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Measurement of (^{40}K, ^{238}U and ^{232}Th) and Associated Dose Rates in Soil and Commonly Consumed Foods (Vegetables and Tubers) at Okitipupa, Ondo State, Southwestern Nigeria

A. Ibitola, Gilbert[1], Ajanaku Olanrewaju[1], Ilori, Abiola Olawale[2*], R. O. Aremu[1] and I. A. A. Omosebi[1]

[1]*Department of Physical Sciences, Ondo State University of Science and Technology, Okitipupa, Nigeria.*
[2]*Department of Mathematical Sciences, Ondo State University of Science and Technology, Okitipupa, Nigeria.*

Authors' contributions

This work was carried out in collaboration between all authors. Author AIG designed the study and wrote the protocol. Authors AO and IAO performed the statistical analysis, wrote the first draft of the manuscript and managed the analyses of the study. Authors ROA and IAAO managed the literature searches, took samples and prepared it for laboratory analysis. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this present study is to collect soil samples and some commonly consumed food materials in Ondo State, Nigeria such as tubers (cassava, *Manihot esculent* and yam, *Dioscorea alata*) samples and vegetables (waterleaf, *Talinium triangulare* and bitter leaf, *Vernonia amygdalina*) samples at some selected locations in Okitipupa, Ondo state, Southwestern, Nigeria in order to determine the following natural radionuclides (^{40}K, ^{238}U and ^{232}Th) levels using a well calibrated NaI(TI) which is well shielded with a detector coupled to a computer resident quantum MCA2100R Multichannel. The transfer factors, annual absorbed dose rate and the annual effective

**Corresponding author: E-mail: iloriabiola99@gmail.com;*

dose in the samples collected were estimated.
The results showed that the measured natural radionuclides were present in the mean concentrations of 323.79 ± 12.45 Bqkg^{-1}, 81.87 ± 45.30 Bqkg^{-1} and 57.62 ± 18.04 Bqkg^{-1} for ^{40}K; 11.76 ± 36.03 Bqkg^{-1}, 4.67 ± 10.12 Bqkg^{-1} and 3.45 ± 2.10 Bqkg^{-1} for ^{238}U and 9.66 ± 0.89 Bqkg^{-1}, 3.07 ± 2.45 Bqkg^{-1} and 2.45 ± 0.92 Bqkg^{-1} for ^{232}Th for soil, yam and cassava samples respectively. The results also showed that the radionuclides were present in the concentrations of 11.76 ± 36.03 Bqkg^{-1} and 9.66 ± 0.89 Bqkg^{-1} for ^{40}K; 9.67 ± 8.53 Bqkg^{-1} and 7.87 ± 1.89 Bqkg^{-1} for ^{238}U and 8.63 ± 6.08 Bqkg^{-1} and 6.58 ± 0.76 Bqkg^{-1} for ^{232}Th for waterleaf and bitter leaf samples respectively. The soil-to-yam transfer factors were found to be 0.26, 0.40 and 0.32 for ^{40}K, ^{238}U and ^{232}Th and soil-to-cassava yam transfer factors were found to be 0.18, 0.29 and 0.25 for ^{40}K, ^{238}U and ^{232}Th respectively. The soil-to-waterleaf transfer factors were found to be 0.37, 0.82 and 0.82 for ^{40}K, ^{238}U and ^{232}Th while the soil-to-bitter leaf transfer factors were found to be 0.32, 0.74 and 0.68 for ^{40}K, ^{238}U and ^{232}Th respectively.
The mean absorbed dose rate was 25.08 ± 0.57 $nGyh^{-1}$ and the mean annual outdoor effective dose was 46.17 $mSvy^{-1}$. The annual effective dose reported for this present study area represents 65.95% of the world average value of 70.00 $mSvy^{-1}$ and 47.11% of Nigeria value of 98.00 $mSvy^{-1}$.

Keywords: Natural radionuclides; transfer factor; absorbed dose rate; annual outdoor effective dose; Nigeria.

1. INTRODUCTION

The environment is constituted by various materials containing different forms and amount of natural radionuclides and their decayed products. The isotopes of Potassium (^{40}K), Uranium (^{238}U) and Thorium (^{232}Th), and their daughter products can be found abundantly in the outer layers of the Earth [1]. The radioactivity and composition of these natural radionuclides will be studied in soil, tubers and vegetables for this present study. Soils with more than average level of radiation can be found in many regions due to the exposure to cosmic rays from the outer space [2]. Knowing the level of radiation in the environment is important in implementing a suitable control for the sake of radiological protection and radiation exposure to a large population since dose about 1.5Sv increases cancer incidence and mortality [3].

