Iranian Journal of Medical Physics

ijmp.mums.ac.ir

Radiometric Assessment of Farm Soils and Food Crops Grown in Kuru-Jos, Nigeria

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ARTICLE INFO

Article type:
Original Article

Article history:
Received: Aug18, 2019
Accepted: Nov17, 2019

Keywords:
Ionizing Radiation
Radiometric Assessment
Cancer Risks
Health Plague

ABSTRACT

Introduction: Human activities, such as mining, result in the elevation of natural ionizing radiation in the environment. Jos-Plateau, Nigeria, including Kuru-Jos has experienced commercial tin mining in the past, and local mining is still being practiced in this area. Therefore, it is important to assess the radiation exposure due to grown crops and the farm soils in Kuru-Jos, Nigeria.

Material and Methods: In total, four crops and soil samples were randomly collected from farmlands in Kuru-Jos. The radioactivity levels in the soil and food samples were measured using a thallium-activated sodium-iodide detector coupled to a Canberra series 10 plus Multi-Channel Analyzer. The effective dose rates in soils and food crops along with the cancer risks in the crops were determined.

Results: According to the results, the highest mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in the food crops were 456±126.0Bq/Kg (yam), 46.9±9.6Bq/kg (yam), and 31.6±23.9Bq/Kg (maize), respectively. Moreover, the mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in farm soil were determined at 1105.6±357.7Bq/Kg (cassava), 167.5±37.6Bq/Kg (yam), and 205.4±124.4Bq/Kg (Guinea corn), respectively. Additionally, yam crop had the highest mean ingestion effective dose of 1231.9µSv/y, and maize crop indicated the minimum mean value of 304.1±179.1µSv/y. The cancer risks of $(3.8\pm 0.7)\times 10^{-3}$ and $(3.0\pm 0.4)\times 10^{-3}$ for yam and cassava, respectively, were higher than the world average value (i.e., $1.0x10^{-3}$).

Conclusion: The results indicated a high radioactivity level which is in line with the results obtained from other areas in Jos-Plateau, Nigeria; however, there have been no radiological health plague reports from the areas so far.

► *Please cite this article as:*
Alausa SK. Radiometric Assessment of Farm Soils and Food Crops Grown in Kuru-Jos, Nigeria.Iran J Med Phys 2020; 17: 289-297.10.22038/ijmp.2019.42643.1633.

Introduction

The crust of the Earth contains natural radionuclides in varying amounts that are distributed depending on the geology of a location. Human activities, such as uncontrolled mining and excavation of radioactive-rich mineral resources by different nations for the purpose of economic and social needs have immensely contributed to the enhancement of natural radioactivity in the environment [1]. Mining activities and the exhaustion of most accessible mineral deposits ended up in significant land surface devastation leading to abandoned pits and ponds, soil erosion, deforestation, and altered surface drainage [2] in local mining fields in Jos-Plateau, Nigeria (Figure1). Therefore, several square kilometers of landmass area was degraded, and the lands became very scarce for farming in Jos, Nigeria [3, 4]. The unavailability of farmlands usually prompted farmers to utilize any available lands, including high background radiation areas for agricultural purposes [5]. The radionuclides along with other nutrients accumulated in arable soils are transferred through plant-root uptake to food crops depending on the soil and vegetation type [6].

Food in liquid or solid form, eaten and digested to provide nourishment and energy, is the first prerequisite for human survival. However, the presence of natural radionuclides in food crops has raised concerns and worries among radiation scientists worldwide. The concerns have motivated different authors [7-12] to investigate the radioactivity levels in various food items across the world. The detection of tin and Columbite Ores in large quantities in Jos-Plateau around 1904, led to commercial exploration and mining of the ores [13]. Mining activities are among the causes of technological natural radiation exposure of the environment; consequently, the entire environment of Jos-Plateau may be exposed to background radiation. However, Jos-Plateau is again located predominantly on migmatites, biotite-granite gneiss, and porphyritic-granites rocks with minor pegmatite and quartz veins [14].

The gneiss granite is known to contain radioactive elements, such as uranium, potassium, and thorium in varying quantities [15] which expose the entire Jos to enhancing natural radioactivity.

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Figure1. A typical local mining field in Kuru-Jos, Nigeria

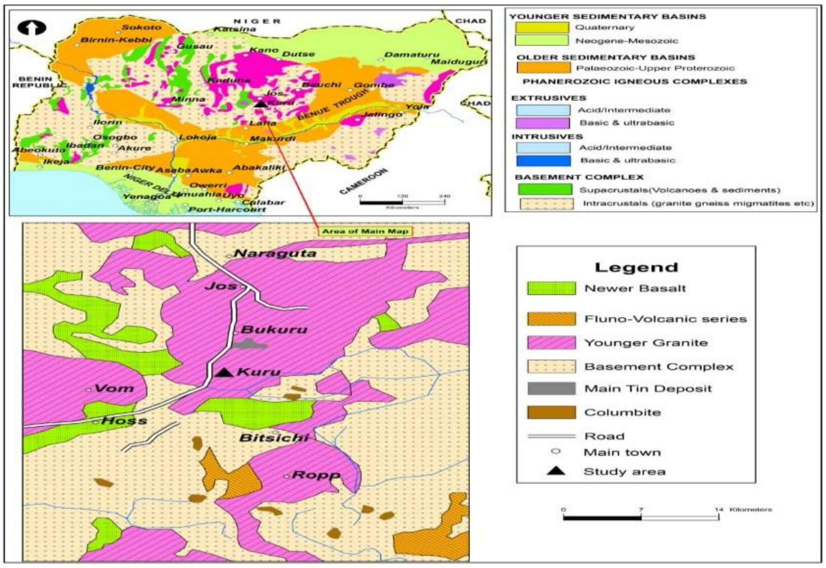

Figure 2. Geological map of Nigeria showing the rock distributions in Jos, Nigeria

