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Research Article

Determination of Radionuclides in Soil and Yam Tubers from Selected Towns across Ogun and Oyo States

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Abstract

Human exposure to naturally occurring radionuclides produces a dose that varies depending on the location, diet, and habits of the individuals concerned. Potassium-40 (^{40}K), Thorium-232 (^{232}Th), and Uranium-238 (^{238}U) are naturally occurring radionuclides present in the soil and therefore contribute to radioactivity in the food we eat, particularly yam tubers due to nutrient uptake from the soil. The consumption of food contaminated with radioactive materials may have some negative health effects due to internal radiation exposure. To quantify the radiation level an individual is exposed to, the activity concentrations of ^{40}K, ^{232}Th, and ^{238}U were determined in sixteen samples of soil and yam (Dioscorea spp.) – eight soil samples and eight yam samples collected from eight different locations in Ogun and Oyo States. We analyzed these samples using a high-purity germanium detector (HPGe). The mean soil activity concentrations of 40K, 232Th, and 238U ranged between (37.40 ± 0.18) Bq/kg and (37.11 ± 1.01) Bq/kg, (2.64 ± 0.15) Bq/kg and (2.73 ± 0.12) Bq/kg, and (3.59 ± 0.26) Bq/kg and (3.87 ± 0.16) Bq/kg for Oyo and Ogun States, respectively. The mean yam activity concentrations of 40K, 232Th, and 238U ranged between (8.79 ± 0.19) Bq/kg and (24.92 ± 0.26) Bq/kg, (1.11 ± 0.02) Bq/kg and (1.76 ± 0.03) Bq/kg, and (1.64 ± 0.04) Bq/kg and (2.54 ± 0.06) Bq/kg for Ogun and Oyo States, respectively. The mean absorbed dose rate for soil was estimated to be (4.87 ± 0.15) nGy/h in Oyo State and (5.04 ± 0.19) nGy/h in Ogun State. The annual effective dose equivalent (mSv/y) was 0.010 and 0.006 for Ogun and Oyo States, respectively. This result was below the world's average value (2.4 mSv/y) as recommended by the International Commission on Radiological Protection (ICRP). Thus, the consumption of the investigated yam samples was found not to pose any significant health risks. However, long-term accumulation of low doses could be radiologically significant.

Keywords: Absorbed Dose, Activity Concentration, Dose, Effective Dose Equivalent, High-Purity Germanium Detector, Radiation, Radioactivity, Radionuclide, Radiological

Introduction

Human exposure to radiation from both natural (background) and artificial sources has been a major concern to nuclear scientists all over the world. The experiences of the Chernobyl nuclear accident and the Hiroshima nuclear weapon test, in which victims suffered a wide range of casualties, including tumors, cancer, and even death, are a clear example of the deleterious effects of radiation [1]. The level of terrestrial radiation varies from one geographical location to another depending on the variation in radionuclide concentration in soil, which largely depends on the local geology [2,3].

The greatest contribution to the average public radiation exposure comes from radioactive elements in the earth's crust and from cosmic radiation originating from space. Natural sources contribute, on average, more than 98% of the human radiation dose, excluding medical exposure [4]. The global average background nuclear radiation, as estimated by UNSCEAR (1982) [5], is 2.4 mSv/y.

The presence of primordial radionuclides such as natural potassium-40 (^{40}K), Thorium-232 (^{232}Th), Uranium-238 series (^{238}U), and Caesium-137 (^{137}Cs) from artificial sources (flowmeters, nuclear weapon tests) in the environment has been established

in some locations within the southwestern part of Nigeria [6-8]. Olomo (1990) [9] found that the levels of radioactivity for ^{238}U and ^{232}Th in food products are very low in Nigeria, with the single largest contributor being ^{40}K. Arogunjo (2003) [10] measured natural radionuclide contents present in cowpea, guinea corn, rice, and soya beans in Akure, southwestern Nigeria, and later established the presence of radioactivity levels of these natural radionuclides.