All foods are reported to be slightly radioactive and that all food sources combined exposes a person to about 0.4 mSv per year [3]. Tubers and vegetables are very vital in human diet, the presence of natural radionuclides (^{40}K, ^{238}U and ^{232}Th) in them may results in radiological implication not only in the food but also on the populace consuming such foods. Tubers are cultivated in nearly all tropical regions of the world providing a staple starchy food for 80 million people and as important source of income [4]. Human beings have always been exposed to ionizing radiations of natural origin, namely terrestrial and extraterrestrial radiation. Radiation of extra-terrestrial origin is from high energy cosmic ray particles and at sea level it is about 30 nGyh^{-1} [3], while that of terrestrial origin is due to the presence of naturally occurring radionuclides; mainly potassium, rubidium and the radionuclides in the decay chains of thorium and uranium [5]. These radionuclides have half-life which is comparable to the age of the earth [6]. The mandate to control nuclear and radiation generating sources in Nigeria is vested with the Nigerian Nuclear Regulatory Authority which is authorized by law to ensure that radiation protection and safety regulations are adhered to several studies have been conducted around the world to assess natural radioactivity levels in the soil of certain areas [7].

Also, agriculture has been one of the backbones of the economy of many developing countries like Nigeria. Many countries in Africa have laid down policies on the provision of sustainable food security. When people have sufficient food to eat, many of the nutrition-related problems are avoided and healthy citizen are available to work for the growth of such respective countries. It is expected that developing countries do not only concentrate on the provision of adequate food for their citizens but also food that is chemically and radiologically safe [3]. This form part of an important goal of the United Nations (UN) relating to sustainable food security which is to assist members' states in ensuring that people have access to food that is sufficient, nutritionally adequate and above all considerably safe for human consumption [8].

The presence of radionuclide in soil above a certain threshold leads to contamination of food products since these food products derived their nutrients for growth from the top soil on which they are grown. Radionuclides in solution can then be incorporated through root hair and then to the root of vegetables for onward transfer to the leave system of the vegetables that human feed on. In most cases, this is facilitated by their chemical similarity with other element that the grasses usually depend on for growth [8].

The absorption of radionuclides associated with particles can be in a form of direct dietary intake or an indirect process following particle weathering and soil-plants-animal transfer. This is dependent on soil water pH, organic matter, microbial activities and the vegetation present [8]. It is therefore very important to assess radiological safety of these tubers and vegetables consumed by human, this is because the ingestion of foods contaminated with radionuclides has the potential of exposing human beings to high level of radiation dose. Furthermore, radionuclides with relatively long half-lives are considered human health risk as they can get into the human system through the food chain and thereby increase the radiation burden for many years [2]. Also, the natural radioactivity levels in soils of some locations in Nigeria, with Benin formation underlay, have been reported to be significantly higher than the world average [7]. The radioactivity levels in vegetables and tubers grown in such soils may be enhanced through the plant-root uptake of radionuclides and such, humans feeding on the food products may have high retention of natural radionuclides in their body causing the concentrations of several pollutants, radioactive or otherwise, including Uranium, Thorium and Potassium, have increased over the last few decades [8]. These elemental pollutants do exist in the environment and are a threat to many organisms. Compared to other physical and biological end points, the effects of pollutants such as radionuclides on human have been the focus of only a few studies. Therefore, it is necessary to measure the activity concentrations of the natural radionuclides in the soil samples and food products grown in the study area. Thus, the aim of this study is to collect soil samples and commonly consumed foods (waterleaf, bitter leaf, cassava and yam samples) at some locations in Okitipupa, Ondo state, Nigeria in order to determine the natural radioactivity levels in the samples with the objectives to measure the activity concentrations of ^{40}K, ^{238}U and ^{232}Th radionuclides in all the samples collected, determine the transfer factors (TFs), estimate the annual absorbed dose rate in the samples collected and estimate the annual effective dose.

2. MATERIALS AND METHODS

2.1 Geographical Description of the Study Area

Okitipupa is a Local Government Area in Ondo State, Nigeria. It is native to the Ikales, who are a sub-set of the larger Yoruba tribe. It has always been the central town for inhabitants of the Ondo South senatorial district of Ondo state comprising okitipupa, Irele, Ilaje, Ese-Odo, Odigbo and Ile-oluji/Oke-Igbo local governments due to the presence of several amenities. It was a district in the colonial days before Nigeria's independence in 1960. It has a university, a Specialist hospital, several private hospitals, a Magistrate court, a High court, a Police division, an Army Base, Commercial banks, a Telephone exchange, numerous primary and secondary schools.

Okitipupa soils are associated with nearly level plains of 0-4% slopes at elevation of 40-60 m above mean sea level and are developed on recent to tertiary sediments termed coastal plain sands or cretaceous Abeokuta formation [9].