An earlier report showed that the radioactivity level of some locations, particularly Bukuru, Ropp, and Bisitchi in Jos-Plateau had been reported as four times higher in the magnitude than the world average value [16]. The study area (i.e., Kuru-Jos) underlain with younger granite (Figure 2) is the host community to National Institute for Policy and Strategic Study, where top-level policymakers and policy administrators in Nigerian Government are being trained. Although the large scale mining activities in Jos ceased many years ago, continuous local and illegal tin mining is still being practiced by the indigenous. The mining may culminate in the incidence of high radioactivity in the study area, and the food crops grown in the area may be subjected to high natural radioactivity resulting from plant root uptake; as a result, the population in the area may be exposed to high ionizing radiation. It is, therefore, necessary to measure the radioactivity level of natural radionuclides in the farm soils and the food crops grown in Kuru-Jos with a view to determining the radiological impact on the population.

Materials and Methods

Sampling and Sample Preparation

Sampling was carried out during the harvesting period (September through November) to facilitate site-specific and direct collection of the food samples from the farmlands. The farmlands considered for the study were randomly selected and sampling was carried out where farming was in practice. The food crops selected for the study were cassava (*Manihot esculenta*), yam (*Dioscorea Sp.*), maize (*Zea mays*), and Guinea corn (*Sorghum bicolor L*).The cereals (i.e., maize and Guinea corn) were plucked, and tubers (i.e., yam and cassava) were uprooted from each selected farm. A total of 37 food crops collected for the study include cassava (6), yam (7), maize (10), and Guinea corn (14); moreover, the soil samples (about 1.0 kg) were collected directly from the same spot where the food crop samples were collected. All samples were carefully packed in polythene bags and transported to the laboratory for preparation and spectroscopic analysis.

The edible portion of the food crops was considered for the radiometric analysis; therefore, the cassava and yam tubers were peeled and sliced, and the maize and Guinea corn grains were removed from their husks. All the samples were thereafter air-dried for six weeks before being oven-dried at 110^{o}C to attain constant mass. The samples were then crushed, pulverized, and sieved with <2.0mm mesh sieve. In total, 200g of each sample was measured with weighing balance and transferred into an uncontaminated container (60 mm in height by 65 mm in diameter). It is pertinent to ensure that radon gas is confined within the volume of the container and their daughters remain in the sample; therefore, the containers were completely sealed for 28 days to attain a secular equilibrium, where the rate of decay of the daughters became equal to that of the parent [17].

Activity Concentration Measurement

Thallium-activated sodium-iodide (NaI(Tl)) detector (Model No: 802-series,76 mm × 76 mm) was used to analyze all the samples collected for the study. The detector was connected through a preamplifier base to a multi-channel analyzer (MCA) (Model No: 1104). The detector, NaI(Tl), and MCA were manufactured by Canberra Incorporation. The NaI(Tl) had an energy resolution of 8%and was tested using the photopeak at 0.662MeV of^{137}Cs for its reliability to distinguish the photo peaks of the primordial radionuclides in the soil and food samples.

Before using the detector, the channel-energy and efficiency calibrations of the detector were carried out. The channel-energy calibration was performed using a reference gamma source and the energy calibration analysis function of the MCA (Model No 1104). A linear equation obtained for the channel-energy calibration was given by:

$$E = 0.0111N + 0.0620 \qquad (1)$$

where N is the channel number and E is the gamma energy in MeV.

This linear *Equation* was stored in the memory of the MCA where it was used to determine gamma energies of various radionuclides for a given different channel.

The efficiency calibration of the detector was carried out at different gamma energies when the sample geometry and matrix were fixed. The reference food sample used for the efficiency calibration has a Ref No: IAEA-152 and was produced by the International Atomic Energy Agency (IAEA). The standard soil sample used for the efficiency calibration (Ref No. 48722-356) was produced at the Rocketdyne Laboratories California, Analytic Inc., Atlanta, GA, USA. The efficiency of the detector at the precise gamma energy of radionuclide sources employed in the calibration is presented in Table1, and the energy-efficient plots obtained for the soil and food samples are shown in Figure 3.

Table 1. Detector efficiency at specific gamma-ray energy of radionuclide source

Radionuclidesource	Channel No	Gamma Energy (MeV)	Food matrix	Soil matrix
			Efficiency ($\varepsilon \times 10^{-3}$) (cps/Bq)	Efficiency ($\varepsilon \times 10^{-3}$) (cps/Bq)
^{137}Cs	54.0	0.662	10.226	11.200
^{40}K	126.0	1.460	7.499	4.400
^{214}Bi (^{226}Ra)	153.3	1.764	6.660	2.710
^{208}Tl (^{232}Th)	230.0	2.614	4.779	1.410