Natural radioactivity is present in soil and concentrations may be changed by anthropogenic activities (like the use of fertilizers) and transported from one place to another into the ground by rain or wind [11]. Yam is one of the most important tubers for human consumption in different parts of the world, especially in Africa (West Africa in particular). It is consumed and processed in different forms (roasted, boiled, fried).

Potassium-40 was found to contribute the highest activity in all food products, especially in yam tubers [12]. Little work has been done on soil and yam samples in these study areas – Isara, Ilisan-Remo, Ifo, and Ilaro in Ogun State; Iseyin, Saki, Eruwa, and Lalante in Oyo State. Thus, it becomes necessary to investigate the presence of radionuclides and establish whether there is a high concentration of radionuclides in soil and yam tubers across the study area. The data obtained would become a baseline for radioactivity levels in soil and yam tubers in Oyo and Ogun States. Therefore, the radiological implications of the activity level in soil and yams would be estimated for the population in the study area.

Materials and Methods

Sampling Procedure and Preparation

Sixteen (16) samples were collected in all – eight (8) samples from four towns in Ogun State and another eight samples from four towns in Oyo State. The locations were: Isara, Ilisan-Remo, Ifo, and Ilaro in Ogun State; Iseyin, Saki, Eruwa, and Lalante in Oyo State. A tuber of local yam (Dioscorea spp.) was purchased directly from the farmers in each of the towns, with their soil samples collected after the topsoil containing decayed organic matter and roots had been removed.

The soil and the sliced pieces of yam samples were first sun-dried to constant weight. They were ground using a mole grinding machine, then sieved with a 2 mm wire mesh to obtain a fine texture of the sample. The sieved yam tuber and soil samples were weighed to about 80 g using a top-pan balance, then sealed in different cellophane bags. The cellophane bags were properly labeled to indicate the location where each sample was collected.

Sample Analysis

The samples were taken to a laboratory of the Ghana Atomic Energy Commission (GAEC), Accra, Ghana, for analysis using a gamma-ray spectroscopy machine. The analysis was done with a coaxial-type High-Purity Germanium (HPGe) detector. The relative efficiency of the detector was 28.5% with an energy resolution of 1.8 keV at a gamma-ray energy of 1332 keV of ^{60}Co. Calibration of the measuring system was done using certified reference standards for various radionuclides. The standard samples were provided by Deutscher Kalibrierdienst (DKD-3) QSAGlobal GmbH, Germany. The spectral analysis was performed with the Ortec Multichannel Analyzer (MCA) and Meastro-32 evaluation software for acquisition and processing.

The specific activity concentration (Asp) of ^{238}U, ^{232}Th, and ^{40}K was determined in Bq/kg for soil and yam samples, respectively. The activity concentrations of the radionuclides were determined using the equation below [13-15].

$$A_{sp} = \frac{N_{sam}}{P_E \cdot E \cdot T_C \cdot M}$$

Where A_{sp} – the specific activity of the radionuclide in the sample

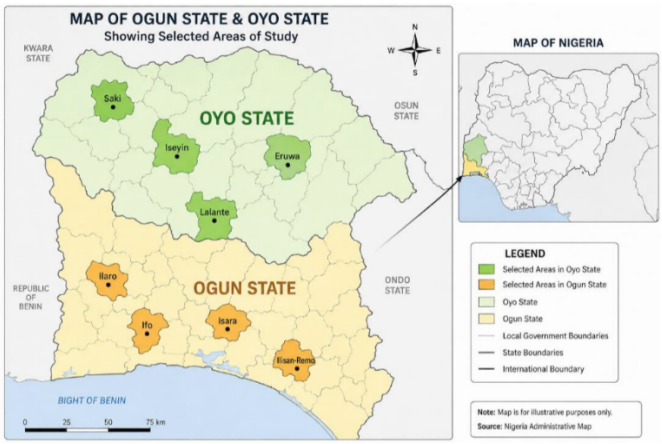
N_{sam} – net counts of the radionuclide in the sample