The Ikale natives are predominantly farmers. The major cash crop being cultivated in the area are oil-palm, rubber and cassava. They also cultivate yam, beans, okro, pepper, melon and vegetables. Staple food includes but is not limited to baked cassava popularly known as pupuru, yam, rice, yam flour and cassava flakes (Garri) among others. Major industries located in the town include the Okitipupa Oil Palm Plc and Oluwa Glass Factory. Palm-oil and rubber plantations litter the landscape. It has an area of 803 km², coordinates $6^0 30' 0''$ North, $4^0 48' 0''$ East and a population of 233,565 [10].

2.2 Samples Collection

10 samples were collected each for soil, cassava, yam, waterleaf and bitter leaf samples respectively for the present study. These points of collection were marked out using a Global Positioning System (GPS). Soil samples were collected from depths 5cm at the different locations within the sample site while all food samples were collected directly from farm lands in the study area. At the collection point, all samples were wrapped in separate black plastic bags and were well labelled with a paper masking tape. The samples were then transported to the laboratory for preparation.

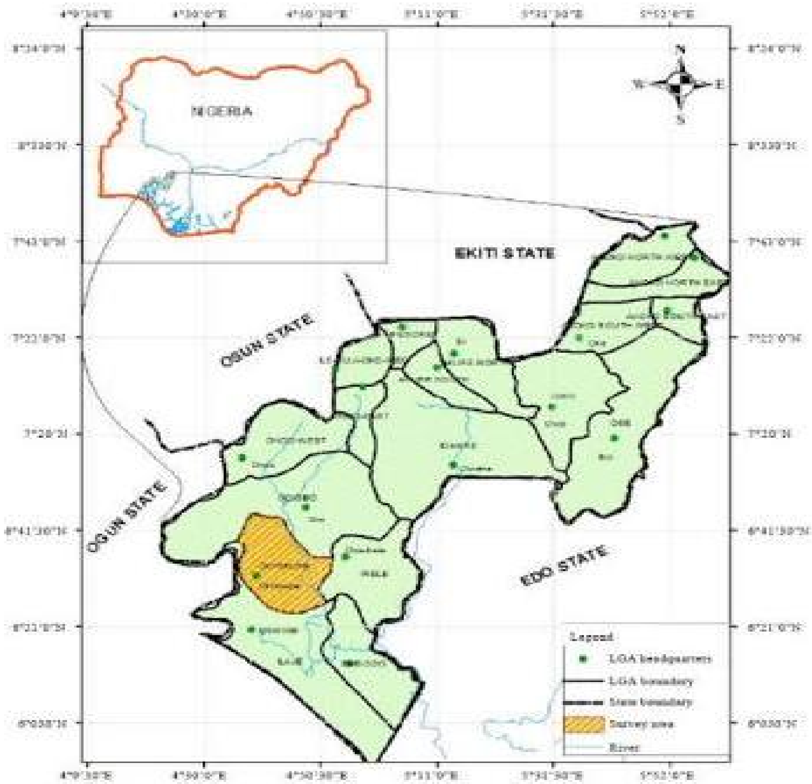

Fig. 1. Geological map of Nigeria showing the study area (Okitipupa)

2.3 Samples Preparation

Soil samples were well mixed after removing extraneous materials such as roots, pieces of stones and gravels. Samples were then weighted and dried into an electric oven at 110°C for 4 days until a constant dry weight was obtained. The dried samples were then crushed using mortar and pestle. After crushing and mixing thoroughly, soil samples were shaken in a sieve shaker using a 2 mm mesh size. The samples were later scaled in 200 g each in a radon tight container for a minimum of 28days so as to reach secular equilibrium between radon and its daughter nuclides before radiometric counting [1].

The vegetable samples were washed thoroughly in order to remove dust and surface contaminations. They were then dried in an oven at 110°C for 24 hours and placed in a furnace. The samples were allowed to ash at this temperature for 24 hours. The ash samples were cooled to room temperature. The cooled ash samples were then weighed [4]. The samples were later scaled into 200 g each in radon tight containers for a minimum of 28 days so as to reach secular equilibrium between radon and its daughter nuclides before radiometric counting [11].

Cassava and yam samples were rinsed to remove sands and dusts so as to avoid contaminations, they were then sliced into bits respectively, sun dried and then oven dried at 80°c until a constant weight is reached. Each sample were crushed and sieved using sieve mesh (2mm) and kept in air-tight containers and sealed. The crushing and sieving were crucial for achieving homogeneous state of the sample. The samples were later scaled in 200 g each in a radon tight container for a minimum of 28 days so as to reach secular equilibrium between radon and its daughter nuclides before radiometric counting [11].