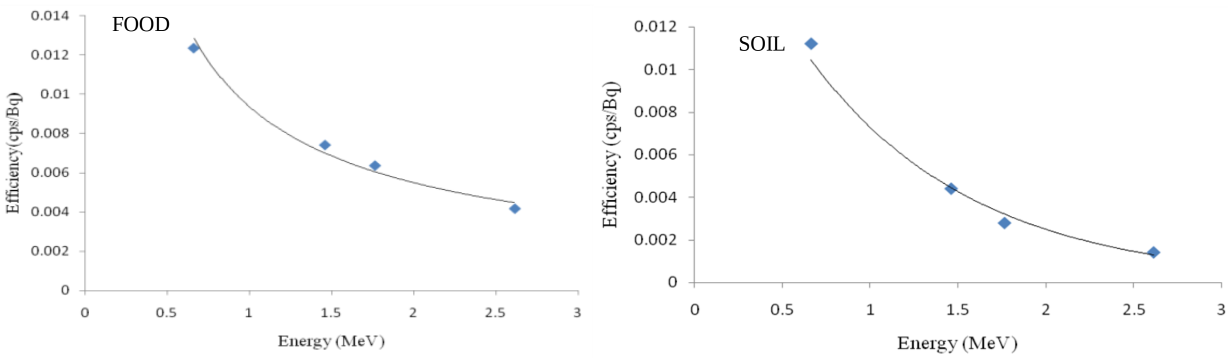

Figure 3. Detector efficiency at specific gamma-ray energy for the food and soil samples

The natural radionuclides were investigated in the food crop, and the farm soil samples included ^{226}Ra (present in the decay series of ^{238}U), ^{232}Th (present in the decay series of ^{232}Th), and ^{40}K (non-series decay radionuclides).

The models by Kitto et al. [18]were used to estimate the minimum detectable activity concentration of radionuclides in a sample, and the obtained detection limits (DLs) were 17.3, 4.2 and 5.1 Bq/kg for ^{40}K, ^{226}Ra, and ^{232}Th, respectively. The ^{214}Bi radionuclide determined at its 1760 KeV gamma-ray energy was considered to estimate the activity concentration of ^{226}Ra in the food and soil samples.The^{208}Tl radionuclides determined at its 2615 KeV gamma-ray energy was employed as an indicator to obtain the activity concentration of ^{232}Th. The energy and 1460 KeV gamma rays emitted during the decay of ^{40}K were considered to determine the activity concentration of ^{40}K.

The reproducibility in the gamma-ray counting was ensured by placing each sample container on the top of the highly shielded detector and counted for 36,000 s (10 h.). The net area counts under the corresponding photo peaks in the energy spectrum was determined by subtracting counts due to background sources from the total area of the photopeak. Subsequently, the activity concentrations of radionuclides in the samples were determined using*Equation*2 [19]:

$$A(Bq/kg) = \frac{C}{\varepsilon \times P_\gamma \times W} \tag{2}$$

where A is the activity concentration in Bq/kg, C signifies the net gamma counting rate in count per second (cps), ε presents the intrinsic photopeak efficiency of the detector, Pγ (gamma yield) denotes the photon emission probability of the radionuclide, and W is the dry mass of the sample.

Transfer of radionuclides from soil to food crop

The interactions between natural radionuclides in the soil and plants determined by factors, such as type and shape of plants, soil characteristics, behavior of radionuclides, and climatic conditions, are highly complicated [20] and the transfer of radionuclides from soil to different plants depends on the chemical characteristics and several parameters of the plant and soil [21]. The migration and accumulation of contaminants from soil to plant is an assessment model commonly utilized in soil-plant activity concentration ratio known as transfer factor (TF). The soil to plant TF is defined as the ratio of activity concentration of radionuclides in a plant to activity concentration of radionuclides in soil. This describes the amount of radionuclide that enters food crops from the soil and can be used as an index to investigate the accumulation of radionuclides in food crops resulting from plant root uptake [22, 23].The TF was calculated using *Equation*3 [23]:

$$TF = \frac{A_F}{A_S} \tag{3}$$

where A_F is the activity concentration of radionuclides in edible parts of food crop, and A_S signifies the activity concentration of radionuclides in soil.

External absorbed gamma dose rate obtained from the soil samples of the farmlands

The absorbed gamma dose rate is an important assessment evaluating necessary for consideration of the radiation risk to the human bio-system. The model provided by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was used to calculate the absorbed gamma dose rate (D (nGy/h)) in the air at 1.0 m above the ground level concerning the concentration of ^{40}K, ^{226}Ra, and ^{232}Th in the soil. The model is expressed in *Equation* 4 [24]:

$$D = a.C_{Ra} + b.C_{Th} + c.C_K + d.C_{Cs} \tag{4}$$

where a is 4.27 x 10^{-10}Gy h^{-1}/Bq kg^{-1}, C_{Ra} signifies the activity concentration of ^{226}Ra in the sample (Bq kg^{-1}), b denotes 6.62 x 10^{-10}Gy h^{-1}/Bq kg^{-1}, C_{Th} presents the activity concentration of ^{232}Th in the sample (Bq kg^{-1}), c indicates 0.43 x 10^{-10}Gy h^{-1}/Bq kg^{-1}, C_K is the activity concentration of ^{40}K in the sample (Bq kg^{-1}), d is 0.30 x 10^{-10}Gy h^{-1}/Bq kg^{-1}), and C_{Cs} signifies the activity concentration of ^{137}Cs in the sample (Bq kg^{-1}). However, the last term in *Equation* 4 was taken as zero since ^{137}Cs was not detected in any of the samples.

Annual effective dose obtained from the soil samples of the farmlands

There are two additional factors that must be considered to determine the annual effective dose rate to the population in an area. The UNSCEAR recommended that the first factor converts Gy to Sv and accounts for the biological effectiveness of the dose to cause damage to human tissue as (0.7 $SvGy^{-1}$). The second factor is the occupancy factor that specifies the proportion of the total time spent by human outdoors (0.2). The effective dose rate due to soil was evaluated using *Equation* 5 [24]:

$$H_R = D \times 0.2 \times 0.7 \times 8760 \tag{5}$$

where D is the absorbed gamma dose rate in (nGy h^{-1}), 0.2 denotes the occupancy factor, and 0.7 $SvGy^{-1}$signifies the conversion factor recommended by UNSCEAR and 8760 in hr/yr.