P_E – gamma ray emission probability (gamma yield)

E – total counting efficiency of the detector system

Tc – sample counting time

M – mass or weight of the sample



Note: Geographical Location of the selected areas in Ogun and Oyo States, Southwestern Nigeria

Figure 1: Geographical Location of the Two States

Results and Discussion Activity

Concentration

(Table 1 and Table 2) present the activity concentrations of radionuclides in soil and yam samples from selected locations across Ogun and Oyo States, respectively.

Sample Location	Soil (Bq/kg)			Yam (Bq/kg)		
	^{40}K	^{232}Th	^{238}U	^{40}K	^{232}Th	^{238}U
Isara	12.74 ± 1.91	1.23 ± 0.19	1.56 ± 0.04	4.05 ± 0.08	0.29 ± 0,02	0.38 ± 0.04
Ilisan-Remo	43.60 ± 0.32	3.34 ± 0.08	4.28 ± 0.13	18.00 ± 0.09	3.16 ± 0.02	4.22 ± 0.04
Ifo	46.81 ± 1.45	3.09 ± 0.10	4.38 ± 0.13	9.66 ± 0.07	0.96 ± 0.02	1.42 ± 0.03
Ilaro	45.28 ± 0.34	3.24 ± 0.10	5.24 ± 0.13	3.44 ± 0.52	0.03 ± 0.02	0.52 ± 0.03
Mean	37.11 ± 1.01	2.73 ± 0.12	3.87 ± 0.16	8.79 ± 0.19	1.11 ± 0.02	1.64 ± 0.04
Note: Specific activity concentration of radionuclides in soil and yam samples from Ogun State – Isara Ilisan-Remo, Ifo, and Ilaro						

Table 1: Specific Activity Concentration of Radionuclides in Samples from Ogun State

Sample Location	Soil (Bq/kg)			Yam (Bq/kg)		
	^{40}K	^{232}Th	^{238}U	^{40}K	^{232}Th	^{238}U
Iseyin	51.34± 0.21	3.81 ± 0.05	4.87 ± 0.09	46.27 ± 0.08	3.24 ± 0,03	4.59 ± 0.05
Saki	3.78 ± 0.32	0.32 ± 0.08	0.41 ± 0.13	3.41 ± 0.08	0.16 ± 0.02	0.88 ± 0.04
Eruwa	50.51 ± 1.45	3.40 ± 0.06	4.82 ± 0.80	45.65 ± 0.24	3.16 ± 0.04	4.39 ± 0.11
Lalante	43.97 ± 0.21	3.04 ± 0.04	4.27 ± 0.08	4.35 ± 0.65	0.02 ± 0.01	0.29 ± 0.04
Mean	37.40 ± 0.18	2.64 ± 0.05	3.59 ± 0.26	24.92 ± 0.26	1.76 ± 0.03	2.54 ± 0.06
Note: Specific activity concentration of radionuclides in soil and yam samples from Oyo State – Iseyin, Saki, Eruwa, and Lalante						

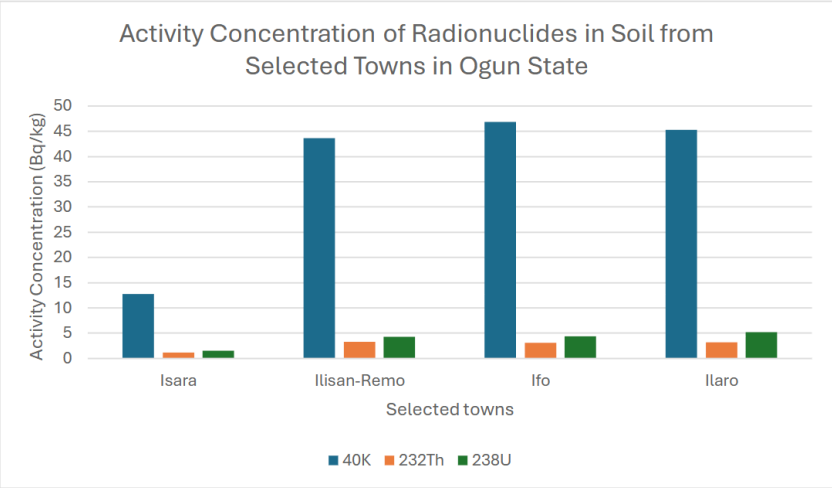
Table 2: Specific Activity Concentration of Radionuclides in Samples from Oyo State