2.4 Specific Activity Determination

The specific activity concentrations of the soil samples were measured using a well calibrated NaI(Tl) and well shielded detector couple to a computer resident quantum MCA2100R Multichannel analyzer for 36,000s. An empty container under identical geometry was also counted for the same time. The 1460KeV gamma-radiation of ^{40}K was used to determine the concentration of ^{40}K in the sample. The gamma transition energy of 1764.5KeV ^{214}Bi was used to determine the concentration of ^{238}U while the gamma transition energy of 2614KeV ^{208}Tl was used to determine the concentration of ^{232}Th while ^{137}Cs was detected by its 661.6KeV gamma transition.

$$C_s = \frac{C_\alpha}{P_\gamma(\frac{M_s}{V_s})\varepsilon_\gamma t_c}\ (BqKg^{-1}) \qquad (1)$$

Where C_s is the sample concentration, C_α is the net peak energy, ε_γ is the efficiency of the detector for a γ-energy of interest, M_s/V_s is the sample mass per volume of soil, t_c is the total counting time and P_γ is abundance of the γ-line in a radionuclide.

The efficiency calibration of the detector was done using a reference standard mixed source traceable to Analytical Quality Control Service (AQCS, USA), which has certified activities of the selected radionuclide and has a geometrical configuration identical to sample container. The standard sources contained ten known radionuclides. The energy calibration was also performed by using the peaks of the radionuclide present in the standard sources. The channel number is proportional to energy; the channel scale was then converted to an energy scale. This produces an energy calibration curve, i.e. energy versus channel.

The detection limit (DL) of a measuring system describes its operating capability without the influence of the sample. The DL is given in $Bqkg^{-1}$ which is required to estimate the minimum detectable activity in a sample. This was obtained using the equation:

$$DL\ (Bqkg^{-1}) = \frac{1.96\left(\frac{B}{T}+SD^2\right)^{1/2}}{k\ x\ \varepsilon\ x\ m} \qquad (2)$$

Where SD is the estimated standard error of the net background count rate in the peak, T is the counting time (s), ε is the counting efficiency (cps/Bq), *m* is the mass of the sample, *k* is the factor that converts cps (counting per seconds) to Bq and 1.96 represents the 95% confidence level.

2.5 Transfer Factor

The soil-to-crop transfer factors (TFs) measured the transfer of radionuclides from the soil to crops. In soil, each radioactive element follows complex dynamics in which a part of its concentration is transported into the soil solution, while another part gradually becomes strongly bound to the particles of the soil. The portion of these radionuclides, which is in the soil solution, can be incorporated via the root into the grass [12].

From observed activity concentrations of the radionuclides in the food crops and in the corresponding soil, the transfer factors (TFs) values were calculated according to the equation:

$$TF = \frac{A_g}{A_s} \qquad (3)$$

Where,

A_g = Activity of radionuclides in crops ($BqKg^{-1}$ dry weight)
A_s = Activity of radionuclides in soil ($BqKg^{-1}$ dry weight).

The dry weight was preferred because the amount of radioactivity per kilogram dry weight is much less variable than the amount per unit fresh weight. The soil-to-crop TF can be used as an index for the accumulation of trace elements by crops or the transfer of elements from the soil to the crop.

2.6 Absorbed Dose Rate

The estimated absorbed dose rate in $nGyh^{-1}$ due to the radionuclide concentration was done according to the equation [13]:

$$D = 0.042S_K + 0.429S_U + 0.666S_{Th} \qquad (4)$$

Where D is the absorbed dose rate in $nGyh^{-1}$ due to the specific radionuclide concentration S_K, S_{Th} and S_U for ^{40}K, ^{232}Th and ^{238}U respectively in $Bqkg^{-1}$ at 1m above the ground.

2.7 Annual Outdoor Effective Dose

Effective dose is a measure of the stochastic effects on health risk due to radiation dose either internal or external to whole or part of the body. The annual outdoor effective dose equivalent was estimated using outdoor occupancy factor of 0.3 and conversion factor of 0.7 $SvGy^{-1}$ [3]. The 0.7 conversion factor shows that an average person stays about 7 hours outside daily.

$$E_x = D_x\ X\ N(h)\ X\ O_f\ X\ K_f \quad (5)$$

E_x is the annual outdoor effective dose ($mSvy^{-1}$), $N(h)$ is the number of hours in a year (24 hours x 365.24 days), D_x is absorbed dose rate in the air ($nGyh^{-1}$), O_f is outdoor occupancy factor and K_f is conversion factor ($SvGy^{-1}$).