Annual effective dose due to the ingestion of food crops

The effective dose is a useful concept in the radioactivity measurement that enables the summation of all radiations absorbed by different organs. The model of radiation (effective) dose delivered due to the ingestion of food contaminated with radionuclides is obtained from *Equation*6 [25]:

$$H_{T,r} = \sum \left(U^i \times C_r^i\right) \times g_{T,r} \tag{6}$$

where i stands for a food group, $U^i$is the food consumption rate (kg/yr), C^i_r signifies the activity concentration of the radionuclide (Bq/kg^{-1}), and $g_{T\ r}$ denotes the dose coefficient for the ingestion of radionuclide r (Sv Bq^{-1}).The values of $g_{T\,r}$ for^{40}K, ^{226}Ra, ^{232}Th, and ^{137}Cs are, 5.9 x 10^{-9}Sv Bq^{-1}, 4.8 x 10^{-8}Sv Bq^{-1}, 2.3 x 10^{-7}Sv Bq^{-1}, and 1.3 x 10^{-8}Sv Bq^{-1} respectively for adult members of the public [26-28].The food consumption rate (U^i) statistics used for the different food crops in Nigeria were obtained from the Food Agriculture Organization (FAO). The U^i statistics used for the different food crops in Nigeria were 32.72, 104.97, 118.86, and 30.64Kg/person/yr for maize, rice, yam, cassava, and Guinea corn, respectively [29].

Excess lifetime cancer risks due to the ingestion of food crops

Cancer manifestations of rapid creation of abnormal cells that grow beyond limits invade adjoining parts of the body and later spread to other organs. However, excess lifetime cancer risk (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(30). The ELCR associated with the intake of food crops was determined using the cancer risk coefficients for the ingestion of radionuclides and per-capital intake of the radionuclides given by the Environmental Protection Agency in *Equation* 7 [30]:

$$R = \sum r_i I_i \tag{7}$$

where R is the lifetime cancer risk, r_i denotes the cancer risk coefficient for i^{th} radionuclide, and I_i signifies the per-capital activity intake of the radionuclide which is the product of A (activity concentration of the i^{th} radionuclide), C (food consumption rate), and T (average life expectancy). The risk coefficients, r for ^{226}Ra, ^{232}Th, and ^{40}K used in the study were 9.56x10^{-9} Bq^{-1}, 2.45x10^{-9} Bq^{-1}, and 5.89x10^{-10} Bq^{-1}[30] respectively. The mean life expectancy at birth is 45.5 years in Nigeria [31]; in addition, the food consumption statistics used in this study were obtained from FAO.

Results

The activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in food crops and farm soil samples collected from Kuru-Jos were determined using *Equation* 2, and the results are presented in Table 2.

Table 2. Activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th (Bq/kg) in food crops and soil samples