(Figure 2) and (Figure 3) show the activity concentration of radionuclides in soil and yam samples from selected towns in Ogun State, while (Figure 3) and (Figure 4) show the activity concentration of radionuclides in soil and yam samples from four selected towns in Oyo State. The activity concentration of ^{40}K ranged from (12.74 ± 1.91) Bq/kg in Isara to (46.81 ± 1.45) Bq/kg in Ifo, with a mean activity concentration of (37.11 ± 1.01) Bq/kg. The activity concentration of ^{232}Th ranged from (1.23 ± 0.19) Bq/kg in Isara to (3.34 ± 0.08) Bq/kg in Ilisan-Remo, with a mean activity concentration of (2.73 ± 0.12) Bq/kg. The activity concentration of ^{238}U ranged from (1.56 ± 0.23) Bq/kg in Isara to (5.24 ± 0.13) Bq/kg in Ilaro, with a mean activity concentration of (3.87 ± 0.16) Bq/kg for soil samples from Ogun State.

The activity concentration of ^{40}K ranged from (3.78 ± 0.32) Bq/kg in Saki to (51.34 ± 0.21) Bq/kg in Iseyin, with a mean activity concentration of (37.40 ± 0.18) Bq/kg. The activity concentration of ^{232}Th ranged from (0.32 ± 0.08) Bq/kg in Saki to (3.81 ± 0.05) Bq/kg in Iseyin, with a mean activity concentration of (2.64 ± 0.05) Bq/kg. The activity concentration of ^{238}U ranged from (0.41 ± 0.13) Bq/kg in Saki to (4.87 ± 0.09) Bq/kg in Iseyin, with a mean activity concentration of (3.59 ± 0.26) Bq/kg for soil samples from Oyo State.

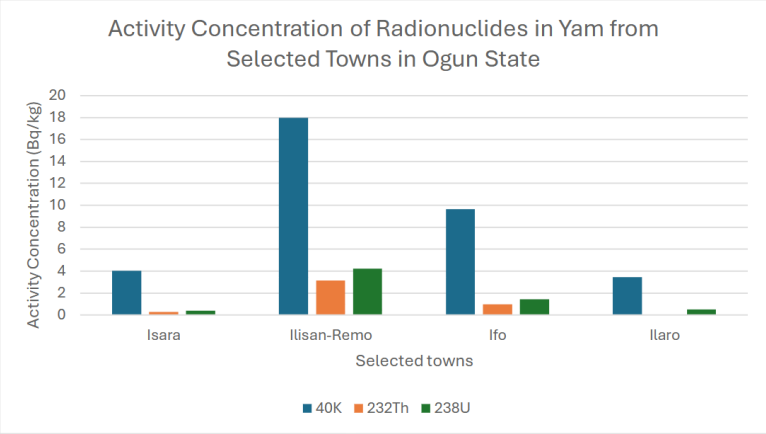
The activity concentration of these radionuclides in the food samples from Ogun State ranged from (3.44 ± 0.52) Bq/kg in Ilaro to (18.00 ± 0.09) Bq/kg in Ilisan-Remo, with a mean activity concentration of (8.79 ± 0.91) Bq/kg, (0.03 ± 0.02) Bq/kg in Ilaro to (3.16 ± 0.02) Bq/kg in Ilisan-Remo, with mean activity of (1.11 ± 0.02) Bq/kg, and (0.38 ± 0.04) Bq/kg in Isara to (4.22 ± 0.04) Bq/kg in Ilisan-Remo, with a mean activity of (1.64 ± 0.04) Bq/kg for ^{40}K, ^{232}Th, and ^{238}U, respectively.