3. RESULTS AND DISCUSSION

3.1 Activity Concentrations in the Soil Samples

In the study, the radioactivity level in the soil samples ranged from 290.09 to 395.22 Bqkg^{-1} with a mean value of 323.79±12.45 Bqkg^{-1} for ^{40}K; 10.19 to 12.35 Bqkg^{-1} with a mean value of 11.76±36.03 Bqkg^{-1} for ^{238}U and 8.42 to 10.93 Bqkg^{-1} with a mean value of 9.66±0.89 Bqkg^{-1} for ^{232}Th. The activity concentrations of ^{40}K, ^{238}U and ^{232}Th radionuclides in the soil samples were higher than the corresponding values in food samples, this affirmed the general assertion as that only a fractional part of the radionuclides in the soil is transferable to the plants [14]. The activity concentrations of ^{40}K, ^{238}U and ^{232}Th were lower than the world average values of 410.0 Bqkg^{-1} for ^{40}K; 35.0 Bqkg^{-1} for ^{238}U and 28.0 Bqkg^{-1} for ^{232}Th [3]. The values were also lower than the mean activity concentration values of 39.24±1.12 Bqkg^{-1}, 52.86±1.40 Bqkg^{-1} and 445.02±12.24 Bqkg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively earlier reported for some food crop producing region in Ondo State [15].

3.2 Activity Concentrations in Water Leaf (*Talinium triangulare)* and Bitter Leaf (*Vernonia amygdalina)* Samples

In the study, the radioactivity level in the water leaf samples ranged from 104.60 to 135.40Bqkg^{-1} with a mean value of 118.96±22.43 Bqkg^{-1} for ^{40}K; 8.43 to 10.40 Bqkg^{-1} with a mean value of 9.67±8.53 Bqkg^{-1} for ^{238}U and 6.98 to 8.92 Bqkg^{-1} with a mean value of 7.87±1.89 Bqkg^{-1} for ^{232}Th. ^{40}K activity concentration exhibited highest values among other radionuclides measured for all samples. The radioactivity level in the bitterleaf samples ranged from 97.34 to 110.70 Bqkg^{-1} with a mean value of 103.26±6.08 Bqkg^{-1} for ^{40}K, 7.80 to 9.50 Bqkg^{-1} with a mean value of 8.63±3.45 Bqkg^{-1} for ^{238}U and 5.97 to 7.03 Bqkg^{-1} with a mean value of 6.58±0.28 Bqkg^{-1} for ^{232}Th. In the present study, the value of ^{238}U was higher than the value of 1.30 Bqkg^{-1} reported for vegetable samples (tomatoes) in Cameron Highlands and Penang [16]. The values for ^{40}K and ^{232}Th were lower than the values of 132.79 Bqkg^{-1} and 47.33 Bqkg^{-1} reported for carrot samples in Barkin Ladi LGA., Plateau State-Nigeria [17].

In the present study, the values of ^{238}U and ^{232}Th were higher than the values of 6.25 Bqkg^{-1} and 0.41 Bqkg^{-1} respectively reported for vegetable samples in Cameron Highlands and Penang [16]. The mean value of ^{40}K is lower than the mean value of 125.17 Bqkg^{-1} reported for vegetable samples in Barkin Ladi LGA., Plateau State-Nigeria [17]. The activity concentrations in waterleaf samples were higher than the values in bitter leaf samples reported in the present study.

Table 1. Activity concentrations of ^{40}K, ^{238}U and ^{232}Th in soil samples from the study area

Samples	GPS Locations		Soil		
	North	East	^{40}K (Bqkg^{-1})	^{238}U(Bqkg^{-1})	^{232}Th (Bqkg^{-1})
S1	$06^0 27'21.2''$	$004^0 27'28.4''$	321.16±13.08	10.19±33.11	9.13±0.93
S2	$06^0 27'28.4''$	$004^0 45'46.5''$	290.09±25.04	10.90±35.14	10.03±1.25
S3	$06^0 26'26.2''$	$004^0 46'11.8''$	312.38±13.91	11.61±30.65	10.93±2.45
S4	$06^0 26'28.6''$	$004^0 46'11.0''$	305.38±3.28	11.82±42.17	9.68±0.80
S5	$06^0 26'27.9''$	$004^0 46'11.2''$	298.37±8.41	12.03±38.01	8.42±1.20
S6	$06^0 26'27.1''$	$004^0 48'11.1''$	322.58±13.21	12.11±29.98	8.82±3.69
S7	$06^0 26'25.0''$	$004^0 47'11.8''$	346.80±4.39	12.19±33.09	9.23±2.20
S8	$06^0 26'27.2''$	$004^0 42'31.1''$	395.22±2.11	12.35±30.13	10.03±1.98
S9	$06^0 27'30.1''$	$004^0 41'27.3''$	347.06±14.31	12.26±28.20	10.13±0.91
S10	$06^0 26'27.5''$	$004^0 46'62.6''$	298.90±8.29	12.17±43.41	10.22±1.19
Range			290.09-395.22	10.19-12.35	8.42-10.93
Mean			323.79±12.45	11.76±36.03	9.66±0.89