Sample (No)	Activity concentration in food			Activity concentration in soil		
	^{40}K	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th
Guinea corn (14)	436.5±18.7	52.7±6.4	83.8±13.5	743.8±44.7	116.2±23.7	128.8±18.7
	401.2±11.2	32.0±2.7	21.8±5.4	839.9±98.3	134.±19.8	186.5±15.1
	201.2±13.7	31.5±1.9	27.6±8.5	369.6±23.9	304.3±10.3	573.5±23.7
	280.6±7.6	44.3±7.6	37.2±5.2	914.9±56.4	121.4±24.1	255.4±18.3
	290.8±15.4	48.7±3.8	22.3±3.8	1219.4±74.3	103.1±13.4	155.3±11.9
	411.6±13.9	42.6±2.1	43.3±11.2	998.7±29.8	128.3±17.4	115.6±9.7
	295.8±22.5	42.1±1.3	26.5±7.1	1109.7±65.3	48.5±11.1	65.7±17.5
	442.2±64.3	27.0±6.2	23.8±9.8	868.6±34.1	154.4±20.2	195.4±13.2
	467.5±31.8	46.2±0.9	19.2±4.9	1515.1±78.9	221.5±19.0	114.6±16.4
	389.8±18.1	42.3±3.1	19.8±6.3	899.7±41.2	152.4±15.7	215.3±21.7
	261.7±10.7	45.1±4.6	35.8±2.9	988.7±61.3	163.2±28.3	235.2±13.9
	601.8±28.9	30.2±5.5	2.6±1.1	1396.6±90.7	135.5±17.5	151.1±29.1
	321.0±56.1	26.6±3.5	28.3±2.4	1079.8±37.9	114.4±21.7	164.4±12.3
	112.6±31.1	20.9±6.3	25.1±3.1	913.5±36.6	123.7±26.1	319.1±15.9
Mean±σ	351.0±123.9	38.0±9.7	29.9±18.3	989.9±279.9	144.4±59.5	205.4±124.4
Maize (10)	110.5±7.4	11.3±2.4	3.0±1.1	329.4±31.2	88.2±24.5	236.2±11.4
	61.8±4.4	13.7±9.7	2.6±2.1	708.8±45.2	90.7±20.1	247.8±12.1
	139.0±11.0	16.0±7.9	39.5±18.4	390.9±29.7	67.1±22.0	144.4±9.3
	38.4±21.9	37.4±11.9	28.6±17.5	351.7±33.2	81.8±17.5	247.0±12.4
	126.5±9.8	4.4±1.9	56.0±19.2	250.1±23.0	127.4±20.1	244.7±11.3
	121.3±7.7	16.4±3.6	72.2±5.1	630.9±34.1	132.3±23.2	225.4±10.5
	90.8±6.5	41.4±14.6	45.4±19.0	760.9±39.0	113.6±23.3	238.3±11.7
	40.2±3.0	32.9±13.7	13.3±4.9	734.3±39.3	146.3±23.0	124.2±8.3
	31.1±2.5	58.8±21.3	45.2±4.0	1500.4±47.1	98.7±18.4	114.6±7.7
	503.1±23.9	36.6±15.0	9.8±1.3	941.6±36.3	104.9±29.2	155.7±9.3
Mean±σ	126.3±83.3	26.9±17.1	31.6±23.9	660.9±372.6	105.1±24.8	197.8±55.7
Yam (7)	272.6±14.8	38.9±±14.1	19.7±3.8	652.9±34.2	201.9±24.3	251.9±11.2
	425.7±10.5	42.7±13.6	28.5±9.6	1211±42.5	166.5±18.8	173.7±13.9
	596.8±23.9	48.7±12.7	38.8±7.2	1154.4±58.7	122.2±16.5	165.7±9.9
	497.4±17.5	39.8±19.1	23.7±11.5	1854±51.7	168.9±27.2	149.6±9.1
	627.3±22.7	45.6±23.2	21.6±13.2	1240.5±42.9	115.3±21.2	153.2±17.0
	396.1±56.7	45.5±9.8	20.1±9.3	793±35.7	182.3±39.1	144.1±13.3
	377.2±34.4	67.3±17.9	54.3±15.8	1921.2±129.1	215.3±25.3	317.4±14.6
Mean±σ	456.2±126.0	46.9±9.6	29.5±12.8	1261±481.4	167.5±37.6	193.7±65.7
Cassava (6)	210.7±52.1	27.0±5.1	22.8±2.4	749.2±33.5	57.9±18.3	151.2±9.1
	370.2±31.2	40.5±24.3	23.5±4.8	843.1±37.2	93.1±21.2	169.1±12.5
	304.7±39.3	38.2±5.9	26.1±5.6	1213±45.7	96.3±18.7	243.2±12.3
	315.5±45.9	28.3±17.0	21.8±11.3	941.2±41.3	86.4±14.9	166.4±10.7
	335.7±67.8	31.7±15.6	25.3±9.8	1145.9±41.2	213.1±31.4	154.3±8.8
	267.2±58.4	33.8±22.3	28.0±12.7	1741±49.1	169.6±37.1	269.2±14.1
Mean±σ	300.7±55.7	33.3±5.4	24.6±2.4	1105.6±357.7	119.4±59.0	192.2±50.7

Table 3. Soil to food crop transfer factor of ^{40}K, ^{226}Ra, and ^{232}Th

Sample (No)		TF_{K-40}	TF_{Ra-226}	TF_{Th-226}
Guinea corn (14)	Range	0.12-0.59	0.10-0.87	0.02-0.65
	Mean±σ	0.37±0.13	0.31±0.19	0.19±0.17
Maize (10)	Range	0.02-0.53	0.03-0.60	0.01-0.39
	Mean±σ	0.23±0.10	0.27±0.17	0.17±0.13
Yam (7)	Range	0.20-0.52	0.19-0.40	0.08-0.23
	Mean±σ	0.39±0.13	0.29±0.08	0.16±0.05
Cassava (6)	Range	0.15-0.44	0.15-0.47	0.10-0.16
	Mean±σ	0.29±0.09	0.33±0.13	0.13±0.02

Table 4. Gamma absorbed and outdoor effective doses, ingestion dose, and excess lifetime cancer risks

Soil Sample (No)		Absorbed dose (nGy/h)	Effective dose (mSv/y)	Ingestion dose (μSv/y)	Excess lifetime cancer risk ($x10^{-3}$)
Guinea corn (14)	Range	111.9-525.5	0.14-0.64	171.5-747	0.46-1.35
	Mean±σ	240.2±94.8	0.29±0.12	329.3±136.7	0.9±0.2
Maize (10)	Range	141.1-239.0	0.17-0.29	53.0-592.5	0.3-1.0
	Mean±σ	204.2±31.6	0.25±0.04	304.1±179.1	0.6±0.3
Yam (7)	Range	204.0-384.7	0.25-0.47	840.4-1883.7	2.8-4.8
	Mean±σ	253.9±64.0	0.31±0.08	1231.9±362.8	3.8±0.7
Cassava (6)	Range	157.0-325.5	0.19-0.40	925.1-1145.7	2.4-3.6
	Mean±σ	225.8±61.1	0.28±0.07	1072.6±96.0	3.0±0.4

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 soil to food crop TF of ^{40}K, ^{226}Ra, and ^{232}Th in each of the food crops was determined using *Equation* 3 and the results are presented in Table 3.

The absorbed gamma dose rate obtained from the radionuclides in the soil samples was calculated using *Equation*4 and the results are presented in Table 4. Moreover, the effective dose rates of the activity concentrations of the radionuclides in the farm soil were calculated using *Equation*5, and the results are presented in Table 4. In the same line, Table 4 summarizes the effective dose rates obtained from the ingestion of the food crops from the study area using *Equation* 6. Furthermore, lifetime cancer risks were evaluated using *Equation* 7 (Table 4).

