean values obtained for TF of ^{40}K in the study areas are higher than the recommended ratio of 2.7 (IAEA, 2010; Ademola, 2019).

Conclusion

The activity concentrations of natural radionuclides, including ^{40}K, ^{238}U, and ^{232}Th in the farm soil and food crops (cassava) grown in Delta State, Nigeria, have been measured, and the radiological health effects were evaluated in this study. The activity concentrations of the radionuclides obtained from the farm soil and food crop samples were found to be lower than the world average values and figures reported in other literature. The radium equivalent in soil can be said to be negligible due to the extremely low value obtained as compared to the world average. The high TFs may be attributed to the high accumulation of radionuclides in the food crops resulting in high annual effective doses. The lifetime cancer risks due to the ingestion were also lower than that of the world average limit of 1.0x10^{-3}. The values obtained show that there is no radiological risk of ingestion in the study area.

REFERENCES

Ademola, A. K. (2019). Natural Radionuclide Transfer from Soil to Plants in High Background Areas in Oyo State, Nigeria. *Radiation Protection Environment*, 42(3): 112 – 118.

Alausa, S. K. (2020). Radiometric Assessment of Farm Soils and Food Crops Grown in Kuru Jos, Nigeria. *Iranian Journal of Medical Physics*, 17(5): 289 – 297.

Alausa, S. K. and Omotosho, O. O. (2017). Natural Radioactivity in Farm Soils and Major Food Crops Grown in Ayetoro, Ogun State, Southwestern Nigeria. *International Journal of Low Radiation*, 10(4): 285 – 303.

Al-Alawy, I. T, Mhana W. J. and Ebraheem, R. M. (2020). Radiation Hazards and Transfer Factors of Radionuclides from Soil to Plant and Cancer Risk at Al-Taji city-Iraq. International Conference of Al-Ayen University. DOI: 10.1088/1757-899X/928/ 7/072139.

Al-Ghamdi, A. H. (2019). Health Risk Assessment of Natural Background Radiation in the Soil of Eastern Province, Saudi Arabia. *Journal of Radiation Research and Applied Sciences*, 12(1): 219 – 225.

Al-Way, I. T., Mhana, W. J. and Ebraheem, R. M. (2020). Radiation Hazards and Transfer Factors of Radionuclides from Soil to Plant and Cancer Risk at Al-Taji City-Iraq. IOP Conference series: Materials Science and Engineering. 928 072139.

Alzubaidi, G., Hamid, F. B. S. and Abul Rahman, I. (2016). Assessment of Natural Radioactivity Levels and Radiation Hazards in Agricultural and Virgin Soil in the State of Kedah, North of Malaysia. *The Scientific World Journal*, 2016: 1 – 9. Doi:10.1155/2016/6178103.

Atat, J. G., Ekpo, S. S. and Abraham, O. E. (2017). Assessment of pH, Temperature, Electrical Conductivity and Refractive Index of Water and Sand from Ibeno, Akwa Ibom State, Nigeria. *World Journal of Applied Science and Technology*, 1(9): 20 – 25.

Atat, J. G. Akankpo, A. O., Umoren, E. B., Horsfall, O. I. and Ekpo, S. S. (2020a). The Effect of Density-velocity Relation Parameters on Density Curves in Tau (τ) Field, Niger Delta Basin. *Malaysian Journal of Geosciences (MJG)*, 4 (2): 54 – 58.

Avwiri, G. O. and Agbalagba, E. (2013). 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. *Environmental Earth Sciences*, 71(4): 1541 – 1549.

Avwiri, G. O., Ononugbo, C. P. and Olasoji, J. M. (2021). Radionuclide Transfer Factors of Staple Foods and its Health Risks in Niger Delta Region of Nigeria. *International Journal of Innovative Environmental Studies Research*, 9(1): 21 – 32.

Beretka, J. and Mathew, P. J. (1985). Natural Radioactivity of Australian Building Materials, Industrial Waste and By-Products. *Health Physics*, 48(1): 87 – 95.

Davies, O. A, Amachree, D. and Teere, M. B. (2019). Effects of Radionuclides in Aquatic Lives of Nigerian Coastal Rivers: A Review. *International Journal of Research Studies in Science, Engineering and Technology*, 6(2): 25 – 33.