Table 2. Activity concentrations of ^{40}K, ^{238}U and ^{232}Th in waterleaf and bitter leaf samples

Samples	Water leaf			Bitter leaf		
	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
S1	120.34±20.12	10.00±8.30	7.50±1.80	110.70±6.00	9.50±3.40	6.70±0.28
S2	119.07±18.37	9.22±4.11	8.21±2.11	108.15±6.99	8.91±3.59	6.87±0.22
S3	117.80±25.22	8.43±7.44	8.92±3.21	105.60±7.20	8.32±3.10	7.03±1.45
S4	126.60±24.18	9.42±2.62	8.29±0.92	101.47±5.46	8.41±3.09	6.77±2.03
S5	135.40±23.42	10.40±3.00	7.65±0.99	97.34±12.29	8.50±4.28	6.50±0.98
S6	127.70±14.99	10.21±3.50	7.48±1.70	98.63±4.01	8.63±2.98	6.37±0.86
S7	120.00±18.91	10.01±4.50	7.32±1.68	99.92±3.99	8.76±3.45	6.24±1.40
S8	104.60±21.25	9.62±3.90	6.98±1.99	102.50±6.22	9.02±3.07	5.97±1.28
S9	107.55±27.00	9.66±2.11	7.79±1.86	103.60±6.81	8.41±3.00	6.43±0.85
S10	110.50±24.10	9.70±1.69	8.60±1.33	104.70±6.01	7.80±2.45	6.89±2.04
Range	104.60-135.40	8.43-10.40	6.98-8.92	97.34-110.70	7.80-9.50	5.97-7.03
Mean	118.96±22.43	9.67±8.53	7.87±1.89	103.26±6.08	8.63±3.45	6.58±0.76

3.3 Activity Concentrations in Yam *(Dioscorea alata)* and Cassava *(Manihot esculenta)* Samples

In the study, the radioactivity level in the yam samples ranged from 65.20 to 97.50 Bqkg^{-1} with a mean value of 81.87±45.30 Bqkg^{-1} for ^{40}K; 3.92 to 5.22 Bqkg^{-1} with a mean value of 4.67±10.12 Bqkg^{-1} for ^{238}U and 2.51 to 3.60 Bqkg^{-1} with a mean value of 3.07±2.45 Bqkg^{-1} for ^{232}Th. ^{40}K activity concentration exhibited highest values among other radionuclides measured for all samples. In the present study, the values of ^{40}K and ^{232}Th were higher than the values of 41.59 Bqkg^{-1} and 52.69 Bqkg^{-1} while the values of ^{238}U is lower than the value of 14.02 Bqkg^{-1} reported for yam samples in Barkin Ladi LGA., Plateau State-Nigeria [17].

The radioactivity level in the cassava samples ranged from 45.34 to 69.42 Bqkg^{-1} with a mean value of 57.62±18.04 Bqkg^{-1} for ^{40}K; 2.50 to 3.95 Bqkg^{-1} with a mean value of 3.45±2.10 Bqkg^{-1} for ^{238}U and 2.06 to 3.06 Bqkg^{-1} with a mean value of 2.45±0.92 Bqkg^{-1} for ^{232}Th. The activity concentrations in the cassava samples were lower when compared with the concentrations in yam samples. The high concentrations of ^{40}K in food samples may be due to the use of fertilizers at the farm lands. The activity concentrations in yam samples were higher than the values in cassava samples reported in the present study.

Table 3. Activity concentrations of ^{40}K, ^{238}U and ^{232}Th in yam and cassava samples

Samples	Yam			Cassava		
	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
S1	88.70±46.83	4.59±9.95	3.60±2.34	55.42±19.46	2.50±2.10	2.54±0.96
S2	93.10±41.76	4.82±8.39	3.59±3.00	59.66±17.92	3.11±1.99	2.80±0.83
S3	97.50±40.23	5.04±12.28	3.57±2.89	63.90±12.66	3.72±1.29	3.05±0.73
S4	86.42±39.77	5.13±11.62	3.26±3.01	66.66±19.73	3.84±2.01	2.56±0.98
S5	75.34±43.83	5.22±10.71	2.94±2.99	69.42±30.53	3.95±1..43	2.06±0.94
S6	77.13±40.92	4.97±9.98	2.91±3.22	63.40±12.71	3.70±2.11	2.17±0.98
S7	78.92±39.91	4.72±10.22	2.87±3.77	57.38±13.84	3.45±2.58	2.28±0.98
S8	82.50±41.94	4.21±12.14	2.80±3.11	45.34±15.45	2.95±2.34	2.49±0.89
S9	73.85±41.38	4.07±9.23	2.66±2.59	46.77±18.94	3.41±1.88	2.37±0.83
S10	65.20±43.39	3.92±11.71	2.51±3.89	48.20±22.84	3.86±1.98	2.24±0.88
Range	65.20-97.50	3.92-5.22	2.51-3.60	45.34-69.42	2.50-3.95	2.06-3.06
Mean	81.87	4.67	3.07	57.62	3.45	2.45