Discussion

As can be seen in Table 2, the activity concentrations are lower in food crops than the farm soils, and this indicates that only a fractional part of the radionuclides in the soil is transferred to each food crop through plant-root uptake. Moreover, the activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in the food crops are higher than the reported values for the same food crops in other studies. According to a study conducted by Akinloye and Olomo [32], the radioactivity levels in tuber food crops ranged from 10.6 to 46.6 Bq/kg for ^{40}K,0.5 to 2.7 Bq/kg for ^{238}U, and below detection limit (BDL) to 1.4 Bq/kg for ^{232}Th which were lower than the values obtained from this study.

The mean activity concentrations of 181.1 Bq/kg, 5.42 Bq/kg, and 107.0 Bq/kg for ^{40}K, ^{226}Ra, and ^{232}Th, respectively, in tuber crops from India [20] were lower than the corresponding values obtained from the present study. Similarly, the activity concentration levels in cereal crops reported for Nigeria ranged from 36.4 to 186.9 Bq/kg for ^{40}K, 0.2 to 1.4 Bq/kg for ^{238}U, and 0.3 to 1.8 Bq/kg for ^{232}Th [33] which were lower than the values in this study. Furthermore, the respective activity concentrations of 48.8 Bq/kg, 13.2Bq/kg, and 4.1 Bq/kg for ^{40}K, ^{226}Ra, and ^{232}Th [34] in maize from Tanzania were lower than the values obtained from this study. The radionuclide levels of 491.6 Bq/kg, 25.8 Bq/kg, and BDL for ^{40}K,^{226}Ra, and ^{232}Th, respectively [35] reported for Turkey were also lower than the values obtained from the current study. Furthermore, the highest radioactivity levels of 287Bq/kg, 96Bq/kg, and 177Bq/kg for ^{40}K, ^{226}Ra, and ^{232}Th, respectively, in farm soils reported for Jos-Plateau [36] were lower than the values obtained in farm soils in this study.

The activity concentrations of 679 Bq/kg, 66.8 Bq/kg, and 49.7 Bq/kg for ^{40}K, ^{226}Ra, and ^{232}Th, respectively, reported in farm soils from Ayetoro [12] were also lower than the values obtained in farm soils from the area under study.

The radioactivity levels obtained in the present study were higher than 470.3Bq/kg, 26.5Bq/kg, and 37.9 Bq/kg for ^{40}K, ^{226}Ra, and ^{232}Th, respectively, reported for the soils from the East of Shazand Power Plant, Iran [37]. Moreover, the values of 459.6 Bq/kg, 62.3 Bq/kg, and 155.4 Bq/kg for ^{40}K, ^{226}Ra, and ^{232}Th, respectively, in the soils from Chikun Environment of Kaduna Metropolis [38] were lower than the corresponding values obtained from the present study. The dispersal of tin tailing all over surfaces, including farmlands due to continuous illegal mining, is attributed to the high radioactivity in the study area.

The mean TFs for ^{40}K were 0.37±0.13, 0.23±0.10, 0.39±0.13, and 0.29±0.09 for Guinea corn, maize, yam, and cassava, respectively. The results indicated that the mean values of transfer of radionuclide from soil were 37%, 23%, 39%, and 29% for Guinea corn, maize, yam, and cassava, respectively. The TFs of ^{232}Th were smaller than the values obtained for ^{226}Ra in all the food crops and this observation is in line with the findings of a study conducted by Martinez-Aguirre et al.[39].The transfer values obtained in this study were higher than the values reported in some other studies [40]. Chen et al. reported that soil to maize TFs were 0.0074 and 0.0061 for ^{226}Ra and ^{232}Th, respectively [41]. These values are remarkably lower than the results obtained from the soil to maize and soil to Guinea corn for ^{226}Ra and ^{232}Th, respectively, in the present study. The radionuclides uptake seemed crop-specific, and therefore, the variation in TF may be attributed to a different characteristic of the food crops and concentration of radionuclides in the soils [42].

Ayşe and Meryem [43], Manjgandan and Chandar [44], Taskin et al. [45], and Adewale et al. [46] estimated the mean gamma dose rates of soils from different countries at 56.9nGy/h, 91.5±34.0 nGy/h, 118±34.0 nGy/h, and 48.12 nGy/h, respectively.

All these reported gamma dose rates were significantly lower than the values obtained in the present study. The highest (0.31±0.08mSv/y)and the lowest (0.25±0.04mSv/y) mean annual effective doses were obtained in yam and maize soil, respectively. Alausa and Omotosho reported the same mean outdoor effective dose rate of 0.11±0.03 mSv/y for the soil underneath maize and cassava [12]. This value is lower than that obtained from all the farm soils in the study area. The high outdoor effective dose rate in the farm soils from the area under study is consistent with that obtained from the studies carried out by Ademola [47] and Jibiri et al.[48].

The annual effective dose of 1231.9±362.8 µSv/y (i.e., yam crop) was the highest followed by 1072.6±96.0 µSv/y (i.e., cassava) and 304.1±179.1 µSv/y (i.e., maize crop), which was the least dose rate. The high annual effective dose exhibited by the food crops are in line with the results obtained from a study carried out by Alausa, [49]. The findings indicated that the ELCRs due to the ingestion of Guinea corn and maize were less than the world average limit of 1.0×10^{-3}, and the risks due to the ingestion of yam and cassava were much higher than that of the world average value.