The activity concentration of these radionuclides in the food samples from Oyo State ranged from (3.41 ± 0.08) Bq/kg in Saki to (46.27 ± 0.08) Bq/kg in Iseyin, with a mean activity concentration of (24.92 ± 0.26) Bq/kg, (0.02 ± 0.01) Bq/kg in Lalante to (3.24 ± 0.03) Bq/kg in Iseyin, with mean activity of (1.76 ± 0.03) Bq/kg, and (0.29 ± 0.04) Bq/kg in Lalante to (4.59 ± 0.03) Bq/kg in Iseyin, with a mean activity of (2.54 ± 0.06) Bq/kg for ^{40}K, ^{232}Th, and ^{238}U, respectively.



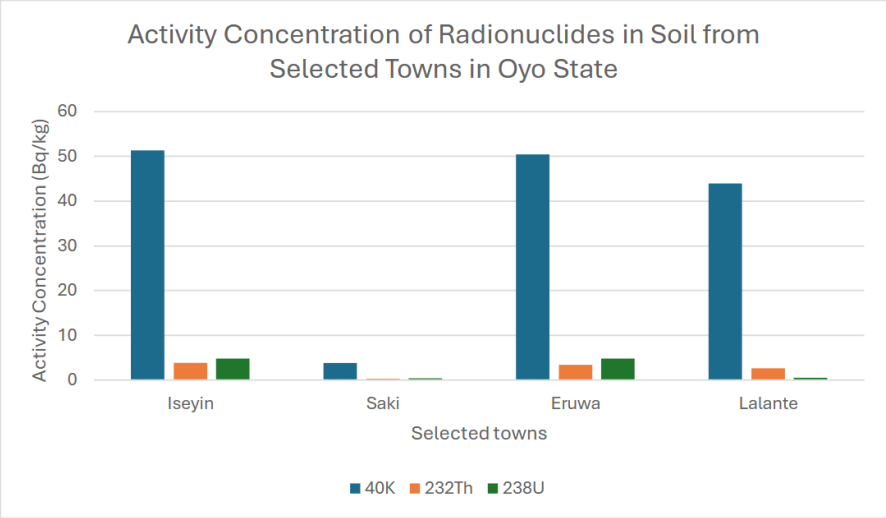
Note: Activity concentration of radionuclides in soil from selected locations in Ogun State.

Figure 2: Activity Concentration of Radionuclides in Soil from Selected Locations in Ogun State



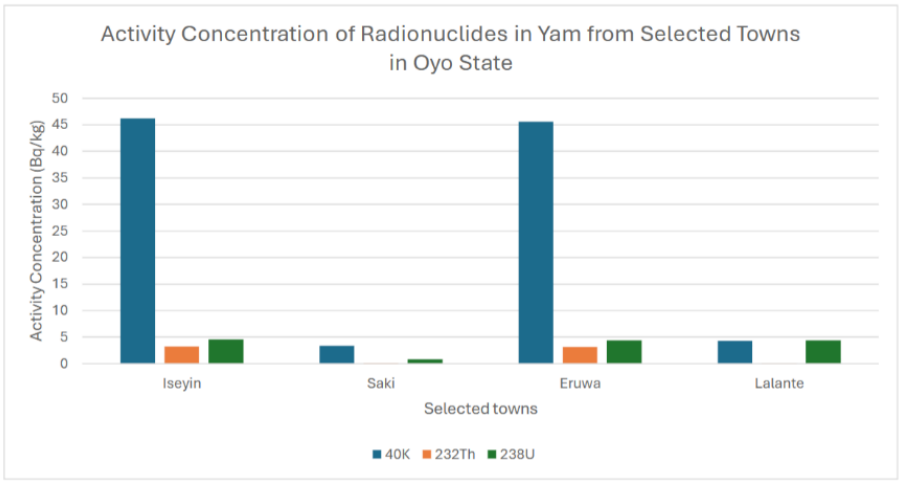
Note: Activity concentration of radionuclides in yam from selected locations in Ogun State