Table 4. Soil-to-yam, soil-to-cassava, soil-to-waterleaf and soil-to-bitter leaf transfer factors (TFs)

Samples	TF (yam)			TF (cassava)			TF (waterleaf)			TF (bitter leaf)		
	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th
S1	0.28	0.45	0.39	0.17	0.25	0.28	0.37	0.98	0.82	0.34	0.93	0.73
S2	0.32	0.44	0.36	0.21	0.29	0.28	0.41	0.85	0.82	0.37	0.82	0.68
S3	0.31	0.43	0.33	0.20	0.32	0.28	0.38	0.73	0.82	0.34	0.72	0.64
S4	0.28	0.43	0.34	0.22	0.32	0.26	0.41	0.80	0.86	0.33	0.71	0.70
S5	0.25	0.43	0.35	0.23	0.33	0.24	0.45	0.86	0.91	0.33	0.71	0.77
S6	0.24	0.41	0.33	0.20	0.31	0.25	0.40	0.84	0.85	0.31	0.71	0.72
S7	0.23	0.39	0.31	0.17	0.28	0.25	0.35	0.82	0.79	0.29	0.72	0.68
S8	0.21	0.34	0.28	0.11	0.24	0.25	0.26	0.78	0.70	0.26	0.73	0.60
S9	0.21	0.33	0.26	0.13	0.28	0.23	0.31	0.79	0.77	0.30	0.69	0.64
S10	0.22	0.32	0.25	0.16	0.32	0.22	0.37	0.81	0.84	0.35	0.64	0.67
Mean	0.26	0.40	0.32	0.18	0.29	0.25	0.37	0.82	0.82	0.32	0.74	0.68

3.4 Transfer Factors (TFs)

Generally, transfer of radionuclides depends on soil type, pH, solid/liquid distribution coefficient, exchangeable K^+ and organic matter contents. The transfer factors (TFs) for ^{40}K, ^{238}U and ^{232}Th were determined and the results were presented in Table 4.

The mean value of the transfer factors for water leaf samples were 0.37±0.32, 0.82±0.10 and 0.82±0.18 for ^{40}K, ^{238}U and ^{232}Th respectively while the mean values of the transfer factors for bitter leaf samples were 0.32±0.12, 0.74±0.09 and 0.68±0.94 for ^{40}K, ^{238}U and ^{232}Th respectively. The TFs values for ^{40}K in the samples were low compared to that of ^{238}U and ^{232}Th. The transfer values in water leaf samples were higher than that of bitter leaf samples.

The mean value of the transfer factors for yam samples were 0.26±0.45, 0.40±0.15 and 0.32±0.88 for ^{40}K, ^{238}U and ^{232}Th respectively while the mean value of the transfer factors for cassava samples were 0.18±0.22, 0.29±0.13 and 0.25±0.81 for ^{40}K, ^{238}U and ^{232}Th respectively. The TFs values for ^{40}K in the samples were low compared to that of ^{238}U and ^{232}Th. The transfer values in yam samples were higher than that of cassava samples.

3.5 Absorbed Dose Rate and Annual Outdoor Effective Dose

The estimated absorbed dose rate in $nGyh^{-1}$ due to the radionuclide concentration in the soil was calculated for the present study. This was done to estimate the health risk associated with exposure to radioactivity in the soil from the study area. The result is shown in Tables below, the values ranged from 23.30±0.67 to 28.58±2.90 $nGyh^{-1}$ and mean value of 25.08±0.57 $nGyh^{-1}$ for Okitipupa. The absorbed dose rate value reported in this present study is higher than the value of 12.35±0.65 $nGyh^{-1}$ reported for Owo but lower than the value of 179.59±4.16 $nGyh^{-1}$ reported for Oba, Ondo State [16].

The annual outdoor effective dose reported in this study ranged from 42.89 to 52.61 $mSvy^{-1}$ with a mean value of 46.17 $mSvy^{-1}$. The value reported is lower to the value of 12.43 $mSvy^{-1}$ reported for Oba [14]. The value reported for annual effective dose represents 65.95% of the world average value of 70.00 $mSvy^{-1}$ [3] and 47.11% of Nigeria value of 98.00 $mSvy^{-1}$ [18].