Conclusion

The activity concentrations of natural radionuclides, including ^{40}K, ^{226}Ra, and ^{232}Th in the farm soil and food crops (tubers and cereals) grown in Kuru-Jos, 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 higher than the world average values and figures reported in the literature. In addition, the absorbed gamma and annual effective doses of the farm soils from the study area were higher than the values reported in similar studies from other areas. The TF that depends on the type of food crops and radioactivity levels in the soil is higher than the reported values in other studies. These 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 higher than that of the world average limit of 1.0×10^{-3}. Apparently, the high radiological health impact assessments obtained from the present study are in the same trend with reported results from other areas in Jos-Plateau; however, there have been no reported cases of radiological health plague on the inhabitants in the area so far.

Acknowledgment

The author is grateful to the Federal Radiation Protection Service, Physics Department, University of Ibadan, Nigeria, for granting permission to use its gamma spectrometry system for the study.

References

1. Lubis S, Shibdawa MA, Adamu H. Determination of natural radioactive elements in vegetable irrigated with water from tin mining ponds around Dorowa in Barkin-Ladi Plateau State, Nigeria. Journal of Pure and Applied Sciences. 2019; 16: 60-5.
2. Ogezi AE. Tin mining and processing related environmental impact and associated hazards on the Jos Plateau, North-Central Nigeria: International Conference on Energy, Environment and Disasters-INCEED, Charlotte, NC, USA. 2005.
3. Pasquini MW, Alexander MJ. Soil fertility strategies on the Jos- Plateau: the need for integrating empirical and scientific knowledge in agricultural development. The Geographical Journal. 2005; 171: 112-24.
4. Mallo SJ, Wazoh HN. Reclamation of abandoned mined-out areas of Bukuru-Rayfield. Journal of Environmental Science, Toxicology and Food Technology. 2014; 8(2): 25-34.
5. Raymond LN, Victor MT. Lifetime cancer risk due to gamma radioactivity in soils from Tudor Shaft mine environs, South Africa. Journal of radiation Research and Applied Sciences. 2016; 9: 310-5.
6. Harb S, El-Kamel AH, Abd El-Mageed AI, Abbady A, Rashed W. Radioactivity levels and soil-to-plant transfer factor of natural radionuclides from Protectorate Area in Aswan, Egypt World Journal of Nuclear Science and Technology. 2014; 4: 7-15.
7. Hashimoto K, Tanabe Y. Investigation of radionuclide concentration of food in Ibaraki Prefecture. Annual Report of Environmental Pollution Research Center of Ibaraki Prefecture. 1997; 8: 65-74.
8. Akhter P, Ashraf N, Mohammad D, Orfi SD, Ahmad N. Nutritional and radiological impact of dietary