Figure 3: Activity Concentration of Radionuclides in Yam from Selected Locations in Ogun State



Note: Activity concentration of radionuclides in soil from selected locations in Oyo State

Figure 4: Activity Concentration of Radionuclides in Soil from Selected Locations in Oyo State



Note: Activity concentration of radionuclides in yam from selected locations in Oyo State

Figure 5: Activity Concentration of Radionuclides in Yam from Selected Locations in Oyo State

From the soil samples in the selected towns in Ogun State, 40K, ^{232}Th, and ^{238}U contributed about 84.9%, 6.3%, and 8.9%, respectively, while in the soil samples from the selected towns in Oyo State, ^{40}K, ^{232}Th, and ^{238}U contributed about 85.7%, 6.1%, and 8.2%, respectively. In the yam samples from the selected locations in Ogun State, ^{40}K, ^{232}Th, and ^{238}U contributed about 76.2%, 9.6%, and 14.2%, respectively, while in the yam samples from the selected locations in Oyo State, ^{40}K, ^{232}Th, and ^{238}U contributed about 85.3%, 6.0%, and 8.7%, respectively.

^{40}K is found to contribute the highest percentage in both soil and yam samples due to its natural abundance in the Earth's crust, plants, and animals, which, when decomposed, contributes to the highest radiation dose [16]. The influence pf human activities such as fertilizer applications also contributes to the high levels of ^{40}K in these samples. Soil-plant transfer factor (TF) also influences the uptake of radionuclides in the selected areas [17].

(Table 3) and (Table 4) show the mean absorbed dose rate for these selected locations in Ogun and Oyo States, which were (5.03 ± 0.19) nGy/h and (4.87 ± 0.15) nGy/h, respectively. These values are less than the world mean values of the absorbed dose rate, which range from 18 to 93 nGy/h, with an average value of 70 nGy/h for areas of normal background radiation [11]. (Table 5) and (Table 6) show the mean annual outdoor effective dose rate for the selected locations in Ogun and Oyo States, which were 0.010 mSv/y and 0.006 mSv/y, respectively. These values are lower than the average value (2.4 mSv/y) recommended by the International Commission on Radiological Protection [18,11] (ICRP, 1999; UNSCEAR, 2000) for normal background and lower than the Nigerian average of 98 μSv/y [2].

Sample Location	Mean Absorbed Dose (Soil) (nGy/h)
Isara	2.03
Ilisan-Remo	5.89
Ifo	5.90
Ilaro	6.31
Mean	5.04
Note: The mean absorbed dose rate in soil samples from selected locations in Ogun State – Isara, Ilisan-Remo, Ifo, and Ilaro	

Table 3: Mean Absorbed Dose Rate in Air from Selected Locations in Ogun State

Sample Location	Mean Absorbed Dose (Soil) (nGy/h)
Iseyin	6.78
Saki	0.55
Eruwa	6.45
Lalante	5.70
Mean	4.87
Note: The mean absorbed dose rate in soil samples from selected locations in Oyo State – Iseyin, Saki, Eruwa, and Lalante	

Table 4: Mean Absorbed Dose Rate in Air from Selected Locations in Oyo State

Sample Location	Mean Absorbed Dose (Soil) (mSv/y)
Isara	0.004
Ilisan-Remo	0.011
Ifo	0.011
Ilaro	0.012
Mean	0.010
Note: The mean annual effective dose rate in soil samples from selected locations in Ogun State – Isara, Ilisan-Remo, Ifo, and Ilaro	