Table 5. Absorbed dose rate and annual outdoor effective dose of the study area

Samples	Absorbed dose rate	Annual outdoor effective dose
	D ($nGyh^{-1}$)	E ($mSvy^{-1}$)
S1	23.94±1.31	44.01
S2	23.54±0.32	43.33
S3	25.38±1.89	46.72
S4	24.34±2.90	44.81
S5	23.30±0.75	42.89
S6	24.62±2.25	45.32
S7	25.94±0.92	47.75
S8	28.58±0.71	52.61
S9	26.58±0.63	48.93
S10	24.58±0.33	45.25
Mean	25.08±0.57	46.17

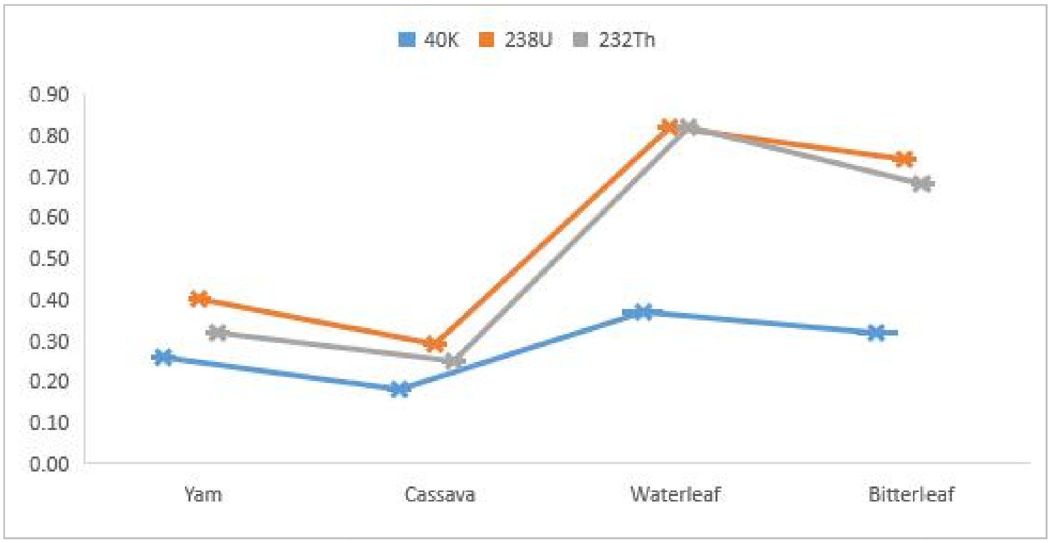

Fig. 2. Soil-to-samples Transfer Factors (TFs)

Table 6. Mean distribution of natural radionuclides in soil

S/N	Location	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
1	Okitipupa, Ondo State, Nigeria (present study)	323.79	11.76	9.66
2	Akoko, Ondo State, Nigeria (Ojo and Gbadegesin, 2013)	445.02	39.24	52.86
3	World Average (UNSCEAR, 2000)	410.00	35.00	28.00

Table 7. Annual outdoor effective dose (E)

S/N	Location	E (mSvy^{-1})
1	Okitipupa, Ondo State, Nigeria (present study)	46.17
2	Nigeria (Jibiri and Farai, 2005)	98.00
3	World Average (UNSCEAR, 2000)	70.00

4. CONCLUSION

The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in soil, waterleaf, bitter leaf, yam and cassava samples collected at Okitipupa, Ondo State Southwestern Nigeria were measured using a well calibrated NaI(TI) and well shielded detector coupled to a computer resident quantum multichannel analyzer. The radioactivity distribution of ^{40}K, ^{238}U and ^{232}Th in all samples were reported, the transfer factors, absorbed dose rate and annual outdoor effective doses were reported and compared with values from other literatures and the world average value.

The results showed that the concentration in the water leaf samples were higher than that in the bitter leaf samples. The results also showed that the concentration in the yam samples were higher than those in the cassava samples. This affirms the opinion that potassium is considered to be an important factor for the tuber growth [4]. Translocation and storage of carbohydrates occur in staple crops rich in starch, and potassium (K^+) move around in these plants. Potassium concentrations in root tubers decreases after a certain stage of plant growth and other radionuclides exhibits same tendency [19].

The concentrations in leaves were higher than those in tubers as several radionuclides concentrations would naturally decreases to about 45% in the plants collected after 58 days of planting and reduced by half after 82 days of planting. It is considered the activity concentrations in vegetables would be higher than that of tuber since vegetables grows faster and spend minimum number of days in soil than tubers [20]. The values reported were higher than values reported for some areas in various articles and lower for values in other areas. It is unlikely for the values obtained in this study to cause additional radiological health risks to the people living in the area studied.

5. RECOMMENDATION

It is recommended that activity concentrations should be measured in other food crops to evaluate the likely effects of consuming such crops in the area of study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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