potassium on the Pakistani population. Food and chemical toxicology. 2003 1;41(4):531-4.
9. Arogunjo AM, Hollrieg V, Giussani A, Leopold K, Gerstmann U, Veronese I, et al., Uranium and thorium in soils minerals sands water and food samples in a tin mining area in Nigeria with elevated activity. J. Environ Radioact. 2009; 100(3): 232-40.
10. Min-Seok C. Daily intake of naturally occurring radioisotope in typical Korean food. J. EnvironRadioact. 2008; 99: 1319-23.
11. Zahra P, Ali E, Mohsen A, Abolfazl N, Abolghasem H, Karim K. Determination of Radionuclide Concentrations in Tea Samples Cultivated in Guilan Province, Iran.Iranian Journal of Medical Physics. 2015; 12(4): 271-7.
12. Alausa SK, Omotosho OO. Natural radioactivity in farm soils and major food crops grown in Ayetoro, Ogun State, Southwestern Nigeria Int. J. Low Radiation. 2017; 10(4): 285-303.
13. Oresegun MO, Babalola IA. The environmental gamma radiation level of Jos-Pleteau, Nigeria. Nigeria. J. Sci.1993; 27: 263-8.
14. Elueze AA, Bolarinwa AT. Appraisal of the residual and sedimentary clay in parts of Abeokuta area, southwestern Nigeria. J. Min. Geol. 2001; 37(1):7-14.
15. Yang YX, Wu XM, Jiang ZY, Wang WX, Lu J, Gand LJ. Radioactivity concentration in soil of the Xinzhuang Granite Area, China. Appl. Radiat. Isotop. 2005; 63: 225-9.
16. Jibiri NN, Farai IP, Alausa SK. Activity concentrations of 226Ra, 228Th, and 40K in different foodcrops from a high background radiation area in Bitsichi, Jos Plateau, Nigeria. Radiat Environ Biophys. 2007; 46:53-9.
17. El-Taher A. Terrestrial gamma radioactivity levels and their corresponding extent exposure of environmental samples from Wadi El Assuity Protective area, Assuit Upper Egypt. Radiation Protection Dosimetry. 2011; 145(4): 405-10.
18. Kitto ME, Fielman EM, Hartt GM, Gillen EA, Semkov TM., Parekh PP, et al. Long- term monitoring of radioactivity in surface air and deposition in New York State. Health Physics. 2006; 90:31-7.
19. Haque M and Ferdous MJ. Transfer of natural radionuclides from soil to plants in Savar Dhaka. Spanish Journal of Soil Science. 2016; 133-45.
20. Golmakani S, Ahabi MVM, Hosseini T. Factors affecting the transfer of radionuclides from the environment to plants. Radiation Protection Dosimetry. 2008; 130(3):1-8.
21. Shanthi G, Maniyan CG, Allan GRG, Raj G, Thampi TKJ. Radioactivity in food crops from high-background radiation area in southwest India. Current Science. 2009; 97(9): 1331-5.
22. Saeed MA, Siti SY, Hossain I, Ahmed R, Hewa YA, Shahid M, et al. Soil to rice transfer factor of the natural radinuclides in Malaysia Rom. Journ. Phys. 2012; 57 (9-10): 1417-24.
23. Uchida S, Tagami K. Transfer of Radium-226 from soil to rice: A comparison of sampling area differences. Journal of Nuclear Science and Technology. 2009; 46(1):49-54.
24. United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR). Report to the General Assembly, New York: United Nations; 2000.
25. Till JE, Moore RE. A pathway analysis approach for determining acceptable levels of contamination of radionuclide in soil. Health Physics. 1988; 55: 541-8.
26. International Commissions on Radiological Protection (ICRP). Dose Coefficients for Intakes of Radionuclides by Workers. ICRP Publication 68. Ann. ICRP 24 (4).1994.
27. International Commission on Radiological Protection (ICRP). Age-dependent doses to members of the public from intake of radionuclides: Part 5. Compilation of Ingestion and inhalation dose co-efficient ICRP Pub No-72 Pergamon Press: Oxford. 1996.
28. Radioactivity in Food and the Environment (RIFE). The Center for Environment, Fisheries and Aquaculture science (CEFAS), Radioactivity in Food and the Environment 2004 Report RIFE-10; 2005.
29. Food Agriculture Organization (FAO). Compilation of annual consumption data/food Balance sheet of Nigeria. A publication of Federal Office of Statistics (FOS), Nigeria; 2013.
30. Environmental Protection Agency (EPA). Cancer risk coefficients for Environmental Exposure to Radionuclides. United States Environmental Protection Agency. Federal Guidance Report No -13 (EPA. 402 R-99-001); 1999.
31. World Health Organization (WHO). Meeting the MDG drinking water and sanitation target: the urban and rural challenges of the decade. WHO Library Catalogue-in-Publication Data; 2008.
32. Akinloye MK, Olomo JB. The measurement of the natural radioactivity in some tubers cultivated in farmlands within the ObafemiAwolowo University Ile-Ife, Nigeria. Nigerian Journal of Physics. 2000; 12:60-3.
33. Arogunjo AM. Natural radionuclides content of some local cereals in Akure, Southwestern Nigeria. Nigeria Journal of Pure and Applied Physics. 2003; 2: 34-5.
34. Mlwilo NA, Mohammed NK, Spyrou NM. Radioactivity levels of stable Foodstuffs and dose estimates for most of the Tanzanian population. Journal of radiological Protection. 2007; 27: 471-80.
35. Bolca M, Sac MM, Cokuysal B, Karal T, Ekdal E. Radioactivity in soils and various foodstuffs from the Gediz River Basin of Turkey. Radiation Measurements. 2007; 42: 263-70.
36. Jibiri NN, Agomuo JC. Trace elements and radioactivity measurements in some terrestrial food crops in Jos-Plateau, North central, Nigeria. Radioprotection. 2007; 42: 29-42.
37. Pourimani1 R, Davoodmaghami T. Radiological Hazard Resulting from Natural Radioactivity of Soil in East of Shazand Power Plant Iran J Med Phys 2018; 15: 192-9.
38. Gyuk PM, Habila SS, Dogara MD, Kure N, Daniel HI, Handan TE. Determination of radioactivity levels in soil samples at Chikun environment of Kaduna metropolis using gamma-ray spectrometry. Science World Journal.2017; 12(2): 52-5.
39. Martinez-Aguirre A, Gacia-Leon M., Ivanovich M. U and Th speciation in river sediments. The Science of the Total Environment. 1995; 173: 203-9.

40. Frissel MJ, Koster J. The IUR project on soil-to-plant transfer of radionuclides expected values and uncertainties. In: Desmet, G (Ed.), Reliability of radioactive transfer models. Elsevier Applied Science, London; 1988.
41. Chen SB, Zhu YG, Hu QH. Soil to plant transfer of 238U, 226Ra and 232Th on uranium mining-impacted soil from southeastern China J. Environ Radioactivity. 2005; 82: 213-6.
42. Tome FV, Blanco MP, Lozano JC. Soil-to-plant transfer factors for natural radionuclides and stable elements in a Mediterranean area. Journal of Environmental Radioactivity. 2003; 65:161-75.
43. Ayşe D, Meryem Y. Determination of radioactivity concentrations in soil samples and dose assessment for Rize Province, Turkey. Journal of Radiation Research and Applied Sciences. 2017; 10: 348-52.
44. Manigandan PKB, Chandar S. Evaluation of radionuclides in the terrestrial environment of Western Ghats.Journal of Radiation Research and Applied Sciences. 2014; 7:310-7.
45. Taskin H, Karavus M, Ay P, Topuzoglu A, Hidiroglu S, Karahan G. Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. Journal of Environmental Radioactivity.2009; 100: 49-53.
46. Adewale OO, Tubosun IA. Ojo JO. Assessment of terrestrial naturally occurring radioactive material in soil and mine tailings of Awo and Ede, Osun-State, Nigeria. Ife Journal of Science. 2015; 17(1): 199-209.
47. Ademola, JA. Exposure to high background radiation level in the tin mining area of Jos Plateau Nigeria. Journal of Radiological Protection. 2008; 28:93-9.
48. Jibiri NN, Alausa SK, Farai IP. Radiological hazard indices due to activity concentrations of natural radionuclide in farm soil from two high background radiation areas in Nigeria. Int. J. Low Radiation. 2009; 16(2): 79-95.
49. Alausa SK. Radioactivity in farm soils and food crops grown in Jos and Abeokuta, Nigeria and Its Associated Cancer Risks. A PhD Thesis, University of Ibadan, Nigeria; 2012.