Table 5: Mean Annual Effective Dose Rate from Selected Locations in Ogun State

Sample Location	Mean Absorbed Dose (Soil) (mSv/y)
Iseyin	0.001
Saki	0.001
Eruwa	0.012
Lalante	0.010
Mean	0.006
Note: The mean annual effective dose rate in soil samples from selected locations in Oyo State – Iseyin, Saki, Eruwa, and Lalante	

Table 6: Mean Annual Effective Dose Rate from Selected Locations in Oyo State

(Table 7) and (Table 8) show the ingestion dose for Ogun and Oyo State. It ranged from 1.5 μSv/y in Isara to 13.0 μSv/y in Ilaro for ^{40}K, from 0.1 μSv/y in Ilaro to 10.9 μSv/y in Ilisan-Remo for ^{232}Th, and from 6.5 μSv/y in Isara to 72.2 μSv/y in Ilisan-Remo for ^{238}U in Ogun State. In Oyo State, it ranged from 1.3 μSv/y in Saki to 17.4 μSv/y in Iseyin for ^{40}K, from 0.1 μSv/y in Lalante to 11.2 μSv/y in Iseyin for ^{232}Th, and from 5.0 μSv/y in Lalante to 79.2 μSv/y in Iseyin for ^{238}U.

Sample Location	Radionuclides (μSv/y)		
	^{40}K	^{232}Th	^{238}U
Isara	1.5	1.0	6.5
Ilisan-Remo	6.8	10.9	72.8
Ifo	3.6	3.3	24.5
Ilaro	13.0	0.1	9.0
Mean	3.3	3.8	28.3
Note: The effective dose of radionuclides in yam samples from selected locations in Ogun State – Isara, Ilisan-Remo, Ifo, and Ilaro			

Table 7: Effective Dose of Radionuclides in Yam Samples from Selected Locations in Ogun State

Sample Location	Radionuclides (μSv/y)		
	^{40}K	^{232}Th	^{238}U
Iseyin	17.4	11.2	79.2
Saki	1.3	0.1	15.2
Eruwa	17.1	10.9	75.7
Lalante	1.6	0.1	5.0
Mean	9.3	6.1	43.8
Note: The effective dose of radionuclides in yam samples from selected locations in Oyo State – Iseyin, Saki, Eruwa, and Lalante			

Table 8: Effective Dose of Radionuclides in Yam Samples from Selected Locations in Oyo State

Comparison with similar studies conducted on soil samples in other locations in Nigeria [7,9] (Innocent et al., 2013; Ademola & Obed, 2012) revealed only natural radionuclide levels in soil samples. While Innocent et al. (2013) investigated the mean activity concentration for ^{40}K, ^{232}Th, and ^{238}U as 426.5 Bq/kg, 12.1 Bq/kg, and 60.1 Bq/kg, respectively, Ademola and Obed (2012) found that the mean activity concentration for ^{40}K, ^{232}Th, and ^{238}U as 384.2 Bq/kg, 17.7 Bq/kg, and 39.8 Bq/kg, respectively. The values from this study are lower than those reported in similar studies and the world average (UNSCEAR, 2000), with mean activity concentrations of 420 Bq/kg, 30 Bq/kg, and 35 Bq/kg for ^{40}K, ^{232}Th, and ^{238}U, respectively.

Conclusion

Naturally occurring radionuclides such as ^{40}K, ^{232}Th, and ^{238}U were determined in soil and yam samples from selected towns in Ogun and Oyo States, southwestern Nigeria. ^{137}Cs (Cesium) was not found in any of these samples. Despite these radionuclides being present in these samples from the study areas, it does not necessarily pose any significant health hazard. However, long-term accumulation of these radionuclides could be of radiological impact.

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