Eke, B.C., Amakom, C. M., Ukewuihe, U. M., Akomolafe, I. R., Ejelonu, B. O. and Okereke, B. O. (2022). Radiological Dose Assessment due to the Presence of Norms in the Top Soil of the Imo State Polytechnic, Imo State Nigeria. Environmental health insight. 16(1): Doi: 10.1177/11786302221137219.

Ekpo, S. S., Atat, J. G., Akankpo A. O., Akpan, V. E. and Essien, I. E. (2020). Dosimetry of Ionizing Radiation in Swamp Rice Farm in Ekoi Ubom and Ekoi Ikot Nyoho, Ini Local Government Area. *IJRDO Journal of Applied Science*, 6(3): 8 – 18.

Ekpo, S. S., Osaho, D. O., Atat, J. G. and Umar, S. (2021). The Effect of Exploration Activities on Mineral Elements in Fluted Pumpkin Leaves. *IJRDO Journal of Biotechnology*, 1(1): 1 – 11.

Emumejaye, K. (2015). Activity Concentration in Cassava Tubers Grown in Ebedei Community, an Oil Producing Area of Delta State, Nigeria. *International Journal of science and research*, 4(11): 2457 – 2460.

Emumejaye, K. and Sawere, B. T. (2018). Estimation of Radiological Risk due to Natural Radioactivity Concentration in Soil Samples from Selected Towns in Isoko, Delta State. *International Journal of Advanced Research in Physical Science (IJARPS)*. 5(6): 29 – 34.

Essien, I. E., Antia, A. D., Atat, J. G. Umoh, U. A., Udofia, A. E. and Inyang, A. J. (2016). Determination of Radioactive Elements Concentrations in Soils of Selected Areas in Akwa Ibom State, Nigeria by Instrumental Neutron Activation Analysis. *Journal of Natural Sciences Research*, 6(19): 52 – 57.

Essien, I. E., Essiett, A. A., Ani, O. B., Peter, I. G. and Udofia, A. E. (2017). Estimation of Radiological Hazard Indices due to Radioactivity in Soils in Ibiono Ibom, Akwa Ibom State, Nigeria. *International Journal of Scientific and Research Publications*, 7(5): 245 – 251.

Essiett, A. A., Ehiwe, O. I., Inam, E. and Bede, M. (2019). Annual Effective Dose, Radium Equivalent Activity and Harzard Indices Assessment in Rainwater from Selected Areas in Akwa Ibom State, Nigeria. *International Journal of Research and Innovation in Applied Science*. 48(7): 33-37.

Harb, S., El-Kamel, A. H., Abd El-Mageed, A. I., Abbady, A. and Rashed, W. (2014). Radioactivity Levels and Soil-to-Plant Transfer Factor of Natural Radionuclides from Protectorate Area in Aswan, Egypt. *World Journal of Nuclear Science and Technology*, 40(1): 7 – 15.

IAEA. (2010) Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Fresh Water Environments, Technical Report Series No. 472.

Ilori, A. O. and Chetty, N. (2020). Soil-to-Crop Transfer of Natural Radionuclides in Farm Soil of South Africa. *Environmental Monitoring and Assessment*, 192(12): 775. Doi: 10.1007/s10661-020-08756-7.

Inuyomi, S. O., Ore, O. T. and Abiodun, O. P. (2019). Evaluation of the Natural Radioactivity Levels and Radiological Assessment of Nuts Commonly Consumed in Ile-Ife, South West, Nigeria. *Radiation Science and Technology*. 5(2): 15 – 19.

Iwetan, C. N., Fuwape, I. A., Arogunjo, A. M. and Obor, G. (2015). Assessment of Activity Concentration of Radionuclides in Sediment from Oil Producing Communities of Delta State, *Nigeria. Journal of Environmental Protection*, 6: 640 – 650.

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.

Rilwan, U., Jafar, M., Musa, M., Idris, M. M. and Waida, J. (2022). Transfer of Natural Radionuclides from Soil to Plants in Nasarawa, Nasarawa State, Nigeria. *Journal of radiation and nuclear applications* 10:1-9.

Sowole O. and Egunjobi K.A. (2019). Radioactivity Assessment of ^{40}K, ^{238}U and ^{232}Th in Surface Soil Samples of Igbokoda, Southwest of Nigeria. *Tanzania Journal of Science*, 45(3): 307 – 314.

UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation (2000). Sources and Effects of Ionizing Radiation, Volume I. United Nations, New York.